Lake	State	Nitrogen (N) Loading [lb/(year acre)]	Nitrogen (N) Retention (%)	Phosphorus (P) Loading [lb/(year acre)]	Phosphorus (P) Retention (%)	Ref.
Washington	Wash.	280	—	12		1
Mendota	Wis.	20[a]	—	0.6[b]		3
Monona	Wis.	81[a]	48–70	7.5[b]	64–88	44
Waubesa	Wis.	435[a]	50–64	62.8[b]	−26–25	44
Kegonsa	Wis.	162[a]	44–61	35.9[b]	−21–12	44
Tahoe	Calif.	2	89	0.4	93	47
Koshkonong	Wis.	90	80	40	30–70	Mackenthun, unpublished
Green	Wash.	—	—	4.8	55	82
Geist	Ind.	440[a]	44	28	25	Mackenthun, unpublished
Sebasticook	Maine	—	—	2	48	Mackenthun, unpublished
Ross R. Barnett	Miss.	—	—	32	—	Mackenthun, unpublished

[a] Inorganic nitrogen only.
[b] Soluble phosphorus only.

50 μg/l. be exceeded where waters enter a lake, reservoir, or other standing water body (49). Those waters now containing less phosphorus should not be degraded because even lower concentrations may be critical in very low alkalinity waters. Adequate phosphorus controls must now be directed toward treatment of nutrient point sources and to wastewater diversion around the lake or dilution within the lake, where feasible.

PHOSPHORUS SOLUBILITY DISTRIBUTION

Total-to-soluble phosphorus ratios may vary from 2 to 17 or even 90%, dependent on the particular water, season, aquatic plant populations, and probably other factors (Table 4). These ratios are of value when they can be determined periodically within the same water body and changes in them correlated with volumetric response changes within the algal mass.

The nutrient loading to the lake on a unit basis gives some measure of comparability among various water bodies (Table 5). Likewise, a lake or reservoir usually retains a portion of those nutrients that it receives from its various sources. The amount or percentage of the nutrients that may be retained by a lake or reservoir is variable and will depend on (*a*) the nutrient loading to the lake or reservoir; (*b*) the volume of the euphotic zone; (*c*) the extent of biological activity; (*d*) the detention time within the basin or time allotted for biological activity; and (*e*) the level of the penstock or discharge from the basin.

Long-term remedial measures might be focused on reducing the nutrient concentration in troublesome areas or in altering some aspect of the topography that concentrates or fosters the development of nuisance algae or aquatic weeds. Such measures often involve costly physical modifications to correct existing conditions, as well as future planning to assure wise use of the area's natural aquatic resources.

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Phosphorus and Ecology

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"OHNE PHOSPHOR KEIN LEBEN" ANONYMO

ECOLOGICAL CONSIDERATIONS

In considering the ecological aspects of phosphorus, or any other eleme for that matter, it is well to remember that a finite amount of each exists a that the Law of Conservation of Matter applies to all, save the radioacti ones. Seldom are the elements per se of significance in environmental co siderations, except for mining and refining operations involved in winni the elements from their ores. Of vastly greater importance are the compoun that are generated from the elements to meet the demands of our mode civilization. Although these compounds are usually widely disseminat throughout populated, and sometimes unpopulated, areas of the worl some of them, unfortunately, tend to become concentrated in certain area The soluble phosphate compounds are a classical example.

PHOSPHORUS DISTRIBUTION IN VARIOUS ECONOMIES

Agrarian

Cropping of land exerts a constant drain upon the phosphorus resource of the soil. Table 1 shows the phosphorus content of a wide variety of crop and food products derived from them. Continual removal of crops withou recycling results in a depletion of available phosphorus in the soil, and cro yields eventually become limited by the amount released by natural weathering action of the soil.

Attachment A3

providing only an approximation for floc size-density relationships.

2. Laboratory measurements of the densities of iron(III) flocs indicate that a size-density variation does exist. Moreover, the size-density relationship observed was, for flocs smaller than about 1 sq mm in projected area, comparable to that predicted by the Vold model.

3. The laboratory observations of the floc size-density relationship support

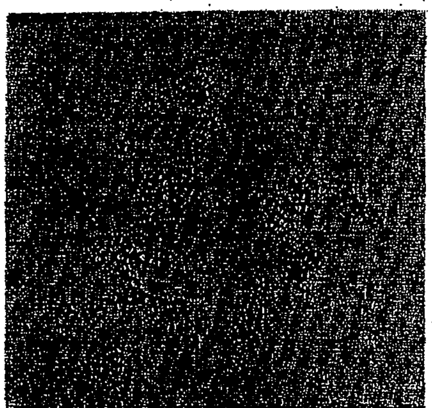

Fig. 6. Floc Aggregates

These third level floc aggregates are comprised of 601 primary particles.[5]

the hypothesis (advanced by others) of multiple levels or stages (at least three) of floc aggregation.

4. The intensity of agitation provided during flocculation does not affect floc density significantly, size-for-size. It does, however, alter the floc size-frequency distribution and thereby the density characteristics of the suspension.

5. Limited studies with the coagulant aid mentioned above indicate that this polyelectrolyte, used in small concentration along with ferric sulfate, does not alter floc densities, size-for-size, but does increase floc strength as indicated by the observation that larger flocs were formed when it was used.

6. Floc size distributions obtained from settling column analyses should be viewed with considerable skepticism unless the floc size-density variation was taken into account.

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The Phosphorus Problem

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A contribution submitted to the Journal *on Jun. 7, 1968, by Kenneth M. Mackenthun (Active Member, AWWA), Acting Chief, Bio. and Chem. Section, Tech. Advisory and Investigations Branch, Div. of Tech. Services, FWPCA, US Dept. of the Interior, Cincinnati, Ohio.*

"REDUCE phosphorus in waste-water sources" has become a slogan to those who would decelerate cultural eutrophication. Phosphorus is a nutrient that often is limiting to aquatic plant growths. When present in excess of a critical concentration, however, and when other environmental conditions are favorable, phosphorus can stimulate plant growths that produce scums and odors and destroy water uses. Although present in sewage, phosphorus concentrations in domestic and industrial wastes can be reduced by treatment, for unlike nitrogen, another essential plant nutrient, phosphorus cannot be fixed from the atmosphere by plants and added to the aquatic ecosystem.

Eutrophication

Eutrophication is a term meaning enrichment of waters by nutrients through either man-created or natural means. Present knowledge indicates that the fertilizing elements most responsible for lake eutrophication are phosphorus and nitrogen. Iron and certain "trace" elements are also important. Sewage and sewage effluents contain a generous amount of those nutrients necessary for algal development.

Lake eutrophication results in an increase in algal and weed nuisances and an increase in midge larvae, whose adult stage has plagued man in Clear Lake, Calif., Lake Winnebago, Wis., and several lakes in Florida. Dense algal growths form surface water scums and algal-littered beaches. Water may become foul-smelling. Filter-clogging problems at municipal water installations can result from abundant suspended algae. When algal cells die, oxygen is used in decomposition, and fish kills have resulted. Rapid decomposition of dense algal scums, with associated organisms and debris, gives rise to odors and hydrogen sulfide gas that creates strong citizen disapproval; the gas often stains the white lead paint on residences adjacent to the shore.

Certain algae are known to be toxic to animals. Water in which certain blue-green algae have bloomed may produce death in mammals and fish, even when the algal cells themselves are excluded. Humans who have accidentally swallowed several mouthfuls of lake water containing an algal scum have suffered severe gastrointestinal distress.

Nitrogen and phosphorus are necessary components of an environment in which excessive aquatic growths arise. Algal growth is influenced by many varied factors: vitamins, trace metals, hormones, auxins, extracellular metabolites, autointoxicants, viruses, and predation and grazing by aquatic animals. Several vitamins in small quantities are requisite to growth in certain species of algae. In a fresh-water environment, algal requirements are met by vitamins supplied in soil runoff, lake and stream bed sediments, solutes in the water, and metabolites produced by actinomycetes, fungi, bacteria, and several algae.

Evidence indicates that: (1) high phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth-promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary producing such growths in one geographical area, but not in another.[1]

Micronutrients (iron, manganese, copper, zinc, molybdenum, vanadium, boron, chlorine, colbalt, silicon) are generally present in freshwater environments in the small concentrations sufficient for plant growth. Vitamins are synthesized by several organisms. Phosphorus, however, is an element found in large quantities in municipal and some industrial wastewaters, and with other water quality characteristics, when it is introduced into the aquatic ecosystem in amounts greater than those found in unpolluted environments, plant problems develop. Using contemporary techniques, phosphorus can be more feasibly reduced in wastewaters than can other constituents essential to the development of aquatic plants. It is logical, then, that diligent effort be made to minimize phosphorus inflows into waterways if they are to be preserved in a usable state, both for recreative and other essential purposes.

TABLE 1

Pounds of Phosphorus to Aquatic Ecosystem

Controllable		Uncontrollable	
Major	Minor	Major	Minor
Sewage: 3/capita/yr* Some industries, e.g., potato processing: 1.7/ton processed	Domestic duck: 0.9/year[11] Sawdust: 0.9/ton[12]	Phosphate rock, 23 states[6] Cultivated agricultural drainage: 0.35–0.39/acre drained/year[7,8,9] Surface irrigation returns, Yakima River Basin: 0.9–3.9/acre/year[10] Benthic sediment release	Rainwater** Groundwater, Wis.: 1/9×10⁶ gal[14] Wild duck: 0.45/year[13] Tree leaves: 1.8–3.3/acre of trees/year[15] Dead organisms; fecal pellets

* Various researchers have recorded the annual/capita contribution of phosphorus in pounds from domestic sewage as 2 to 4 (2), 2, 3 (3), 1.9 (4), and 3.5 (5).
** Influenced by pollution present in atmosphere "washed out" by rainfall.

Sources

Depending on their contributions to the aquatic ecosystem (not to sustain life, but to encourage its production to nuisance proportions), sources of phosphorus may be classed as major and minor. Phosphorus amounts in these sources are controllable or incontrollable, within the limits of economics and present technology (Table 1).

TABLE 2

Standing Crop Per Surface Acre in Lakes

	Phytoplankton	Attached Algae	Submerged Vascular Plants	Fish	Midges
Wet weight—*lb*	1,000-3,600 (16)	2,000 (17)	14,000 (18)	150-600 (19)	200-400 (20)
Dry weight—*lb*	100-360	200	1,800	—	40-80
Percentage N (dry wgt)	6.8 (21)	2.8 (16)	1.8 (22)	2.5 (23)	7.4 (16)
Percentage P (dry wgt)	0.69	0.14	0.18	0.2	0.9
N in crop—*lb*	7-25	6	32	3.8-15	3-6
P in crop—*lb*	0.7-2.7	0.3	3.2	0.3-1.2	0.4-0.7
Harvestable N—*lb*	—	—	16	1.0-3.8	0.2-0.4
Harvestable P—*lb*	—	—	1.6	0.1-0.3	0.02-0.04

In the ecosystem, phosphorus is found in solution and is bound in bacteria, algae, zooplankton, vascular plants, benthos, fish, and fecal pellets (Table 2). Some phosphorus bound in this manner is in "temporary storage" and, upon death of the organism, becomes available to support life within the standing body of water.

Watt and Hayes[24] found that organic phosphorus compounds were released into solution from dead or dying organisms. Rapidly growing populations of bacteria and green plants did not release organic phosphorus compounds. Dissolved organic phosphorus compounds were absorbed by bacteria and broken down, and inorganic phosphorus was released.

Animal excretions are a major source of plant nutrients in the sea and also contribute nutrients in fresh water. According to Johannes,[25] the rate of excretion of dissolved phosphorus per unit weight increases as body weight decreases. As a result, microzooplankton may play a major role in planktonic nutrient regeneration. Although data are not available on quantitative nutrient excretions from these organisms in the freshwater ecosystem, the importance of this as a continuing nutrient source must be considered.

Cultures of bacteria and mixed microorganisms have been found to actively release a large portion of their phosphorus to the medium in a matter of hours, when kept under anoxic conditions. Only phosphorus is lost, probably as orthophosphate and apparently from the acid-soluble fraction of the cells. The process is completely reversible under aeration.

Nuisance Plant Growths

Important factors affecting aquatic growths include temperature, sunlight and its penetration in water, size, shape, type of substratum, and contour of lake basin, and water quality. The total supply of an available nutrient depends on the total volume of water and concentration of the element in the water. The surface area is important because 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, for prevailing winds, blowing along a long axis, will push the algal production of a large water mass into a relatively small area. The most offensive conditions develop during periods when very mild breezes send floating algae toward windward shores. Shallow lakes, too, respond differently than deep, stratified lakes, where the deeper waters are seasonally confined as separate volumes by a thermocline. In nonstratified waters all nutrients dissolved are potentially available to support algal bloom. When waters stratify, only nutrients confined to the epilimnion are available, except during those periods when complete circulation occurs.

Sawyer[8] studied the southeastern Wisconsin lakes and concluded that a concentration of 300 μg/l of inorganic nitrogen (N) and 10 μg/l of soluble phosphorus (P) at the start of a growing season may help produce nuisance algal blooms. Chu[27] found that optimum growth of organisms studied in cultures can be obtained in phosphorus concentrations from 90 to 1,800 μg/l, while a limiting effect on organisms occurs when phosphorus concentration is 9 μg/l or less. The lower limit of optimum growth occurred in phosphorus concentrations from about 18 to about 90 μg/l, which may exert a selective limiting influence on a phytoplankton population.

Experiments by Ketchum[28] with the diatom, *Phaeodactylum*, show a reduction in rate of cell division, when phosphate in the medium is less than 17 μg/l P. Strickland[29] states that the limiting phosphorus concentration in some cultures is less than 5 μg/l. The problem is complicated, because auxiliary compounds may affect the availability of phosphate to a plant cell. Sylvester[10] found that nuisance algal blooms began in Seattle's Green Lake (a very soft-water lake) when nitrate nitrogen (N) levels were above 200 μg/l and soluble phosphorus (P) levels were greater than 10 μg/l.

Because the ratio of total phosphorus to that form of phosphorus readily available for plant growth is constantly changing, it is desirable to establish limits on the total phosphorus, rather than on that portion that may be available for immediate plant use. Most relatively uncontaminated lake districts are known to have surface waters that contain 10–30 μg/l total phosphorus (as P); in waters that are not obviously polluted, higher values may occur.[30] Data collected by the FWPCA, Division of Pollution Surveillance, indicate that total phosphorus concentrations, principally in streams, exceeded 50 μg/l (P) at 48 per cent of the stations sampled across the nation and averaged less than 50 μg/l at 52 per cent. Some potable surface water supplies now exceed 200 μg/l (P). Turbidity in many of the nation's streams, however, negates the algal-producing effect of high phosphorus concentrations.

To prevent biological nuisances, total phosphorus concentrations should not exceed 100 μg/l at any point within a flowing stream, nor should 50 μg/l be exceeded where waters enter a lake, reservoir, or other standing water body. Waters now containing less than the specified amounts of phosphorus should not be degraded by the introduction of additional phosphates.

When waters are detained in a lake or reservoir, the phosphorus concentration is reduced by precipitation or uptake by organisms, with subsequent deposition in sediments as fecal pellets or dead organism bodies. Some receiving waters may experience algal nuisances at and below the proposed phosphorus level in influent streams. Suggested phosphorus limits will restrict noxious aquatic plant growths in flowing waters and should restrict such growths in other waters that receive these flowing streams.

Control

Many measures have been proposed to limit the eutrophication problem in lakes, ponds, and reservoirs. Some of these are: dredging, algal harvesting, tertiary treatment of wastewaters, fish harvesting, diversion of wastes around lakes, dilution of standing waters with waters of lower nutrient concentrations, treatment of inflowing streams to remove phosphates, and sealing off benthic sediments with inert materials. Within the present state of the art, adequate controls are limited to treatment of point sources to remove nutrients and to diversion or dilution, where feasible.

The relationship of the total volume of water in the lake or reservoir to the area of land drained is important. For example, when the 3-month inflow of nitrogen and phosphorus from nonpoint waste sources within the drainage basin exceeds the quantity of those elements within the receiving waters, eutrophication deceleration may be impossible without drastic land management changes. The critical ratio of lake volume (acre-feet) to land drainage (square mile) will depend on detention time within the lake, lake depth, interchange with lake bed sediments, and the pounds of inflowing nutrients. In fertile agricultural areas, where runoff may contribute 250 lb of phosphorus per square mile of watershed per year, 1,800 acre-ft of storage might be necessary for each square mile of drainage area to prevent nuisance algal blooms from runoff alone. This assumes a detention time approximating 1 year and a 50 per cent reduction of inflowing phosphorus per year within the lake.

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 could approach at least 7 tons/acre (wet weight) and contain 3.2 lb/acre of phosphorus (Table 2). 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.

Dredging has often been suggested as a means of removing the storehouse of nutrients contained within the lake bed sediments. These sediments are usually rich in nitrogen and phosphorus, for they represent the accumulation of years of settled organic materials. Some of these nutrients are recirculated within the water mass and furnish food for a new crop of organic growth.

Hasler[31] found that, in an undisturbed mud-water system, the percentage of nutrients, as well as the amount of phosphorus that is released to the superimposed water, is very small. In laboratory experiments, when P^{32} is placed at various depths in the mud, the diffusion into the overlying noncirculating water is negligible, if the phosphorus is placed more than 1 cm in the mud. Application of lime to the water or mud reduces the amount of soluble phosphorus released. Acidification of previously alkalized mud will, upon agitation, increase the amount of phosphorus entering solution. In an aquarium experiment, circulation of the water above phosphorus-rich mud, with the aid of air bubbles, increased the phosphorus in solution.

Zicher *et al.*[32] found in laboratory experiments that the percentage of phosphorus released to water from radioactive superphosphate fertilizer placed in an undisturbed mud-water system was very small, with virtually no release of phosphorus from fertilizer placed at depths greater than ½ in. below the mud surface. Radiophosphorus placed ½ in. below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at a 1-in. depth did not diffuse into the water at all.

Dredging deepens an area within a lake and can be beneficial if the increased depth is sufficient to prevent growth of larger nuisance plants. Dredging uncovers yet another soil strata that will contain phosphorus in some quantity, subject to solution in water. The newly dredged area immediately begins to receive organic fallout from waters above, forming a new interface at which nutrient exchange is substantial. Sediments disturbed during a dredging operation liberate nutrients at a rate more rapid than sediments left undisturbed and all of these factors must be considered when recommending dredging for nutrient removal. Based entirely on nutrient considerations, dredging can be advantageous only when it removes sediments that contain a higher concentration of nutrients than the interface likely to be formed by fallout.

The chemical precipitation of phosphates as a treatment supplemental to conventional secondary processes is now feasible, both technologically and financially. Without question, other technological advances in nitrogen and phosphorus removal from wastewaters will be forthcoming. Wastes usually are discharged initially into flowing waters. These waters often enter lakes and reservoirs before their added nutrients are spent. To maintain receiving waters in a condition satisfactory for multiple use, maximum phosphate removal must be practiced at the waste source. If eutrophication is to be decelerated, removal of nutrients must be accomplished before wastes are permitted to enter receiving waters.

Summary

Wastewater phosphorus inflows to receiving waters must be reduced to check accelerating cultural eutrophication. A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 µg/l P at any point within the flowing stream, nor should 50 µg/l be exceeded where waters enter a lake, reservoir, or other standing water body. Those waters now containing less phosphorus should not be degraded.

Adequate phosphorus controls must now be directed toward treatment of nutrient point sources and to wastewater diversion around the lake or dilution within the lake, where feasible. Once nutrients are combined within the ecosystem of the receiving waters, their removal is tedious and expensive. Results of harvesting an aquatic crop, dredging, or other means to remove nutrients after they have reached receiving waters must be compared to inflowing nutrient quantities to evaluate accomplishments.

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New Developments in Automatic Cathodic Protection for Water Storage Tanks

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In earlier years, cathodic protection systems for water storage tanks and other water utility structures were hit-or-miss propositions. Although it was known that a potential could be achieved on submerged steel that would render its surface corrosion-free, little was known about the effect of applied currents on protective coatings, and system adjustment was rarely based upon actual field conditions and requirements.

Cathodic protection requirements change from time to time and from place to place. For any given water utility structure, the amount of cathodic protection current required to achieve and maintain a protection condition changes scores of times each day. Given two identical storage structures with identical coatings and storing identical waters, differing degrees of cathodic protection need will exist.

There are literally scores of variables that have a direct effect on the rate of corrosion activity within a structure, and these variables cannot be assumed to remain stable and reproducible. They include:

1. *Water resistivity changes.* These can be caused by changes in water source or treatment, changes in chemical content, changes in temperature, and so on.

2. *Water corrosivity changes.* Variations in DO, chloride ion content, and so on, affect a given water's propensity to support galvanic corrosion.

3. *Accumulated ampere hour effect.* Less cathodic protection current is required to maintain a protection effect than is required to achieve it. This variable is also related to the quality of applied paint coatings.

4. *Loss of coating effectiveness.* Paint coatings are applied to submerged steel surface areas for the sole purpose of isolating the steel from the corroding medium. All coatings are subject to deterioration in service due to water absorption, abrasion, bond failure, delamination, ice damage, and so on.

5. *Anode consumption in service.* Anode material is consumed as direct current flows from it. As the anodes are consumed, the circuit resistance of the cathodic protection system is increased. This necessitates changes in applied voltage to maintain a protection effect.

6. *Water level fluctuation.* Naturally, the current required to protect a given tank or other structure varies as more or less steel is exposed to the water electrolyte.

It is not enough to recognize that these changes occur without the cor-