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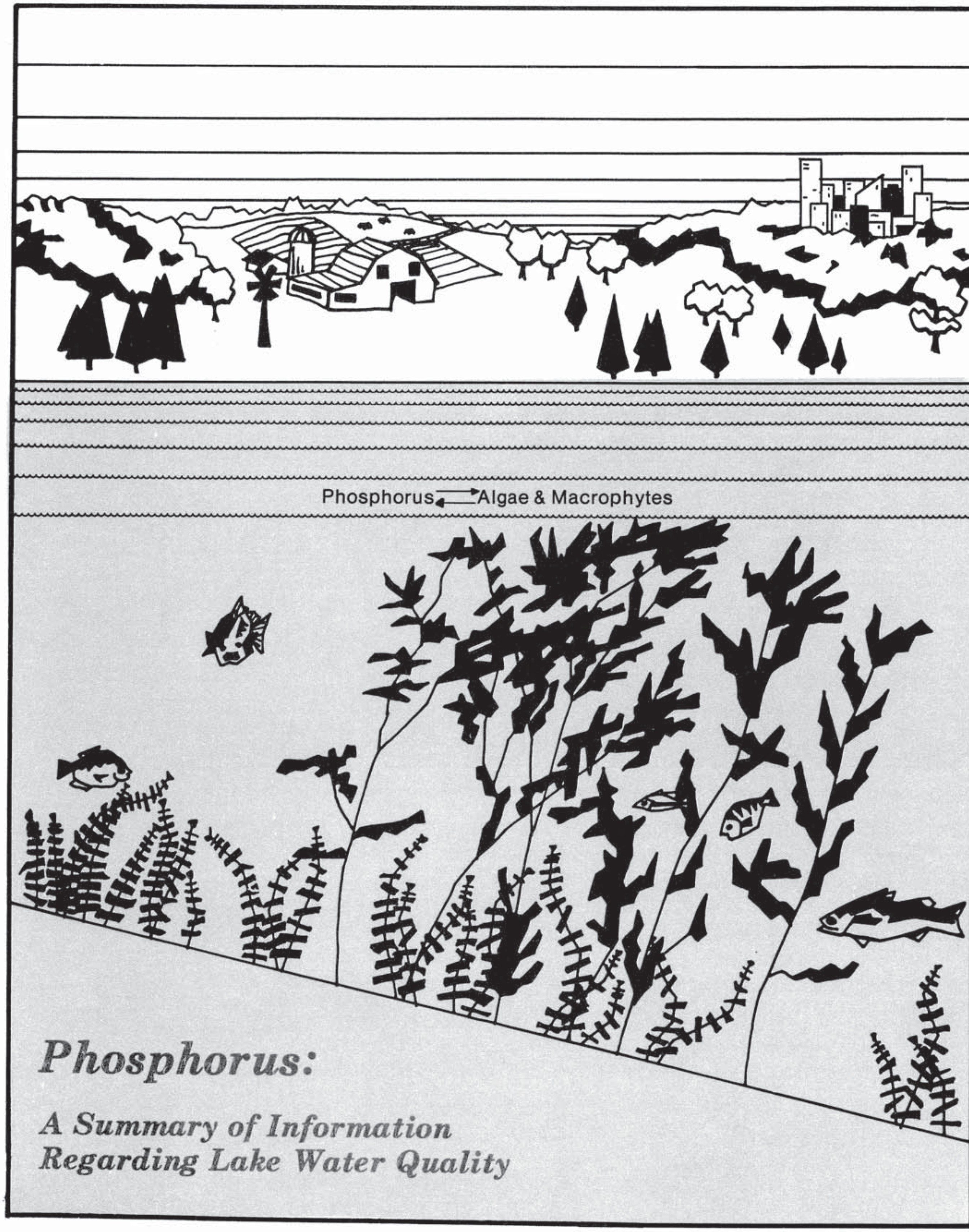


# Phosphorus:

## A Summary of Information Regarding Lake Water Quality

# *Phosphorus: A Summary of Information Regarding Lake Water Quality*


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Table of Contents

## TABLES AND FIGURES

# EXECUTIVE SUMMARY

In the process of bringing municipalities into compliance with the present phosphorus regulations, questions have arisen regarding the efficacy of point source phosphorus reduction in view of the large contribution from nonpoint sources. This document represents a review of scientific literature and information from Illinois watersheds for the purpose of clarifying the influence of phosphorus on lake water quality and relative contribution of point and nonpoint sources.

Several forms of phosphorus occur in the aquatic environment. Major forms discussed in this review are orthophosphorus (OP), dissolved or soluble phosphorus (DP), particulate phosphorus (PP), and total phosphorus (TP). Orthophosphorus is the form immediately available for algal growth. Particulate phosphorus is considered to be potentially available. This potential availability indicates that a portion of the PP (50 percent or less based on review of the literature) may be converted to OP.

Water samples taken during routine monitoring are most commonly analyzed for DP and TP. Measurements of DP and TP, in this case, are used to approximate available and potentially available phosphorus.

According to the literature, domestic wastewater and agricultural runoff are major sources of orthophosphorus, although urban runoff is important in some watersheds. Domestic wastewater contains the highest proportion of OP of the three sources; however, levels may be higher in agricultural runoff in spring.

During stream transport, orthophosphorus is likely to become incorporated into the particulate fraction. A portion of the phosphorus bound to the sediment particles can also be released as OP. Upon reaching the lake, exchange between available and potentially available forms continues through processes of sediment and algal uptake and release.

It is recommended that strict control of phosphorus effluent levels from direct and proximal discharges to lakes be maintained because of the high level of OP delivery from these discharges.

Transport distance from phosphorus sources to lakes is recognized as a major factor determining the availability and timing of load delivery. Control of phosphorus in wastewater discharges further upstream from the lake should be based on the distance between the discharge and the lake.

Through review of information on Illinois watersheds, it was found that nonpoint sources account for approximately 85 percent of TP contributions to Illinois lakes. The largest nonpoint source contributor of phosphorus comes from agricultural land. Phosphorus has a high affinity for silt and clay particles, therefore, most phosphorus from agricultural lands is lost and transported to lakes or reservoirs through the processes of soil erosion and sedimentation. Generally from 70 to 90 percent of the agricultural TP load to lakes is sediment associated (PP) while 10 to 30 percent is found in the dissolved form (DP).

Many factors interact to determine the amount and rate of phosphorus transport from lake watersheds, including the type of land use, soil type (texture), frequency and intensity of rainfalls, specific watershed characteristics (i.e., land slope, shape), and sediment yields. Due to the complexity of these interactions, annual loading rates vary considerably from watershed to watershed. Literature values reported for TP ranged from 0.13-12.90 lbs/ac/yr (0.15-14.50 kg/ha/yr).

Urban and construction site phosphorus loads are generally much smaller than those from agricultural areas, however. their impact upon nearby lakes and streams leading directly to lakes can be extremely damaging. A review of Nationwide Urban Runoff Program (NURP) studies was used to highlight the effects of urban runoff on receiving lakes. According to the studies, lakes which received urban runoff generally exhibited decreased water quality. Although the degree of detrimental effects varied, the studies concluded that accelerated eutrophication may result, and that phosphorus was often a major contributor to the problem. Annual phosphorus loads could not be consistently correlated with land uses in the watersheds. The NURP final report did conclude, however, that commercial urban areas contributed the larger loads due to more impervious areas. Total loads were strongly influenced by runoff volume.

The magnitude of point source phosphorus loads, both domestic and industrial, is determined by four primary factors. They include: a) population served, b) detergent usage, c) type of industrial waste, and d) extent of municipal waste treatment. Estimated phosphorus contributions from domestic waste, which includes human wastes and detergent usage, range from 2.25-3.00 grams/caput/day (person/day). Industrial wastewater inputs, especially those associated with the food processing industry, can be very large. Industrial sources of phosphorus include fertilizer manufacturing and metal finishing. The type of wastewater treatment used can also influence the amount of point source phosphorus discharge. The residence time of waste in a system will affect the settling and biological removal of phosphorus.

Internal as well as external (nonpoint and point) sources of phosphorus must be considered in determining lake trophic status. Impoundments built on fertile Illinois soils often have high sediment phosphorus levels from the start. Phosphorus release from the sediments in these lakes can cause early development of eutrophic conditions. Inputs of point and nonpoint sources serve to intensify the eutrophic conditions and add to the sediment phosphorus levels. Significant amounts of available phosphorus may be released from lake sediments. The largest release occurs under anaerobic conditions near the sediments; although some phosphorus is released under aerobic conditions, as well. Another internal source of phosphorus is the release of phosphorus from dead and decaying algae and macrophytes.

Most researchers agree that phosphorus is the nutrient whose input must be controlled for control of algal and macrophytic productions in lakes such as those in Illinois. Excessive phosphorus additions increase plant production which ultimately disrupts the natural oxygen balance of a system. Algae blooms can impart undesirable tastes and odors to the water, interfere with water treatment, and cause unpleasant scums. A decline of lake water quality (eutrophication) is the end result.

In this review a variety of BMPs are examined to determine their effectiveness in reducing agriculturally related phosphorus loads to lakes. It was found that any BMP which reduces soil erosion, water runoff, and/or increases plant nutrient uptake efficiency will, in turn, reduce phosphorus losses. Individual BMP effectiveness can be found in Section VII of this report.

Average reductions in gross soil erosion and sedimentation of 45.7 and 45.8 percent respectively were found in a review of ten Illinois Watershed Land Treatment Projects (WLTPS). Since 70-90 percent of total phosphorus (TP) loads to Illinois reservoirs is sediment associated (PP), reductions in TP loads may realistically range from 32.1-41.2 percent.

Best management practice application in urban areas has similarly been examined. The NURP Final Report and several other studies assessed the effectiveness of urban BMPs in controlling urban runoff. They concluded that wet detention basins were highly effective at removing total pollutant masses. Phosphorus reductions of greater than 50 percent were noted. Moderate improvement in urban runoff quality was found in studies of grassed swales. This technique was considered very promising. Streetsweeping was found to be generally ineffective in controlling urban runoff quality, although a Madison, Wisconson study found reduction of phosphorus loading rates between 47-59 percent. The use of porous pavement to reduce runoff was one of the most effective BMPs at removing available nutrients, along with wet detention basins combined with alum coagulation.

Dry detention basins, on the other hand, had much lower removal rates.

A variety of approaches to reduce point source loads of phosphorus have been developed and utilized by other states to meet the conditions mandated by the USEPA under Public Law 92-500. Illinois is one of 25 states which has specified criteria for phosphorus control. Illinois utilizes a numeric criterion. Other types of criteria include narrative criteria, a combination of numeric and narrative criteria, and criteria based on natural nitrogen to phosphorus ratios.

Various methods of wastewater treatment exist which help meet existing phosphorus discharge standards. The most common method of reducing wastewater phosphorus concentrations is the addition of a precipitation-flocculation material such as aluminum salts, iron salts or lime. Costs involved vary with the chemical utilized and the extent of existing facility modification. Removal of phosphorus by increased uptake of sludge biota has also been investigated. From 70 to 90 percent of the TP from influent waste can be removed by these methods if managed properly.

Another useful approach to phosphorus control is diversion of wastewater to less sensitive stream reaches distant from lake inflow. Diversion of wastewater around Long Lake in northern Illinois has resulted in an improvement in water quality.

Due to the predominance of agricultural loading, the quality of all Illinois lakes may not improve with point source control. However, there are water bodies, or portions of water bodies, which will benefit by protection or improvement of quality from control of point source phosphorus loads.

Illinois impoundments inherently support numerous beneficial uses. The extent to which these uses are impaired or further degraded depends on 1) the character of the impoundment, 2) watershed characteristics, and 3) in-lake management practices. This document offers the following recommendations regarding each of the above mentioned factors:

1. Future efforts should be directed toward categorization of lakes according to phosphorus sensitivity and potential for restoration/protection with control of input from various sources.

2. In view of the variability of conditions within lakes and their watersheds, adjustment of the current point source phosphorus regulations to emphasize control of direct or proximal discharges is in order.

3. Governmental and private entities should adhere to and accelerate nonpoint source control programs since these programs constitute a great potential for reducing external phosphorus loads.

4. Due to the importance of internal loading from regeneration of lake sediment phosphorus, more effort should be given to development and implementation of in-lake management practices.

# *INTRODUCTION*

The State of Illinois lake and effluent standards for phosphorus are being scrutinized because of questions regarding their efficacy in view of the cost of compliance.

In 1970 the Illinois General Assembly adopted, and the Governor signed into law, the Illinois Environmental Protection Act establishing the Illinois Pollution Control Board (IPCB) and the Illinois Environmental Protection Agency (IEPA) to deal with environmental matters. With repeal of its predecessor, the Sanitary Water Board, and the rules promulgated by that body, adoption of water quality standards was among the Pollution Control Board's early priorities. A regulatory docket was opened and extensive public hearings were conducted. The board adopted its first water quality standards on December 21, 1971.

Included among the regulated parameters was phosphorus, limited to 0.05 mg/l for lakes and reservoirs and tributaries at the point of entry to a lake or reservoir. While the Sanitary Water Board had previously adopted water quality standards in response to the Federal Water Pollution Control Act of 1965, the IPCB's December 21, 1971 action constituted the first statewide regulatory control of phosphorus in Illinois.

Point source discharge standards adopted by the Board on January 6, 1972 include prohibition of discharges that cause or contribute to violation of a water quality standard (originally IPCB Regulations Chapter 1, Rule 402, subsequently recodified 35 Ill. Adm. Code 304.105). During the early and mid 70's virtually all lakes and reservoirs subject to IEPA monitoring exhibited excursions above the 0.05 mg/l standard, albeit at varying degrees. Viewing the phosphorus water quality standard as unachievable, at least in the short term, and given the inability of point source phosphorus removal technology to meet a 0.05 mg/l effluent concentration, IEPA petitioned the Board to modify its phosphorus regulations in January, 1976. The current water quality and discharge standards are the result of that proceeding (IPCB Docket R76-1).

They are as follows:

> Section 302.205 Phosphorus
>
> Phosphorus (STORET number 00665): After December 31, 1983, phosphorus as P shall not exceed 0.05 mg/l in any reservoir or lake with a surface area of 8.1 hectares (20 acres) or more, or in any stream at the point where it enters any such reservoir or lake. For the purposes of this Section, the term "reservoir or lake" shall not include low level pools constructed in free flowing streams or any body of water which is an integral part of an operation which

includes the application of sludge on land. Point source discharges which comply with Section 304.123 shall be in compliance with this Section for purposes of application of Section 304.105.

(Source: Amended at 3 Ill. Reg., no. 20, page 95, effective May 17, 1979)

Section 304.123 Phosphorus (STORET number 00665)

a) No effluent discharge within the Lake Michigan Basin shall contain more than 1.0 mg/l of phosphorus as P.

b) No effluent from any source which discharges within the Fox River Basin above and including Pistakee Lake and whose untreated waste load is 1500 or more population equivalents shall contain more than 1.0 mg/l of phosphorus as P.

c) No effluent from any source which discharges to a lake or reservoir with a surface area of 8.1 ha (20 acres) or more or to any tributary to such a lake or reservoir and whose untreated waste load is 5000 or more population equivalents shall contain more than 1.0 mg/l of phosphorus as P.

d) No effluent from any source which discharges to a lake or reservoir with a surface area of 8.1 hectares (20 acres) or more which does not comply with Section 302.205 or to any tributary to such a lake or reservoir and whose untreated waste load is 1500 or more population equivalents and which is not governed by Sections 304.120(a) or 304.120(c) shall contain more than 1.0 mg/l of phosphorus as P.

e) For the purpose of this Section, the term "lake or reservoir" shall not include low level pools constructed in free flowing streams or any body of water which is an integral part of an operation which includes the application of sludge on land.

f) Compliance with the limitations of paragraph (c) shall be achieved by the following dates:

1) New sources shall comply on the effective date of this regulation, and

2) Existing sources shall comply by December 31, 1980, or such other date as required by NPDES permit, or as ordered by the Board under Title VIII or Title IX of the Act.

g) Compliance with the limitations of paragraph (d) shall be achieved by December 31, 1985, or such other date as required by NPDES permit, or as ordered by the Board under Title VIII or Title IX of the Act.

(Source: Amended at 3 Ill. Reg. no. 20, page 95, effective May 17, 1979)

In the application of the above standards to Illinois waters, the effectiveness of reducing point source phosphorus has been questioned when input from nonpoint sources is high. The purpose of this study is to summarize information from scientific literature and from selected Illinois watersheds in order to elucidate the role of phosphorus in determining water quality and the relative influences of point and nonpoint source contributions.

# PHOSPHORUS FORMS, SOURCES, AND AVAILABILITY

## Forms of Phosphorus

The total phosphorus load in aquatic systems is comprised of several forms of phosphorus which have been classified in a variety of ways. Stumm and Morgan (1971) point out that almost all of the phosphorus in nature is in the form of phosphate, a negatively charged ion consisting of four oxygen atoms bound to one phosphorus atom that may be free or bonded with positively charged atoms or particles. Pyrophosphates, triphosphates, and other polyphosphate ions are also found in waters, especially those receiving agricultural runoff and waste water with detergents. Researchers most commonly report measurement of elemental phosphorus (P) rather than the quantity of phosphate ions ($PO_4^{-3}$). So, unless otherwise noted, we will speak in terms of elemental phosphorus. For purposes of this paper orthophosphorus (OP), dissolved phosphorus (DP), particulate phosphorus (PP), and total phosphorus (TP) categories will be used.

Orthophosphorus is a soluble inorganic component which reacts with an acid-molybdate solution for colorimetric analysis. Another category of similar description is called soluble reactive phosphorus (SRP). The soluble reactive category is used to indicate that the component measured with filtration and exposure to acid-molybdate contains a small fraction of polyphosphates which have unavoidably been hydrolyzed, as well as, orthophosphorus (Standard Methods 1985). For our purposes, OP and SRP will be considered interchangeable.

The dissolved phosphorus designation indicates that the analysis involved filtration and acid hydrolysis and/or digestion before reaction with the acid molybdate solution. Dissolved phosphorus is composed of inorganic polyphosphorus and organic phosphorus in addition to orthophosphorus (usually the main component).

Particulate phosphorus may be analyzed by sequential chemical extraction of solid material filtered from a sample (Sonzogni et al. 1982). However, the particulate component is often derived from the difference between the dissolved and total phosphorus measurements.

Total phosphorus is measured through digestion of unfiltered samples and includes both dissolved and particulate phosphorus.

## Sources of Phosphorus

Phosphorus undergoes transformations from dissolved to particulate and from inorganic to organic forms (via plants) in aquatic systems. Figure 1, modified from Welch 1980, illustrates phosphorus cycling in aquatic systems with natural sources of phosphorus. Processes of greater magnitude are the input from soil erosion, uptake of dissolved inorganic phosphorus by algae and macrophytes, contribution of plant and bacterial tissue to dissolved and particulate organic phosphorus and settling of organic phoshorus to the sediments. The replenishment of inorganic phosphorus by lake sediment can also be of great magnitude under conditions which will be discussed in the section titled "Internal Regeneration".

Sources of phosphorus include natural inputs mentioned in Figure 1, as well as inputs from human activity. These sources are listed as follows:

- weathering and solution of phosphate materials
- atmospheric deposition
- groundwater
- agricultural runoff
- urban runoff
- domestic and industrial sewage
- septic systems
- waterfowl waste

### Weathering

A certain amount of phosphorus occurs naturally in aquatic systems due to weathering of rock within the basin (Stumm & Morgan 1971). Mineral phosphorus can be bonded to calcium (apatite), iron (strengite), or aluminum (variscite)(Kramer et al. 1972). In soil, upper horizons become enriched with phosphorus through the accumulation of plant material containing phosphorus brought up by the

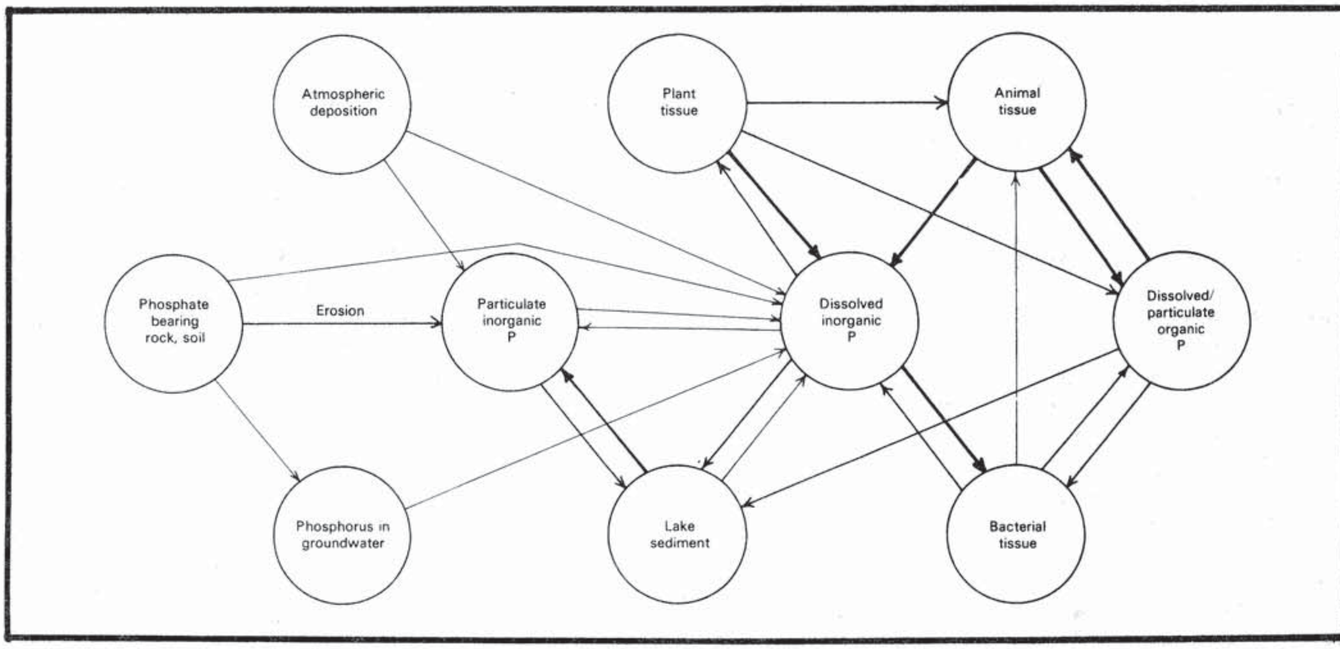



***Figure 1. Phosphorus cycle. The natural aquatic phosphorus cycle with transfers of greatest magnitude emphasized (modified from Welch 1980).***

roots. Limestone and rock phosphate are accumulations of ancient plant and animal remains (Keup 1968). Phosphorus is most available and easily leached from soils at a pH of six to seven. At higher pH the phosphorus combines with calcium (Wetzel 1975). The weathered phosphorus enters the water in the dissolved state and as phosphate bearing soil particles from erosion. Background levels, attributable to weathered phosphorus, vary depending on the geology and climate of the region. General levels of phosphorus in Illinois soils will be discussed in Section IV.

### Atmospheric deposition

Atmospheric deposition through precipitation and fallout is another natural source of phosphorus input. The loading through deposition tends to be small, but with increases in airborne soil particles and urban and industrial pollutants, phosphorus concentrations in precipitation and fallout have increased over natural levels in many areas. Rast and Lee (1983) give an estimate of 0.025 $g/m^2/yr$ of phosphorus as precipitation generated within a typical watershed based on a review of literature values. Wetzel (1975) found a loading range of 0.01 to 0.1 $g/m^2/yr$ (0.1 to 1.0 kg/ha/yr) with most values falling at the lower end. He also noted that the phosphorus content of precipitation and fallout of particulate material was variable with highs in agricultural regions in the spring.

Contributions of phosphorus from precipitation in some Illinois lakes.

| Lake | kg P/yr (lbs/yr) | % total load | Source of Information |
|---|---|---|---|
| Crab Orchard | 495 (1091) | 0.6 | USEPA-NES[1] |
| Lake Decatur | 200 (441) | 0.2 | USEPA-NES[1] |
| Lake Vermilion | 50 (110) | 0.1 | USEPA-NES[1] |
| Wonder Lake | 50 (110) | 0.1 | USEPA-NES[1] |
| Le-Aqua-Na | 2.3 (5) | 0.1 | Study 2 |
| Lake of the Woods | 10.02 (22) | 6.0 | Study 2 |
| Johnson Sauk Trail | 24 (52) | 12.7 | Study 2 |
| Skokie Lagoons | 151 (333) | 0.2 | Study 2 |

[1] U.S. Environmental Protection Agency-National Eutrophication Survey. 1975 a, b, d and e.

### Groundwater

Phosphorus concentrations in groundwater are generally low since phosphorus adheres to soil (Keup 1968). An average value for the U.S. is approximately 20 ug/l (Wetzel 1975). Twelve percent (2,684/22,000) of the samples taken from public water supply wells in Illinois contained measurable amounts of phosphate ion ($PO_4^{-3}$). The majority of the samples were taken from 1974 to 1984 by the Illinois State Water Survey. Phosphate concentrations for those wells giving detectable levels ranged from 0.01 mg/l (approx. 0.003 mg/l as $PO_4$-P) to 7.95 mg/l (approx. 2.59 mg/l as $PO_4$-P). The median value for wells in shallow sand and gravel aquifers was 0.705 mg/l (approx. 0.230 mg/l as $PO_4$-P). Wells in shallow and deep bedrock aquifers had median values of 0.433 mg/l (approx. 0.14 as $PO_4$-P) and 0.832 mg/l (approx. 0.271 as $PO_4$-P), respectively. It must be kept in mind, however, that a typical public supply well would have low to undetectable phosphorus levels. The data above refer to 12 percent of the samples with elevated levels at some time over the period of record (S. Schock, personal communication).

### Agricultural runoff

In all but the most urbanized of watersheds of the Midwest, runoff from agricultural land is a major contributor of the total phosphorus load entering a lake. The amount of phosphorus in runoff is influenced by 1) the amount of phosphorus in the soils, 2) topography, 3) vegetative cover, 4) quantity and duration of runoff, 5) land use, and 6) cropping practices (modified from Wetzel 1975). Rast and Lee (1983) give an estimate of 0.05 $g/m^2/yr$ for an export coefficient (or rate) from rural and agricultural portions of a typical watershed. Most of the agricultural phosphorus load occurs in spring in the form of particulate phosphorus from eroded soil and organic material. However, soluble phosphorus is also carried in runoff from fertilized land and, because of its immediate availability, can be important in lake eutrophication. Baker (1984) found that soluble phosphorus accounted for 20 percent of the total agricultural phosphorus entering Lake Erie and suggested that it may impact the lake.

The total phosphorus contributions of agricultural and rural runoff in several Illinois watersheds are estimated as follows:

| Lake | kg P/yr (lbs/yr) | % total load | Source of Information |
|---|---|---|---|
| Crab Orchard | 51,715 (114,012) | 65.2 | USEPA-NES[1] |
| Lake Decatur | 95,255 (210,001) | 91.7 | USEPA-NES[1] |
| Lake Vermilion | 19,830 (43,718) | 68.7 | USEPA-NES[1] |
| Wonder Lake | 9,960 (21,958) | 27.3 | USEPA-NES[1] |
| Le-Aqua-Na | 1,668 (3,679) | 92.6 | Kothandaraman and Evans 1983a |
| Lake of the Woods | 824 (182) | 50.0 | IL State Water Survey 1983 |
| Johnson Sauk Trail | 51 (111) | 27.6 | Kothandaraman and evans 1983a |

[1] U.S. Environmental Protection Agency-National Eutrophication Survey. 1975 a, b, d and e; values may include urban runoff and other diffuse sources.

### Urban runoff

Urban runoff can be defined as the water that comes off lawns, rooftops, streets and other paved areas during and after a rainstorm or as snowmelt (Fratoni et al. 1982). As the runoff travels, it picks up contaminants, including nutrients, sediments, metals, litter and organic and bacterial wastes in its path. Through natural or man-made drainage systems, urban runoff travels across urban areas and into receiving waters. Atmospheric deposition, fertilizers, construction site erosion and plant materials are common sources of phosphorus found in urbanized areas.

Urbanization accelerates erosion through alteration of the land surface. Disturbing the land cover, altering natural drainage patterns and increasing impervious area all increase the quantity and rate of runoff, thereby increasing both erosion and flooding potential (USEPA, NURP Final Report, 1983).

The impervious nature of urban areas contributes to problems with flooding. The rate and volume of water that runs off of sidewalks, streets and rooftops is greater than in undeveloped areas. Immediate concerns of the public are with flooding, especially after a heavy storm when many basements flood. Less visible, but no less important, are the effects of increased runoff draining into urban streams and water bodies.

The phosphorus export coefficient estimated for urban runoff by Rast and Lee (1983) was 0.1 $g/m^2/yr$, which is higher than the coefficient for rural and agricultural runoff. Urban runoff is more concentrated than agricultural runoff but watershed area covered by agricultural land is usually much greater than urban area.

### Domestic and industrial waste

Domestic and industrial wastes are sources of phosphorus that may play a major role in the water quality of a lake. Loading from domestic waste depends on the population served, extent of sewage treatment and point of discharge. Phosphorus in sewage comes from the breakdown of organic phosphorus in waste and from phosphate additions in household detergents. The importance of detergents has declined over the last several years. Phosphate bans established in some areas and voluntary reduction by many detergent manufacturers have reduced the phosphorus content of detergents. Phosphorus in industrial waste comes from by-products of manufacturing or food processing and from industrial water softening.

The total phosphorus contributions of wastewater in several Illinois watersheds are as follows:

| Lake | kg P/yr (lbs/yr) | % total load | Source of Information |
|---|---|---|---|
| Crab Orchard | 20,880 (46,032) | 26.4 | USEPA-NES[1] |
| Lake Decatur | 8,390 (18,497) | 8.1 | USEPA-NES[1] |
| Lake Vermilion | 8,805 (19,412) | 30.5 | USEPA-NES[1] |
| Wonder Lake | 25,985 (57,287) | 71.1 | USEPA-NES[1] |
| Skokie Lagoons | 65,889 (145,285) | 87.5 | Kirschner 1983 |

[1] U.S. Environmental Protection Agency-National Eutrophication Survey. 1975 a, b, d and e.

**Septic systems**

Input from septic systems which have failed or from systems in subsoil with low phosphorus sorption (sand) tends to be small compared to other loads and is not commonly measured as a separate input. Unless there is a concentration of septic systems close to a lake, the contribution of septic waste phosphorus is small (Jones and Lee 1979). In the Sandusky River Basin above Fremont, the closest city to the mouth, about 50 percent of the population had septic systems, but load contributions were very small (Baker 1984).

**Waterfowl waste**

Waterfowl in high densities can add to the phosphorus in a lake. Paloumpis and Starrett (1960, as cited in Vollenweider 1971) estimated that wild ducks contributed 1.43 ug of phosphorus per square meter of lake surface for one year in Lake Chautauqua, Illinois. Input from ducks and geese in Crab Orchard Lake was estimated at 6,250 kg phosphorus/yr and comprised 7.9 percent of the total phosphorus load to the lake (USEPA 1975). This estimate was based on an average of 50,000 over-wintering geese and 25,000 over-wintering ducks. On a typical lake of low waterfowl density, contributions of phosphorus by the waterfowl would be small.

## Availability of Phosphorus

In consideration of the importance of various phosphorus sources it is necessary to talk about the biological availability of the various forms. Availability of phosphorus to algae can be considered from three standpoints - 1) chemical availability, 2) seasonal availability, and 3) positional availability.

In terms of chemical availability, soluble inorganic phosphorus (orthophosphorus) is immediately available for uptake by algae. Soluble organic phosphorus, polyphosphates, and colloidal organic phosphorus must be hydrolyzed before they can be considered available (Meals and Cassel 1978).

Particulate organic and inorganic phosphorus is considered potentially available. Although these forms are unavailable in an immediate sense, some portion of them can become available through time by decomposition and desorption. Breakdown of the organic particles through decomposition, and desorption of phosphorus from inorganic particles with changes in chemical equilibrium are processes which release dissolved phosphorus.

While the end product of the weathering of mineral phosphorus (apatite) is available, the mineral phosphorus itself is considered unavailable because the rate at which it becomes available is very slow (Logan 1980).

That portion of phosphorus which is never available to algae and aquatic macrophytes is designated as the refractory fraction. Peters (1981) used radioactive phosphorus tracers and measurement of enzymatically released soluble phosphorus from particulate phosphorus to determine availability and indirectly estimate the refractory fraction. Both the tracer and enzyme methods supported the expectation that most of the particulate phosphorus in open lake water can become available. Availability of phosphorus in river waters was found to be highly variable. Eighty-three percent of the total phosphorus in lake water and 18-57 percent of the total in river water was determined available. The refractory phosphorus fraction was identified as inorganic particulates (clays and apatites), and both high and low molecular weight soluble material. The high molecular weight material was believed to be the colloidal material to which phosphorus can be tightly bound described by Rigler (1973).

Cowen and Lee (1976, as cited in Meals and Cassel 1978) used an algal bioassay to determine that 40 percent of the total phosphorus in Madison, Wisconsin snow samples was available. In a review of precipitation phosphorus availability, Logan (1980) found an average of about 50 percent of the total phosphorus was available although the actual values ranged from 7 to 100 percent.

Sonzogni et al. (1980) summarized phosphorus availability for several sources in the following table based on a review of the literature.

| Form & Source | Approx. % Potentially Available P |
|---|---|
| Particulate P in River Water | 40 or less |
| Total P in River Water | 50-60 or less |
| Particulate P in Urban Runoff | 50 or less |
| Total P in Rural Runoff | 50 or less |
| Total P in Municipal Point Sources | 70 or less |

Caution must be exercised in interpreting availability information since different methods have been used to determine availability. Some of the uppermost values obtained for availability come from chemical analysis of soluble phosphorus while other values are from bioassays measuring uptake of phosphorus by algae. Chemical analysis tends to overestimate availability (Logan 1980).

Effluent from municipal sources usually has more available orthophosphorus than any land runoff. In the Fox River, Wisconsin study, however, rural runoff in springtime contributed more orthophosphorus. DePinto et al. (1980, as cited in Rast and Lee 1983) found that about 80 percent of the total soluble phosphorus and approximately 50 percent of the particulate phosphorus in domestic waste effluent is readily available. These availability values are applicable to lake algae if the effluent is directly discharged into the lake. Effluent discharged upstream from a lake can undergo sedimentation and recycling during transport so availability, as it enters the lake, can be reduced to levels similar to diffuse sources (Logan 1980). The amount of reduction depends on the distance to the lake which will be discussed in the section entitled "Phosphorus Transport in Streams".

Rural runoff loads are composed of between 75 and 82 percent particulate phosphorus (Baker 1984). The availability of the particulate component ranges from 10 percent to 40 percent depending on the particle size and origin (Logan 1980). The overall availability of rural runoff is 50 percent or less (Sonzogni et al. 1980). Lee et al. (1980) proposed that 20 percent was a good approximation of availability for particulate phosphorus in the Great Lakes basin so that the total availability of the phosphorus loading to the Great Lakes is equivalent to the sum of the orthophosphorus concentration of the tributary loads and 20 percent of the particulate phosphorus (total availablity =OP+.20PP).

The season in which phosphorus loads are delivered to lakes is important in terms of phosphorus being available when algae are actively growing and phosphorus' resultant impact upon water quality. In the early 1970's the seasonal contributions of orthophosphorus (OP) from rural runoff and wastewater effluents for the Fox River as it enters Green Bay, Wisconsin were as follows:

| | Rural Runoff Loads Approx. load (lbsx$10^3$) | | | Municipal Treatment Plant Loads Approx. load (lbsx$10^3$) | | |
|---|---|---|---|---|---|---|
| | TP | OP | OP/TP x 100% | TP | OP | OP/TP x 100% |
| Summer | 47 | 30 | 64 | 775 | 500 | 65 |
| Fall | 60 | 32 | 53 | 525 | 425 | 81 |
| Winter | 190 | 45 | 24 | 420 | 380 | 90 |
| Spring | 1100 | 590 | 54 | 700 | 275 | 39 |

The period of maximum growth for algae in the Green Bay area is from June to November. Within the growing season, it appears that effluent phosphorus is the main source of phosphorus available to algae in Green Bay. Rural runoff is the main source of ortho (dissolved) phosphorus during spring but low water temperatures and, possibly, reduced light availability due to suspended solids limit algal growth at that time. However, with internal regeneration, phosphorus added in spring and settling to the sediments can become available in subsequent growing seasons (Sager and Wiersma 1975).

The lower Fox River is an example of a system in which the load was dominated by effluent from several municipalities in the early 70's. Since that time wastewater treatment plants have had to comply with a 1 mg/l effluent standard. The total phosphorus load in the river has declined by 80 to 90 percent of its early 1970's load. The amount of total phosphorus in Green Bay has declined approximately 40 percent. The discrepancy in load reduction to reduction in Green Bay has been attributed to internal regeneration of phosphorus from the sediments (P. Sager, personal communication).

Availability in terms of position of the phosphorus relative to the algae becomes important in a lake. Phosphorus derived from shoreline erosion is available mainly to algae and plants in the near shore zone. Since the shore material is coarse, it settles rapidly, allowing only a short time for particulate phosphorus to go into solution. Particulate phosphorus in open lake waters drops through the water column at a rate dependent upon particle size and water turbulence. Sand-sized particles settle rapidly, giving little time for desorption of phosphorus (Sonzogni et al. 1982) or, in the case of organic particulates, breakdown of organic bonds. Silt and clay sized particles generally settle more slowly, allowing more time for release of phosphorus. Once the phosphorus has dropped past the photic zone the chance of it being actively picked up by algal cells declines. Phosphorus can also be adsorbed onto dead algal cells and proceed to the lake sediments.

Algae can derive some phosphorus from sediment in the photic zone (Logan 1980). Phosphorus can also be made available from the bottom sediments after lake inversion following anoxic conditions and to a lesser extent under aerobic conditions. However, immediate availability is limited to dissolved phosphorus in the photic zone during periods of active algal growth. Within the water column dissolved phosphorus is constantly being recycled. Algae and bacteria take up dissolved phosphorus only to release it upon death and decomposition. Algal uptake rate depends on the levels of other nutrients, the algal species and abundance, light availability, temperature, and pH (Sonzogni et al. 1982). Dissolved phosphorus can be released by desorption from suspended particles when the aqueous concentration declines due to algal uptake.

## Summary

Orthophosphorus is the most important form of phosphorus in terms of immediate availability to algae. Dissolved phosphorus, an often measured component, is predominantly orthophosphorus. Particulate phosphorus is important from the standpoint of potential availability. Potential availablity indicates that a portion of the particulate phosphorus (50 percent or less) can be converted to orthophosphorus. Major sources of ortho- and particulate phosphorus are domestic wastewater and agricultural runoff, although urban runoff may be important in some watersheds. Domestic wastewater contains the highest proportion of orthophosphorus out of the three sources except in spring when orthophosphorus in agricultural runoff may be greater. Although effluent and runoff may be initially high in orthophosphorus, by the time the phosphorus is transported downstream, the load can be converted to mainly particulate phosphorus. Distance of transport has a major effect on the amount of available phosphorus reaching a lake. Direct effluent discharges to a lake undoubtedly contribute a large amount of readily available phosphorus.

Timing of phosphorus loads can determine their immediate impact. Dissolved phosphorus loads from rural runoff early in the spring would not affect algal growth as much as deliveries in late spring and throughout the summer when algal growth is not limited by other factors such as temperature or light availability. A part of the phosphorus that sinks to the sediment in particles can become available within that season or in another growing season after anaerobic conditions and lake overturn or wind-induced disruption of the thermocline.

# *PHOSPHORUS TRANSPORT IN STREAMS*

Phosphorus can affect stream water quality by stimulating algal production and increasing oxygen demand. Although the importance of stream water quality should not be discounted, for purposes of this review, we will be concentrating on the movement of phosphorus through the stream system and delivery to lakes.

Particulate and dissolved phosphorus entering streams (from point or diffuse sources) are not directly conveyed downstream. Rather, they travel downstream through three compartments: water, particulates (sediments) and consumers (biota). Newbold et al. (1981) developed this concept of "nutrient spiraling" to explain the interactive transport of nutrients in streams. Processes involved in nutrient spiraling are similar to those of nutrient cycling in lakes except that stream flow is a predominant factor affecting the rate of cycling and distance the nutrient travels in any of the three compartments. During high flows much of the nutrient, in this case, phosphorus, remains in the water compartment and is conveyed further downstream than under lower flows when dissolved phosphorus is likely to be adsorbed onto particles or taken up by stream biota, and particulate phosphorus can settle to the bottom.

## Phosphorus in Stream Water

Samples have been taken over set intervals downstream from point source effluents in some studies to determine the length of time phosphorus remains in the water compartment. Figure 2 illustrates the change in total phosphorus concentration in three sites downstream from a sewage treatment plant in Ohio without phosphorus control and with an effluent flow rate of 1.9 MGD (million gallons per day). At Kestetter, 0.55 miles (0.9 km) downstream from the discharge, the peak concentration of total phosphorus is over 10 mg/l. At Caldwell, approximately four miles (6.53 km) downstream, the phosphorus concentration has declined to about 2.5 mg/l and the diurnal variation dampened to a nearly uniform concentration. Since differences in flow are insignificant, the decreases in concentration were attributed to deposition and biological processing (Yaksich et al. 1980).

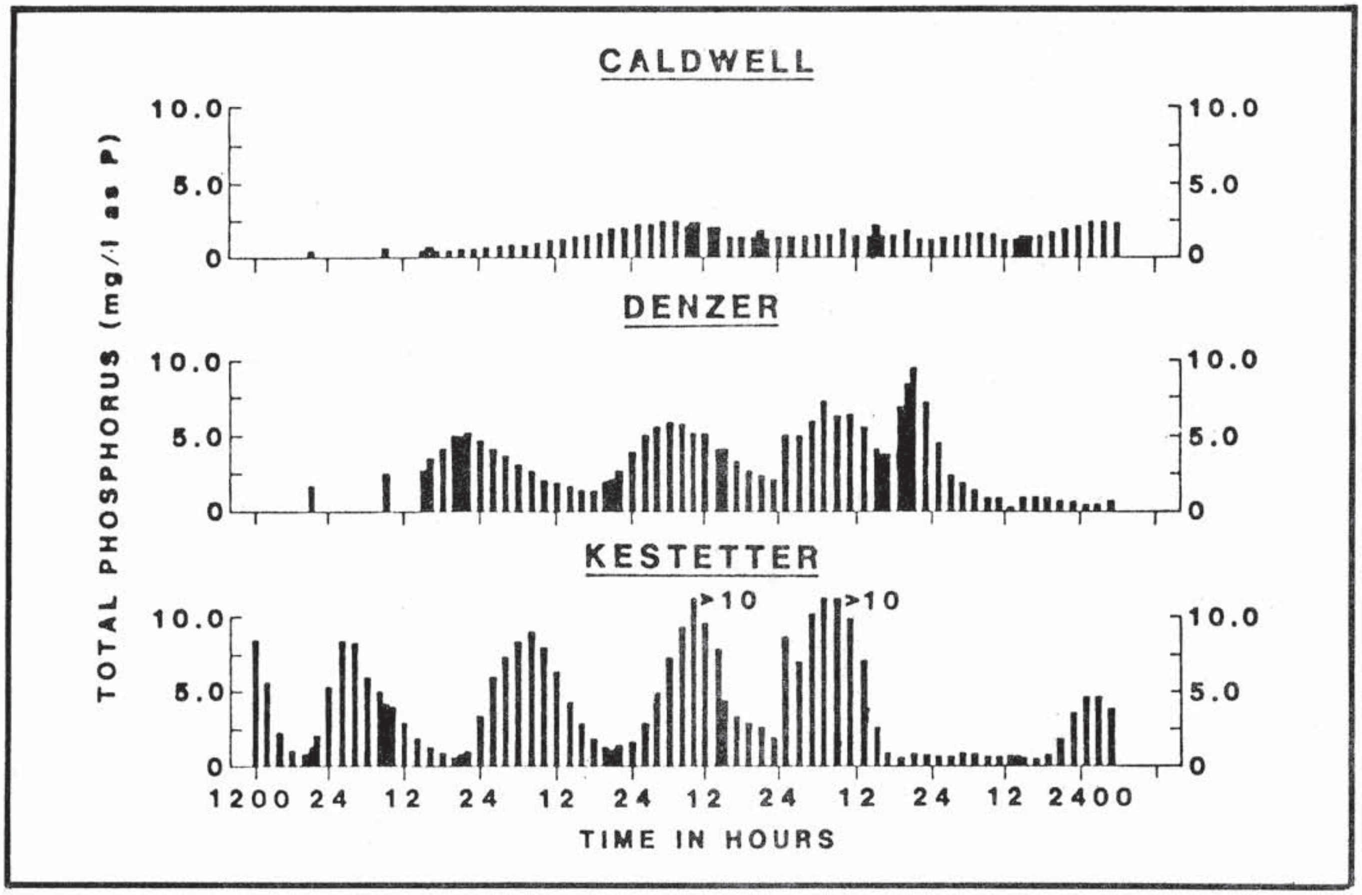



*Figure 2. Total phosphorus concentrations in the Sandusky River downstream of Bucyrus, Ohio. Kestetter (0.9 km), Danser (4.25 km), and Caldwell (6.53 km) at 2-hour intervals (Yaksich et al. 1980).*

In another study of the same Lake Erie tributary (Sandusky River), mean total phosphorus and soluble reactive (ortho) phosphorus for June through September were plotted to show the changes in phosphorus downstream from Bucyrus and two other sewage treatment plants (Fig. 3). Since the values for this graph are averages of several months of data, the concentrations are lower than those of the first graph which were actual values over a six-day period. The plot shows that mean phosphorus concentrations peak at the point of effluent discharge and then fall off as the water is transported downstream. Once again dilution effects were minimal since flow through the reaches was not appreciably different. The decline in phosphorus concentration was attributed to deposition and biological uptake (Baker 1980).

Standard deviation bars for the means of this graph would have supplied additional information as to the strength of this trend in the face of natural variability. Phosphorus loads (lb/day or kg/day) instead of concentration (mg/l) would have also been helpful in incorporating any differences due to stream flow in the plotted values.

Using the time dependency of flow and phosphorus concentrations during a storm event and the flow versus area curve for a rated point in a stream, the average distance traveled by the total phosphorus during a storm event can be calculated. Plotting this estimated distance of travel against the cumulative probability that portions of the phosphorus load will drop out produces estimates of the proportion of a phosphorus load travelling a stated distance. Figure 4 illustrates a plot of cumulative probability and distance of travel calculated for stations in the Sandusky River Basin. It was estimated from this plot that 50 percent of the phosphorus from Bucyrus, some of which drops out and is resuspended, will move at least 52 miles to Lake Erie. The rest of the phosphorus is deposited in sediment or in biota before it reaches the lake. Elevated flows at least as great as the flow event for which these calculations were made occur on the average of nine times a year (Verhoff et al. 1978).

The greatest transport of soluble reactive phosphorus occurs during storm events. In the Sandusky Basin 50 percent of the annual export of soluble reactive phosphorus occurs during five percent of the time with highest flows.

Orthophosphorus loading rates at these times exceed 61.2 kg/hr. During normal conditions of no storm events, much of the soluble reactive phosphorus is processed within the stream and, so, makes it to the lake as particulate phosphorus (Baker 1980).

Calculations made by Yasich et al. (1980) for deposition in the Sandusky River show that about 75 percent of the total phosphorus load drops out after traveling 16 km (9.94 mi) during low flow conditions which occur 35 percent of the time.

In general, immediately available orthophosphorus is converted to potentially available sediment and organic phosphorus during normal to low flow conditions. Potentially available particulate phosphorus either settles out or is transported out of the system depending on flow rate during normal to low flows. During high flow, dissolved phosphorus from point and nonpoint sources is transported directly through the stream system without any instream processing. Particulate phosphorus stored in the stream or entering the stream with storm events is also flushed through the system, although, when the streams meet or top their banks a portion of the phosphorus is left on the floodplain or in bank material.

***Figure 3. Mean total phosphorus concentrations at three sites downstream from sewage treatment plants (June through September 1974). Mileages shown are the distances from the mouth of the river. The three peaks in phosphorus concentration are caused by effluents of the Bucyrus, Upper Sandusky and Tiffin sewage treatment plants.***

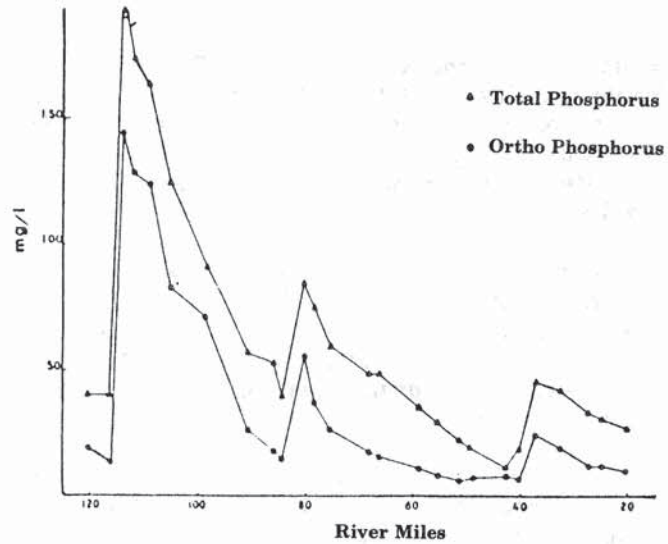
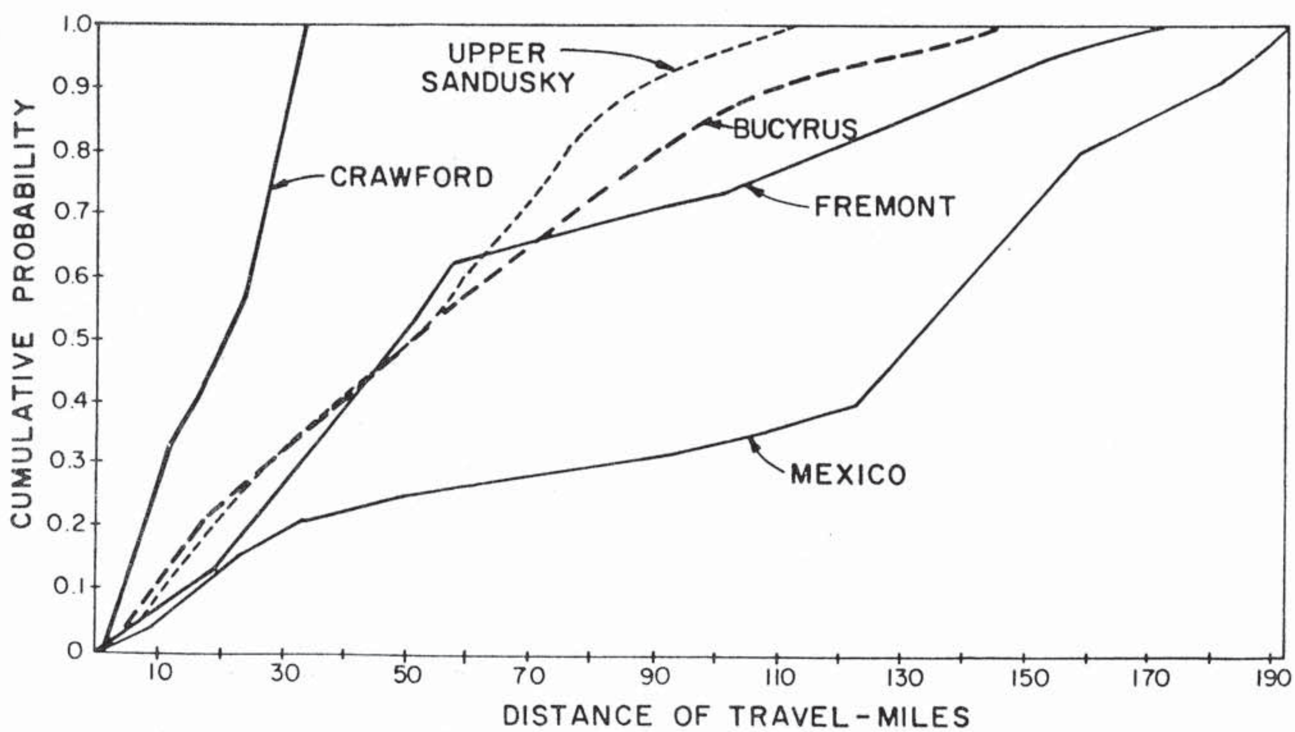



***Figure 4. Plot of cumulative probability and distance of travel for total phosphorus in the Sandusky River, Ohio (Verhoff, et al. 1979).***



Data collected from a New York stream system draining into Lake Champlain resulted in the following estimates of stream-borne phosphorus delivery:

| River Miles | Percent of Total Phosphorus Loading |
|---|---|
| 0-25 | 100 |
| 25-50 | 75 |
| over 50 | 50 |

(from Henson and Gruendling 1977 as cited in Meals and Cassel 1978). These estimates include allowances for resuspension and flushing during subsequent high flows. The delivery values estimated for the Sandusky River Basin emptying into Lake Erie (Fig. 4) fall into a similar range.

In another study, the phosphorus load was reduced at a faster rate. Keup (1968) found assimilation of 29 percent of the total phosphorus load (71 percent delivery) from municipal waste (8.7 lbs/day May, 5.7 lbs/day July) in a four mile reach of the Sebasticook River in Maine.

He also reported a reduction to background levels in the total phosphorus load produced by a wastewater treatment plant in a 42 mile reach of the South

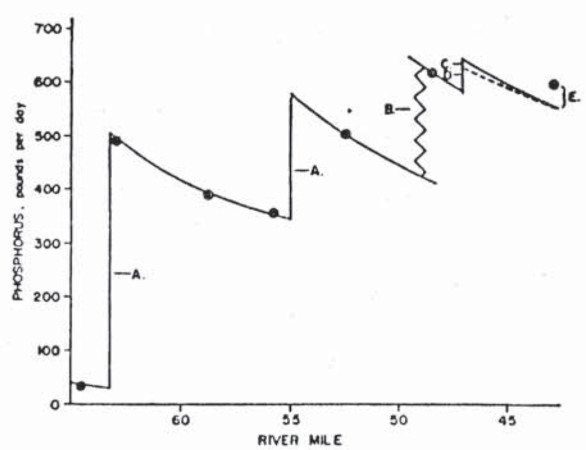



***Figure 5. Total phosphorus, Pigeon River, North Carolina. A — sources of municipal and industrial waste waters. B — resuspension of bed-load transported phosphorus. C and D — respectively, assimilated waste-related phosphorus and nonassimilated soil-related phosphorus from a tributary, Johnathans Creek. E — additional non-assimilated soil-related phosphorus originating along the Pigeon River reach between the tributary confluence and the sampling station (Keup 1968).***

Platte River, Colorado and a reduction of over 5 lbs P/day/mile in a 20 mile reach below a wastewater outfall on the Pigeon River, North Carolina. The contributions of several sources of phosphorus and the assimilation and resuspension of phosphorus in the Pigeon River are illustrated in Figure 5.

Inspection of data from two diel surveys (August and September 1982) of the Sangamon River below the Decatur Sanitary District treatment plant shows a drop of 73 percent in mean total phosphorus concentration within two miles of the treatment plant in August. At 37.8 miles the concentration had dropped another 13 percent to 0.92 mg/l (Appendix Figure 1). Flow in the two day August sampling period averaged 158 cfs, a portion of which resulted from release from Lake Decatur.

Flow in the reach during the September sampling period averaged 95 cfs and was dominated by flow from the sewage treatment plant since there was no release from Lake Decatur. The drop in concentration was less abrupt in this period, declining 11 percent in the first two miles and another 63 percent to 1.32 mg/l by 37.8 miles.

Loading rates were calculated to account for flow differences between sites and periods. Appendix Figure 2 shows the differences in loading due to flow differences in the two periods. As with concentration, mean total phosphorus loading rate dropped 73 percent in the first two miles and ten percent in 37.8 miles during the August period. The September low flow period produced a less drastic reduction, 11 percent in two miles and 54 percent in 37.8 miles.

The decrease in phosphorus concentration and load in the Sangamon River study, as in the other studies mentioned, is most likely due to settling and biotic uptake processes within the river reach.

One might expect phosphorus to settle out or be incorporated in algae quickly under low flow conditions. However, loading from the Decatur plant in September declined gradually over an extended reach. It is suggested that the gradual decline is a result of low levels of suspended solids for adsorption and settling of phosphorus and possible contributions from groundwater and release from the sediments.

Chlorophyll **a** concentrations, indicative of algal growth and uptake of nutrients, showed increases in the mid to downstream stations of the study reach. Chlorophyll **a** concentrations were particularly high in the September sampling period, reaching a high of 284 mg/l.

Within the first four to ten miles downstream of the treatment plant, algal growth, based on chlorophyll **a**, appears to be limited by some adverse condition caused by the effluent. In this stretch, reduction of phosphorus concentration is more likely due to adherence of phosphorus to the sediments. By 25 miles downstream, algal growth increased indicating uptake of phosphorus by algae.

A few researchers have used radioactive phosphorus tracers to follow the course of phosphorus through the stream system. Carlson (1977, as cited in Meals and Cassell 1978) measured a phosphorus loss of approximately 0.6 kg P/day over a 5 km reach of a New York stream. This amounted to a reduction in total phosphorus concentration from 1.39 mg/l to 0.16 mg/l. Kevern, Nelson, and Wilhm (unpubl., as cited in Keup 1968) found that about 75 percent of a $^{32}P$ spike was assimilated in a 100 meter long section of a small Tennessee stream. Ball and Hooper (1963) found that an atom of phosphorus travelled from 450 to 11,235 yards (411-10,274 m) in a Michigan stream.

## Uptake of Phosphorus by Stream Biota

Assimilation of phosphorus by stream biota (the consumer compartment as described by Newbold et al. 1981) has been most effectively studied in the $^{32}P$ tracer studies. The three tracer studies cited above found, under normal flows, uptake by periphyton, algae and bacteria present on substrates, to be of primary importance in the immediate removal of dissolved phosphorus from the water column. The periphyton removal rate in one New York stream was calculated as 0.5 kg phosphorus/day (Carlson 1977, as cited in Meals and Cassell 1978). Carlson found different periphyton uptake rates for different streams since the periphyton communities in each stream varied.

Ball and Hooper (1963) and Carlson (1977) found that aquatic macrophytes such as **Potamogeton**, **Elodea**, and **Fontinalis** were important points of phosphorus uptake in stretches of dense growth. Benthic invertebrates which filter feed or graze off of periphyton were also found to take up phosphorus in feeding but they were not as important as the periphyton (Ball and Hooper 1963).

While assimilation of phosphorus by stream biota may cause a decline in immediate concentration, the change is usually temporary since dissolved phosphorus is released as a product of cell metabolism and organic particulate phosphorus is released upon death and decay of plants and animals.

## Particulate and Sediment Phosphorus

Sonzogni et al. (1982) reported that about 25 percent of a typical Great Lakes tributary load is dissolved phosphorus and 75 percent is particulate phosphorus. The particulate phosphorus comes from several sources. Decay of algae, aquatic plants, tree leaves, woody material, and stream animals adds to the organic particulate phosphorus under all flow conditions. Under normal and low flows, phosphorus is incorporated in the bed load and particles resuspended from the sediments. During high flow periods soil particles from agricultural land runoff and from scouring of stream sediment can make up a major portion of the particulate phosphorus. Soil particles washed into the stream or resuspended during typical runoff events tend to be more fine-grained and richer in organic matter than the soils from which they were derived (Logan 1980). These two attributes make these particles excellent receptors of phosphate ions in solution.

Extremely high flows and high suspended solids concentrations are frequently associated with lower phosphorus to sediment ratios. It has been deduced that high sediment concentrations may tend to have large average particle size distribution and since large particles have less total surface area than small particles there is less surface for phosphorus adsorption (Baker 1984). If the dissolved phosphorus concentration is low in relation to particulate phosphorus, some of the phosphorus associated with particles will go back into solution (Johnson et al. 1976). In this manner, some of the phosphorus removed to the sediment during low flow reappears as dissolved phosphorus during high flow. Under extremely high flows, which exceed stream channel capacity, some of the particulate phosphorus is permanently deposited on the floodplains but, the amount of phosphorus lost this way has never been measured (Keup 1968, Baker 1980).

As flow returns to normal, suspended sediment with its associated phosphorus begins to settle out. Due to the turbulent nature of stream flow the particles settle out much slower than in lakes so there is more chance for recycling and downstream transport (Keup 1968). As much as 50 percent of the solids traveling downstream have been measured as material bouncing along the stream bottom (Benedict et al. 1963). Phosphorus associated with this bed load is not commonly measured since samples are most often taken as mid depth grab samples (Keup 1968). The Illinois Ambient Water Quality Monitoring Network uses a depth integrated sampling procedure developed by the U.S. Geological Survey which is more effective at sampling the water column than mid-depth grab samples. Time constraints associated with an extensive monitoring system make bed-load sampling prohibitive.

In addition to flow, longitudinal variation in stream morphology can affect phosphorus transport. Upper stream reaches of high gradient (change in stream bed elevation) have higher flow velocities and, so, less settling of particulates. Lower reaches of less gradient tend to retain more phosphorus (Meals and Cassel 1978). A change in the stream gradient from 15 to 23 feet per mile in the Pigeon River, N.C. was suspected in increasing suspension of sediment due to increased turbulence, thereby, increasing total phosphorus load in that reach by 30 percent (Fig. 5). In pool areas of slow flow, anoxic periods due to high BOD levels or nighttime respiration of algae can lead to significant amounts of phosphorus release from sediments just as in lakes (Fillos and Swanson 1975) (See Section VII A for description of regeneration from the sediments).

During elevated flows, a large proportion of the dissolved and particulate phosphorus from nonpoint sources and point sources will be delivered immediately to a lake. Under normal to low flows dissolved phosphorus mainly from point source discharges, is often stored temporarily in stream organisms and sediments to be delivered to a lake at some later time.

Keup (1968) suggested that a portion of the phosphorus load can be stored in the stream sediments at any one time but unless the stream is aggrading (and few are) annual storage is less than inflow. However, Johnson et al. (1976), working in a New York watershed for two years, found that six times more phosphorus went into the watershed from sewage, agriculture, and precipitation than was transported out as dissolved phosphorus and particulate phosphorus. Additional long term studies are necessary to determine the quantity and length of time phosphorus is stored in watersheds.

Stream retention of phosphorus is important from the aspect of the timing of phosphorus delivery to lakes. Sager and Wiersma (1975) found that more than 50 percent of the annual total phosphorus load to Green Bay, Wisconsin from the Fox River was delivered in spring. Nearly 40 percent of the orthophosphate load was delivered during that time. In summer, uptake by stream flora was at its peak and flows were not as high, so total phosphorus (40 percent) and orthophosphorus (5 percent) delivery was not as great. Fall was also a period of low phosphorus delivery (TP = 48 percent, OP = 19 percent). Orthophosphorus delivery in winter was relatively high at 77 percent. Lake algae are most active from May to November so they are given a phosphorus boost early in their growing season and then in summer and fall they must rely on phosphorus recycling in the water column and release from the sediments.

## Stream Phosphorus Entering a Lake

Upon entering a lake there are several factors which determine the fate of the phosphorus load. Depending on whether the lake is mixing or stratified, the stream phosphorus load will either mix throughout the lake or be concentrated in the epilimnion (Meals and Cassell 1978). In many Illinois lakes there is a good chance for mixing in spring when winds and spring overturn cause lake water to circulate. In spring phosphorus inputs are dominated by nonpoint source runoff (Baker 1980). In summer many of the lakes stratify so phosphorus inputs are likely to enter the epilimnion. However, if the stream water is heavily laden with particulates and the lake is stratified, the load may be carried along the bottom (Meals and Cassell 1978).

If spring water temperatures have warmed to permit algal growth, orthophosphorus is rapidly taken up and recycled in the water column until it becomes incorporated into organic or inorganic particles dense enough to sink to the bottom sediments. In winter, when algae are not growing the phosphorus sinks to the sediments with particulates (Meals and Cassell 1978).

As a stream empties into a lake, the flow rate drops off so large amounts of phosphorus bearing sediments drop out at the mouth (Keup 1968). Some of this sediment is likely to be overlain with more sediment so that a portion of the phosphorus becomes unavailable. However, the top few inches of the sediment contain phosphorus that may be recycled. When tributary water with its dissolved phosphorus and particulate phosphorus in equilibrium is diluted by lake waters, desorption of phosphorus from particles occurs (Sonzogni et al. 1982).

In some cases control of point source phosphorus alone would not do much to decrease the total phosphorus concentration in a lake. In other cases, such as with the Fox River entering Green Bay, point source control can significantly decrease the amount of phosphorus in a lake. As previously mentioned, with implementation of an effluent standard of 1.0 mg/l, total phosphorus loads were reduced by 80-90 percent and phosphorus in the bay was reduced by 40 percent.

Long Lake, in Illinois is another case where reduction of point source phosphorus loading has significantly reduced total and dissolved phosphorus concentrations. The 1979 diversion of Round Lake Sanitary District effluent out of a stream flowing three miles to Long Lake resulted in a 17 percent reduction in lake mean total phosphorus and a 14 percent reduction in dissolved phosphorus the following year. In 1985, six years after the diversion, the mean total phosphorus in the lake had declined by 83 percent, and dissolved phosphorus by 88 percent.

Reduction of nonpoint as well as point source loading may eventually reduce the total phosphorus concentration, but it may take as many as ten years to rid the system of the residual phosphorus built up in stream and lake sediments (Wetzel 1975).

# *CONTRIBUTING FACTORS AND ULTIMATE LOADS NONPOINT AND POINT*

Nonpoint sources account for 84.8 (±10.8 percent) of the total phosphorus contribution to Illinois lakes (Illinois Institute for Environmental Quality 1978). Sources of phosphorus include, but are not limited to, internal regeneration, atmospheric deposition, septics, livestock operations and waterfowl contributions. However, the greatest nonpoint source contributor of phosphorus loading is agricultural land.

Generally in Illinois, phosphorus contributions from urban areas and construction sites are much smaller than from agricultural areas, however, their impact upon urban areas and streams leading to lakes can be immediately damaging. Urbanization often accelerates erosion by disturbing land cover, altering drainage patterns and increasing impervious layers, which all increase the quantity and rate of phosphorus laden runoff water.

Eighty-six percent of all Illinois lakes surveyed exhibit eutrophic characteristics (Grede and Sefton 1985). These eutrophic conditions arose, in part, because natural soil fertility provided sufficiently high levels of phosphorus in the waters. Agricultural, urban and other nonpoint phosphorus loads play an important role in intensifying these eutrophic conditions, in some cases, to the point of resource degradation.

### Agricultural Loading

Agriculture in Illinois is big business. Of Illinois' 32 million acres of rural land, 24.7 million acres are considered cropland, which grow a wide variety of crops including corn, soybeans, wheat, and vegetables. Corn and soybeans account for the greatest planted and harvested acreage in Illinois. In 1984, 11.2 million acres of planted corn produced 1.25 billion bushels (avg. 111 bu/ac) while 9.2 million acres of planted soybeans produced 288.6 million bushels (avg. 31 bu/ac). These totals indicate that Illinois ranked #1 and #2 in soybean and corn production, respectively, in the United States in 1984.

In part, as a result of agriculture, Illinois also ranks high in gross soil erosion throughout the U.S. In 1982, the USDA Soil Conservation Service conducted the National Resources Inventory (NRI) which provided basic data on the current status of soil erosion in Illinois. The data showed that over 200 million tons of soil on 33 million acres are being eroded each year, for an average soil loss of approximately 6.3 tons/acre/year (IDOA 1985). Eight thousand acre-feet of Illinois lake storage capacity is lost as a result of lake sedimentation due to soil erosion each year (IEPA 1983).

Soil erosion not only degrades the productive capacity of Illinois soils, but also leads to excessive sedimentation of public water supplies, and has also been identified as a major contributor in the reduction of fish species in the State (Illinois Institute for Environmental Quality 1978). Erosion carries fertilizers to water bodies causing eutrophication in many Illinois lakes. Both phosphorus and nitrogen are described as the two major contributors to the eutrophication process.

Factors influencing nonpoint source phosphorus loads to lakes from their watersheds include:

1. forms of phosphorus,
2. type of land use,
3. soil types within the watershed,
4. watershed characteristics, and
5. sediment yields transported to the lake.

**Forms of phosphorus**

As previously mentioned, the three main forms of phosphorus discussed in this document are particulate (PP), dissolved or soluble (DP), and total phosphorus (TP). Generally, total phosphorus can be calculated when knowing the quantities of PP and DP, by using the simple equation PP + DP = TP. The literature reviewed indicated that total phosphorus figures generally correspond positively with the amount of soil being lost. Hubbard (1982) found that 90-98 percent of the TP contributions to small agricultural watersheds in the Great Lakes Basin were transported by sediment. Lake and Morrison (1977) found that approximately 85-95 percent of the TP losses found in the Black Creek Project in northeastern Indiana were transported by sediment. According to Monteith, Sullivan and Heidke (1981), the reduction in phosphorus contributions is assumed to be 60-90 percent of the reduction in soil loss. Therefore, it can be assumed that reducing soil erosion (and thereby lake sedimentation) will greatly reduce the amounts of both PP and TP found in Illinois lakes.

Fifty-six Illinois lakes, measured for TP and DP during the 1982 and 1983 water years, also showed that PP is the major fraction of TP loads, although not to the extent as mentioned by the above citations. According to the Illinois Environmental Protection Agency (1984) the mean dissolved to total phosphorus (DP/TP) ratio of these lakes ranged from 0.000-0.967, with the grand mean of 0.297 ±0.209) for surface waters. This indicates that an average 29.7 percent of Illinois lake TP loads result from DP contributions, while the majority of the load (71.3 percent) results primarily from the PP fraction.

Although the PP may be the greatest contributor to the TP load, some authors feel that the DP form may be the most important form to control. Holt, Timmons and Latterall (1970) found that the phosphorus content of surface waters is frequently the limiting factor for the growth of algae and aquatic weeds, and that a very small increase in DP can create conditions suitable for abundant algal production. According to the Illinois Institute for Environmental Quality (1978), it is the DP that is responsible for algal blooms, and is the form which should be regulated. However, most of the authors reviewed believe that the potential availability of particulate phosphorus should not be discounted, and so, TP should be targeted for control.

In summary, although there exists a high degree of site-specific variance throughout Illinois lake watersheds, it can be said that sediment associated phosphorus (PP) is generally responsible for approximately 70-90 percent of the total phosphorus (TP) found in Illinois lakes, while dissolved phosphorus (DP) is responsible for approximately 10-30 percent of the TP load. Because the majority of phosphorus is transported by sediment, the question is raised as to what extent soil and water conservation practices will reduce phosphorus loadings to lakes and streams during implementation of the "T by 2000" program ("T by 2000" will be discussed in depth in latter portions of the text).

### Land use relationships to phosphorus loads

Any land use which serves to reduce soil erosion and water runoff will reduce phosphorus transport. Such land uses would include pastureland, ungrazed forest land, orchards, etc. Cropland, if adequately protected with soil conservation practices, can also serve to reduce phosphorus transport. Various land uses, their acreages and average soil losses found in Illinois are shown in Table 1.

**Table 1. Estimated Average Annual Erosion By Rural Land Use, 1982**

| Land Use | Total 1,000 Acres | Total 1,000 Tons | Tons/Acre |
|---|---|---|---|
| Cropland | 24,727.4 | 172,432.0 | 7.0 |
| Pastureland | 3,157.3 | 9,417.6 | 3.0 |
| Grazed Forest Land | 638.1 | 8,325.7 | 13.1 |
| Ungrazed Forest Land | 2,791.3 | 4,349.5 | 1.6 |
| Other Rural Land[1] | 622.8 | 6,253.9 | 10.0 |
| TOTAL | 31,936.9 | 200,778.7 | 6.3 |

(1982 National Resource Inventory Data Tables for Illinois, USDA Soil Conservation Service, as reported in IDOA 1985.)

[1]Other rural land includes mines, quarries, houses, etc.

Cropland in Illinois accounts for 77.4 percent of the total rural acreage. For crop production purposes, phosphorus fertilizers are often added to the soil on an annual basis. However, since soybeans do not require a great deal of phosphorus for abundant growth, farms in corn/soybean rotations normally apply phosphorus fertilizers once every two years, either after the harvest of soybeans in the fall or before planting the corn crop in the spring. Because cultivation most often follows phosphorus applications, the soil and PP are left unprotected against water erosion, especially during frequent and heavy rainstorms in the spring of the year. High soil losses from sheet, rill and gully erosion occur carrying PP with the eroded soil. Because of this, cropland land uses are responsible for the greatest source of phosphorus losses and loadings to Illinois lakes.

Pasture and hayland land uses make up 9.8 percent of the total rural land acreage. Because of a low average soil loss per acre per year, and because phosphorus fertilizers are not applied to these lands on an annual basis, sediment and associated phosphorus losses are low relative to land under cultivation. Contributions of phosphorus from livestock wastes on these acreages have little effect on phosphorus related water pollution problems unless they are concentrated in a small area, which in itself is a poor management practice (IEPA 1979). It is recognized that the potential of nonpoint source pollution of pastured livestock exists, and is dependent upon the proximity of the lake, the stocking density, length of grazing period, average manure loading rate, manure spreading uniformity by grazing livestock, and disappearance of manure as a result of climate as well as insect and soil microbe action. Generally however, livestock raised on pastureland do not present a major threat to water quality; and with confinement of animals on the increase, potential pollution from pasture livestock will become even less of a problem, if confinements are managed properly.

Because of its dense vegetative floor and canopy effect, ungrazed forestland (8.7 percent of the total rural land acreage) is effectively protected from both wind and water erosion. Ungrazed forestland soil losses averaging only 1.6 tons/acre/year contribute little impact on phosphorus additions to water courses. However, should grazing be allowed on forestland, phosphorus additions to streams and lakes may increase. Erosion rates increase and livestock often have direct access to streams allowing frequent defecation directly into the stream or on the banks. Livestock also wade into the streams, stirring up bottom sediments, and resuspending PP. Research is needed before any definite statement can be made as to whether this is a significant problem or not. It seems that the existence of a problem depends upon individual site conditions.

### Soil relationships to phosphorus loads

There are currently 395 different soil types in Illinois categorized by: (1) the amounts of sands, silts and clays contained within them, (2) soil texture, (3) soil structure, (4) organic matter content, and (5) soil depth. Because of these differences, and because of differences in watershed shape, watershed size, rainfall, land use, etc., soil types erode at various rates (Cooperative Extension Service 1983). Part of the overall Universal Soil Loss Equation (USLE), which is used to estimate the amount of soil loss occurring on a one acre parcel of land per year, is the K factor, a measure of the erodibility potential of a given soil type. Generally, the higher the K factor, the greater the erosion rate will be if all other factors remain constant (i.e., rainfall, percent slope, length of slope, cropping management system, etc.).

Table 2 gives an outline of general soil types in Illinois and their corresponding K factors. As can be seen in this table, loose sands and sandy loam soils have low K factor values because water is allowed to permeate through the soil profile, which reduces water runoff and therefore soil erosion. On the other hand, soils having restricted permeability (i.e, silty clay loams) will enhance the erosion process since water is unable to infiltrate into the soil fast enough, causing increased water runoff and erosion.

The permeability of a soil and size of the soil particles influence the soil's erosion potential. Because sands are the largest of the three identified soil particles (sands, silts or clays), more energy is naturally required to suspend and transport (erode) sands than much smaller silt and clay particles. This is reflected in Table 2 as loose sands and sandy loam soils have low K factors compared to the high K factors for silt loam and silty clay loam soils (i.e., Fayette silt loam and Swygert silty clay loam).

As mentioned previously, phosphorus losses are closely associated with the amount of soil erosion taking place in a given watershed. Therefore, the K factor must be taken into consideration when developing strategies to reduce soil erosion and phosphorus loading to Illinois lakes.

**Table 2. Soil Erodibility (K) Values for Certain General Soil Types (University of Illinois Cooperative Extension Service 1983)**

| Soil Type | K Value | Soil Loss Tolerance (tons/acre/year) |
|---|---|---|
| Dark and moderately dark soil somewhat wet and with good permeability (for example, Muscatine, Ipava, Flanagan, and Herrick) | 0.28 | 5 |
| Dark and moderately dark prairie soil with good permeability (for example, Catlin, Harrison, Proctor, Saybrook, and Tama) | 0.32 | 4-5 |
| Dark and light prairie soil with restricted permeability (for example, Cisne, Cowden, and Clarence) | 0.37 | 2-3 |
| Dark prairie soil with very restricted permeability (for example, Swygert) | 0.43 | 2-3 |
| Light-colored forest soil with good permeability (for example, Alford,Birkbeck, Clinton, and Fayette) | 0.37 | 4-5 |
| Light-colored forest soil with restricted permeability (for example, Ava, Blount, Grantsburg, Hosmer, and Wynoose) | 0.43 | 3-4 |
| Sandy loam soil (for example, Dickinson, Onarga, and Ridgeville) | 0.20 | 3-4 |
| Loose sand (for example, Ade, Plainfield, and Sparta) | 0.17 | 5 |

Inherent phosphorus supplying power of the soil below the plow layer (the "plow layer" refers to the top eight inches of soil) in dominant soil types also differs throughout Illinois (Univ. of Illinois-Cooperative Extension Service 1982). This supplying power refers to soil conditions which allow for root penetration and branching throughout the profile, allowing the plant to take up available phosphorus which exists inherently in the soil. Inherent phosphorus amounts range from 30-65 lbs/ac in Illinois (E. Rankin, personal communication). Regional differences in phosphorus supplying power are shown in Figure 6. Parent material and degree of weathering were the primary factors considered in determining the various regions.

Low phosphorus supplying power may be caused by one or more of these factors:

1. A low supply of available phosphorus because (a) the parent material was low in phosphorus, (b) phosphorus was lost in the soil forming process, or (c) the phosphorus is made unavailable by high pH (calcareous) material.

2. Poor internal drainage that restricts root growth.

3. Dense or compact layers inhibiting root penetration.

4. Shallowness to bedrock, sand or gravel.

5. Other conditions reducing crop growth and root penetration (i.e., drouthiness, strong acidity, etc.).

The "high" region occurs in western Illinois where loess parent materials (wind blown silts) of more than four to five feet thick are present. The loess contains high phosphorus amounts and roots can spread and easily utilize available phosphorus in these moderately permeable profiles.

The "medium" region occurs in central Illinois with arms extending into northern and southern sections of the State. The primary parent material was more than three feet of loess over glacial till, glacial drift or outwash, which contain less available phosphorus in the subsoil. Also, more of the soils are poorly drained compared to those found in the "high" region, which are more likely to contain lower available phosphorus levels.

The "low" region in southeastern Illinois has from two and one-half to seven feet of loess over weathered Illinois till. The profiles are highly weathered compared to the other regions and are slowly or very slowly permeable. Inherent phosphorus levels may be high, but this is offset by conditions that restrict root penetration, inhibiting phosphorus uptake.

***Figure 6. Regional differences in phosphorus supplying power.***


The "low" region in northeastern Illinois was formed in thin loess (less than three feet) over glacial till. Glacial till is generally low in available phosphorus and shallow carbonates reduce the phosphorus supplying power because of basic conditions. Slow permeability in the subsoil restricts rooting in many soils of the region.

Since phosphorus losses occur primarily through soil erosion, buildup and maintenance applications of phosphate fertilizers to the plow layer are the major sources of agriculturally related nonpoint source loads. However, in areas having steep topography, much of the topsoil may have already been totally eroded away. These soils are found along streambanks and drainageways leading to lakes, and have been developed under forest cover which appear to have more available inherent soil phosphorus than those developed under grass (Univ. of Illinois-Cooperative Extension Service 1982). In these areas, inherent phosphorus can be lost through the erosion process and impact phosphorus loading rates to lakes.

### Watershed characteristic relationships to phosphorus loads

According to the literature reviewed, watershed size was not found to be a consistently good indicator of phosphorus loading potential to lakes.

However, the watershed to surface acreage ratio is an important factor. If watershed to surface area (WA:SA) ratios exceed 20:1, nonpoint source pollution can contribute significant nutrient and sediment loadings to a lake (Hawes and Newman). Experience has shown that lakes with large WA:SA ratios (greater than 100:1) are less likely to respond to lake protection measures and are most difficult to improve due to their large watersheds magnifying even low rates of nonpoint source pollution, and frequent inflows of runoff containing high levels of soil and associated nutrients (Sefton and Little, 1984). Lakes with ratios of 20:1 or less have the greatest potential for exhibiting and maintaining quality water.

Observations made by Hubbard, Erickson, Ellis and Walcott (1982) indicate that microrelief, watershed shape and field conditions are more important factors to consider than overall watershed size. Microrelief imposed by planter ridges and plant stalks retarded cross-row runoff, giving water time to infiltrate into the soil. It was shown that watersheds with long, steep slopes will increase surface water runoff more so than flat, lesser sloping watersheds. Field conditions, or more specifically, textural discontinuities in stratified subsoils promoted lateral seepage particularly during winter and early spring thaws.

Logan (1979), from studies conducted in the Maumee River Watershed in Ohio, found that TP yields are less dependent on drainage basin size than are sediment delivery rates and the type of sediment delivered. Because of phosphorus' high affinity for clay particles and organic matter, the type and amount of topsoil eroded and then delivered to a water body were more significant elements to consider than watershed size.

## Sediment yield relationships to phosphorus loads

Sediment yields delivered to lakes are dependent upon many factors such as land slope, soil type, annual rainfall and rainfall intensities, land use, conservation practices, micro-relief, field conditions, etc. Obviously, flat watersheds having many acres in pasture/hayland land uses in combination with cropland protected to below "T" erosion rates will reduce erosion and sedimentation much more than a watershed containing many acres of steeply sloping, conventionally tilled cropland.

Most hydrologists believe that the proportion of sediment transported out of a watershed will be lower for larger watersheds than for smaller ones (Clark et al. 1985). Clark cites one particular study (Novotny and Chesters 1981) that used data from Texas, Oklahoma, the Missouri River Basin, and the Southeastern Piedmont area. The data showed that watersheds with drainage areas of 1 square kilometer (247 acres) lost about 40 percent of their eroded soil, while watersheds with drainage areas of 100 square kilometers (24,700) lost approximately 10 percent.

Regional differences in sediment yields can be noticed throughout the state. As can be shown in Table 3 and Figure 7, the deep loess soils of the Springfield Plain showed the lowest median sediment yield per acre per year average (Illinois Institute for Environmental Quality 1978). Although this area is intensively farmed, the flat topography in the area produces low soil losses and related sedimentation rates. The highest median sediment yield average (excluding the miscellaneous reservoirs which were known to have sediment problems) was found in the Galesburg Plain. These steeper, deep loess soils are intensively farmed and highly erosive, creating more erosion which directly deposits sediments in lake reservoirs throughout the area. The southern claypan soils are not as productive as deep loess soils and consequently are not farmed as intensively. Claypan soils are much tighter and consequently less erosive than deep loess soils.

It is evident that a mixture of watershed characteristics and their interrelationships affect lake sedimentation rates. Table 4 illustrates the wide variation in sedimentation rates found in Illinois.

**Table 3. Amounts of Sediment Delivered to Reservoirs in Illinois (Illinois Institute for Environmental Quality 1978)**

| Area Description | Number of Reservoirs | Median Sediment Yield in Tons per Acre per Year |
|---|---|---|
| Southern Illinois (claypan soils) | 36 | 1.5 |
| Springfield Plain (deep loess soils) | 20 | 1.3 |
| Galesburg Plain (deep loess soils) | 20 | 2.2 |
| Miscellaneous Reservoirs not in a Study Area[1] | 25 | 2.3 |
| Total | 101 | |

1 These reservoirs were known to have sediment problems and were not a representative sample.

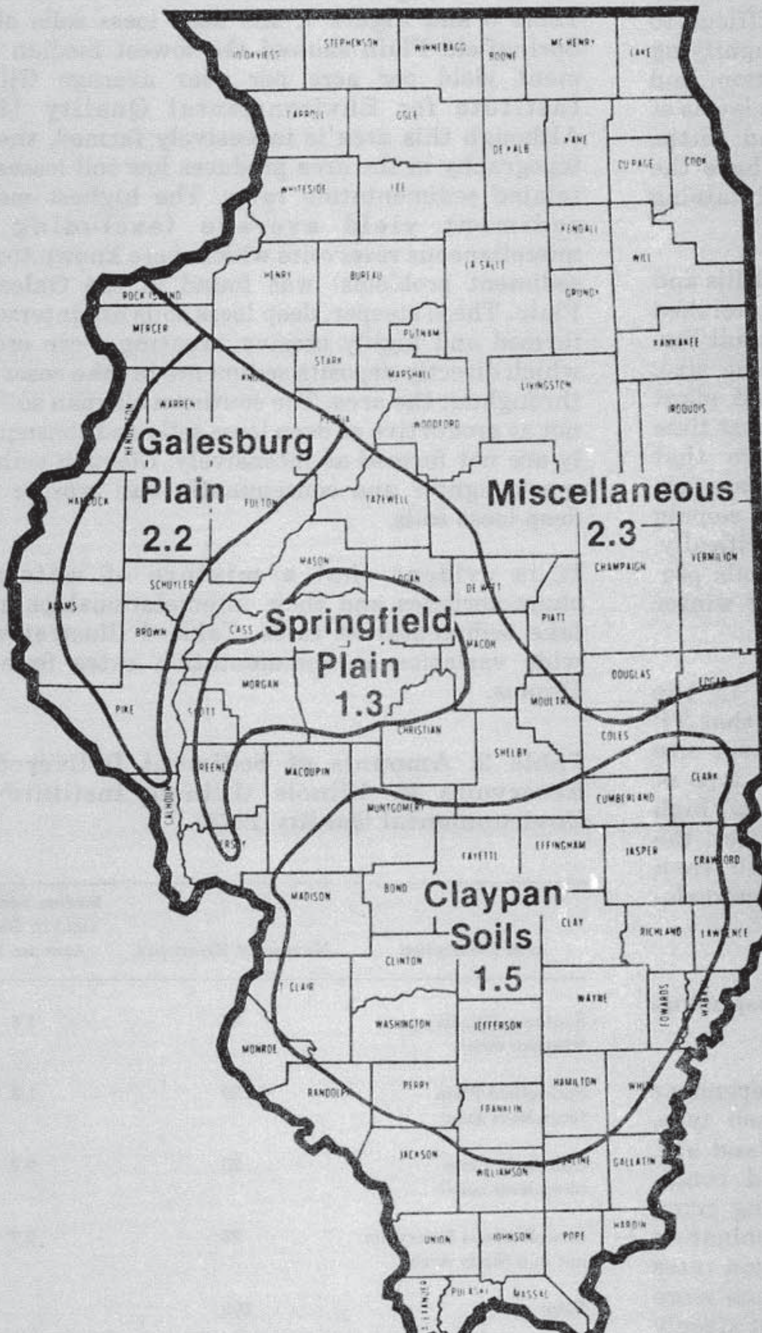



***Figure 7. Median sediment yields in reservoirs in tons per acre per year.***

**Table 4. Sedimentation Rates of Several Illinois Lakes (Estimated by R.D. Walker in Illinois Institute for Environmental Quality 1978)**

| Lake | Period of Study | Watershed Size in Sq. Miles | Tons of Lake Sediment per Year per Acre of Watershed | Lake Sedimentation Rate Percent Per Year | Estimated Soil Loss Tolerance for the Watershed (t/ac/yr) |
|---|---|---|---|---|---|
| Carbondale Reservoir | 1926-48 | 3.10 | 7.70 | 0.63 | 2-3 |
| Herrin Reservoir #2 | 1926-36 | 3.10 | 7.00 | 1.30 | 2-3 |
| Eldorado Reservoir | 1920-48 | 2.23 | 5.00 | 0.48 | 3 |
| West Frankfort | 1926-49 | 4.03 | 4.00 | 0.33 | 3 |
| Little Grassy | 1942-51 | 15.10 | 3.70 | 0.15 | 2-3 |
| Crab Orchard | 1940-51 | 185.00 | 2.80 | 0.43 | 3 |
| Marion Reservoir | 1921-51 | 6.50 | 0.72 | 0.55 | 3 |
| Central Illinois | | | | | |
| Ridge Lake (Charleston) | 1941-51 | 1.40 | 4.36 | 1.29 | 4 |
| Lake Springfield | 1934-51 | 265.00 | 1.03 | 0.30 | 4-5 |
| Lake Vermilion | 1925-76 | 320.00 | 0.49 | 0.88 | 4-5 |
| Lake Decatur | 1922-66 | 905.00 | 0.28 | 0.84 | 4-5 |
| Western Illinois | | | | | |
| Pittsfield Reservoir | 1923-46 | 1.84 | 4.83 | 1.71 | 4 |
| Lake Bracken (Galesburg) | 1923-49 | 8.91 | 3.45 | 0.58 | 4 |
| Lake Carthage | 1926-49 | 2.90 | 2.50 | 1.03 | 4 |
| Spring Lake (Macomb) | 1927-49 | 20.20 | 1.40 | 2.32 | 4 |

**Table 5. Phosphorus Contribution Ranges from Literature in lbs/acre/year (kg/ha/year). Ranges are taken from authors cited in Table 6**

| | |
|---|---|
| Total Phosphorus (TP) | 0.13-18.40 (0.15-20.67) |
| Dissolved Phosphorus (DP) | 0.003-0.80 (0.003-0.90) |
| Particulate Phosphorus (PP) | 0.52-7.20 (0.58-8.09) |

These wide variations in phosphorus contributions can be attributed to many factors. Because some soils erode more readily than others, erosion rates varied greatly. Rainfall amounts, and the intensity of those rainfalls were anything but constant. Watershed shapes and sizes varied from flat to very steep in shape, and from very small (less than 2 acres) to very large (more than 4,000,000 acres). Also cropland land uses in the watersheds reviewed ranged from 6.2 percent to greater than 90 percent. Other variations were noticed. Therefore, it would be inaccurate to make any assumptions as to what an average phosphorus loading rate to Illinois lake watersheds would be according to the literature reviewed (Table 6 shows the literature review findings).

## Measured phosphorus loads

Fourteen studies were examined to identify phosphorus loading rates for lake watersheds on a per acre watershed basis. Review areas included the following states: Illinois, Ohio, Georgia, Michigan, Wisconsin, Missouri, Minnesota, and Iowa. From the review, particulate and dissolved phosphorus were, as previously mentioned, the main sources of the total phosphorus load found in lakes, and the forms which help to accelerate the eutrophication process. As can be seen in Table 5, phosphorus contributions to lakes varied considerably.

**Table 6. Phosphorus Loadings From the Literature Reviewed**

| Citation | State | Phosphorus Loadings in lbs/ac/yr (kg/ha/yr) Total P | Particulate P | Dissolved P | DP/TP |
|---|---|---|---|---|---|
| Baker 1984 | Ohio | 1.09 (1.22) | 1.05 (1.18) | 0.28 (0.31) | 0.257 |
| Logan 1979 | Ohio | 1.76 (1.98) | — | 0.17 (0.19) | 0.108 |
| Lake 1977 | Ohio | 2.79 (3.13) | 2.54 (2.85) | 0.16 (0.18) | 0.065 |
| Langdale 1985 | Georgia | 3.56 (4.00) | — | — | — |
| Haith 1979 | Georgia | — | 2.19 (2.46) | 0.43 (0.48) | 0.180* |
| | Michigan | — | 1.39 (1.56) | — | — |
| Monteith 1981 | Many States Combined | 0.70 (0.78) | | — | — |
| Hubbard 1982 | Great Lakes Basin | 14.00 (15.73) | — | 0.80 (0.90) | 0.058 |
| Mueller 1981 | Wisconsin | — | 7.2 (8.09) | 0.003 (0.003) | 0.001* |
| Raman 1985 | Illinois | 0.13 (0.15) | — | 0.064 (0.072) | 0.492 |
| Holt 1970 | Minnesota | — | 0.90 (1.01) | 0.05 (0.06) | 0.056* |
| Uttormark 1974 | Many States | 0.34 (0.38) | — | — | — |
| Schuman 1973 | Missouri | 0.50 (0.56) | — | 0.12 (0.13) | 0.240 |
| Alberts 1978 | Missouri | — | 0.52 (0.58) | 0.10 (0.11) | 0.161* |
| Alberts 1985 | Iowa | 0.45 (0.51) | | — | — |

*Calculations were made assuming DP + PP = TP.

Table 6 shows the DP/TP ratios as calculated from figures given according to the literature review. The mean average of the ten DP/TP ratios is 0.162, indicating approximately 16.2 percent of the TP load results from DP, while 83.8 percent is related to PP. These figures are consistent with estimated ranges for Illinois lakes as described previously

**Table 7. Total Phosphorus Loading Rates and Watershed Characteristics of Six Illinois Lakes**

| Citation | Lake Name | Watershed Size (ac.) | WA:SA[1] Cropland | Percent Cropland (t/ac/yr) | Avg. Erosion Rate (t/ac/yr) | Avg. Sediment Yield (lbs/ac/yr) | Avg. Total Phosphorus Load (lbs/ac/yr) |
|---|---|---|---|---|---|---|---|
| USEPA 1975c | Highland Silver Lake | 30,639 | 55:1 | 83.3 | 3.40 | 1.54 | 0.67 |
| Kothandaraman 1983 | Johnson Sauk Trail Lake | 876 | 15:1 | 6.2 | 0.73 | 3.30 [2] | 0.13 |
| Kothandaraman 1983 | Lake Le-Aqua-Na | 2,308 | 58:1 | 68.0 | 3.53 | 1.53 | 1.60 |
| Makowski and Lee 1983 | Lake of the Woods | 589 | 26:1 | 48.2 | 2.40 | 1.45 | 0.23 |
| Davenport 1983 | Lake Pittsfield | 7,136 | 30:1 | 56.5 | 8.10 | 5.40 | 0.06 (1980)<br>12.90 (1981)<br>0.22 (1982)[3] |
| USDA-SCS 1983a and NES #302 1975b | Lake Decatur | 587,700 | 193:1 | 87.0 | 4.50 | 0.65 | 0.36 |

1 Watershed acreage to surface acreage ratio.

2 Because interim sedimentation data were not given, an average sedimentation rate over the lifespan of the lake is shown. However, most sedimentation occurred during the first 10-15 years of its formation, after which the IDOC began a program of land acquisition and watershed management.

3 Data only show total phosphorus loadings from April 1982 - September 1982.

Phosphorus loading rates were reviewed for six Illinois lake watersheds. Various watershed characteristics and related total phosphorus loadings (TP) are summarized in Table 7.

Total phospnorus loadings for the Illinois lakes reviewed ranged from 0.13-12.90 lbs/ac/yr (0.15-14.50 kg/ha/yr). Johnson Sauk Trail lake showed the least amount of loading; only 6.2 percent of its watershed land was in cropland. The Department of Conservation owns a majority of the land in the watershed which is mostly in forest, wildlife habitat and pasture land uses which serve to reduce erosion and increase water infiltration (reduce runoff).

Of the six Illinois lakes reviewed, Lake Pittsfield, in 1981 (extensively studied during the Blue Creek ACP Special Water Quality Project), showed the greatest TP loading from its watershed, primarily because of high erosion rates (8.1 t/ac/yr) and sediment yields (5.4 t/ac/yr). Particulate phosphorus was carried by the eroded soil to the lake causing high TP loads. The difference between the 1980, 1981 and 1982 water years nutrient transport relationships result from above normal precipitation during July of 1981 (Davenport 1983).

Highland Silver Lake and Lake Le-Aqua-Na may be the most representative of the Illinois lake watersheds reviewed. Although they differ greatly in size, their watershed to surface area ratios, average erosion rates, and average sediment yields are almost identical. Le-Aqua-Na showed a greater TP loading due to a fairly steep watershed with loess soils which erode more easily than Highland Silver's tightly bound claypan soils. It should be noted that Highland Silver's average sediment yields correspond precisely with yields shown in Figure 7.

## Urban Runoff

The effects of urban runoff on receiving water quality were largely unknown and unquantified until 1978 when the Nationwide Urban Runoff Program (NURP) was initiated. The NURP program was implemented to build upon pertinent prior work and to provide practical information and insights to guide the planning process, including policy and program development and implementation (USEPA, NURP Final Report 1983). The program included 28 projects, managed by designated state, county, city or regional government associations. Criteria used to select the projects were: 1) identification of an urban runoff problem; 2) type of receiving water; 3) hydrologic characteristics; 4) urban characteristics; and 5) beneficial use of receiving water.

This section concentrates on urban runoff and its effects on receiving waters. Studies conducted by the United States Environmental Protection Agency for NURP are discussed, along with projects from other states. Construction erosion, a sub-set of urban runoff which contributes to water quality problems is included. A study of Washington County, a collar county of Milwaukee, Wisconsin, is also discussed. The project, completed in 1979, examined the effects of sedimentation on receiving waters in an urbanizing area. The study concluded that excessive sedimentation, carrying phosphorus and nitrogen, contributed to water quality problems in the county.

### Urban Runoff as Characterized by NURP Studies

The effects of urban runoff on receiving water quality are highly site-specific. They depend on the type, size, and hydrology of the water body, the urban runoff quantity and quality characteristics, the designated beneficial use, and the concentration levels of the specific pollutants that affect that use.

The NURP studies concluded that, with regard to effects of urban runoff on lakes as receiving water bodies, nutrients in urban runoff may accelerate eutrophication problems and severely limit recreational uses (USEPA, NURP Final Report 1983). The lake projects indicated that the degree of beneficial use impairment varied, as did the significance of urban runoff. The following NURP studies provide examples of lakes where urban runoff was perceived to contribute to a decline in water quality.

Lake Quinsigamond, in northwest Massachusetts, was one of two NURP studies conducted in that state. The lake consists of a deep narrow northern section, Lake Quinsigamond, and a shallow southern basin, Flint Pond. Lake Quinsigamond is between Worcester and Shrewsbury, the two most populated municipalities in the watershed, and has a drainage basin of about 16,000 acres.

Since the early part of the century, the region underwent rapid urbanization, industrial development and increasing population. Shrewsbury has experienced high population growth and slow industrial/commercial growth (McGinn 1982). Worcester is in an area of slight population and industrial/commercial growth.

The Lake Quinsigamond study concluded that, while some variations in constituent concentrations occurred between the northern and southern sections of the lake, total and dissolved phosphorus values showed no significant differences. Nutrient balances indicated that surface runoff accounted for 89 percent of the total phosphorus (9,152 lbs/yr) and 67 percent of the dissolved phosphorus inputs (1,738 lbs/yr). The remaining loadings were attributed to tributary baseflow and atmospheric input. Total phosphorus loads were 2,596 lbs/yr. On a per acre basis, this is 0.65 lbs/acre of total phosphorus and 0.16 lbs/acre of dissolved phosphorus.

The Upper Mystic Lake Watershed, the site of a 1982 NURP study, is an example of another area of rapid urban growth. The 17,920 acre drainage basin, which comprises the northern portion of the Mystic River Basin, is located in eastern Massachusetts and extends northeast from Boston Harbor. Nine communities are within the watershed. The Aberjona River flows into the lake's upper forebay, one of three basins within the lake. Two major interstate highways cross the watershed in its northern and eastern section.

In the past two decades intensive urbanization has occurred in most areas of the watershed (Fratoni et al. 1982). All communities except for one showed substantive increases in populations between 1950 and 1970, a trend expected to continue at a slower rate.

Land use in the watershed has reflected these population changes, with single family housing becoming the predominant form of housing (Fratoni et al. 1982). Industrial and commercial growth followed the changing economic trends by moving away from water-intensive practices toward a technical service-oriented economy.

Annual loads of total phosphorus to Upper Mystic Lake from various in-stream sources were estimated to total 5,670 pounds. The largest load came from the Aberjona River, which contributed approximately 4,640 pounds of phosphorus per year. Baseflow, urban runoff and a sanitary connection contributed close to equal amounts (38 percent, 34 percent and 28 percent, respectively). On a per acre basis, phosphorus loads ranged between 0.41 lbs/acre to 1.75 lbs/acre.

Approximately 6,500 lbs/yr entered the lake and approximately 3,500 lbs/yr (54 percent) was estimated to remain in the lake after deduction for outflow as residual phosphorus. This residual load was considered very high, and contributed to the eutrophic conditions in the lake.

The Austin, Texas NURP report documented impacts of stormwater runoff and loading on Town Lake and Lake Austin water quality. It also characterized runoff water quality from low to medium density residential land uses, and one structural control measure. The stormwater monitoring program was divided into a receiving water and a stormwater sampling program. Table 8 presents land use information for sites sampled in the study.

The Northwest Austin site, which typified a high impervious cover residential area, was located within the Shoal Creek watershed, which is a tributary to Town Lake. The Rollingwood site, a low impervious cover residential development, was adjacent to Town Lake. The Turkey Creek site drained directly to Lake Austin and was the control site for the study, representing an undisturbed watershed.

Town Lake is a 5 mile long lake downstream of Lake Austin. Town Lake is the receiving body for substantial quantities of urban stormwater runoff from primarily high-density residential and commercial areas of the City of Austin.

The study found that similar to the stormwater sampling sites, the receiving water quality during a runoff event was affected mainly by the physiographical characteristics of the basin terrain, the degree of open space and vegetation, as well as urbanization in the watershed.

**Table 8. Characteristics of Selected Study Sites Austin, Texas**

| | Site | | |
|---|---|---|---|
| Item | Northwest Austin (Medium-Density Residential) | Rollingwood (Low-Density Residential) | Turkey Creek (Virgin) |
| Area of Housetops and Driveways (acres) | 101.86 | 6.31 | - |
| Paved Roads* (acres) | 46.33 | 6.57 | - |
| Total Watershed Area (acres) | 377.71 | 60.21 | 1,297.0 |
| Total Impervious Cover (percent) | 39.23 | 21.39 | 1.0 |

*Street surface paved with shallow curbs and gutters.

Data developed for Austin residential land use indicated that a medium density residential land use (impervious cover approximately 39 percent) does produce a larger runoff pollutant load than a low density residential land use (impervious cover approximately 21 percent) primarily because of the quantity of stormwater runoff from the two areas (USEPA, Austin, Texas NURP project, 1983). The study estimated loads of 0.27 lbs per acre of total phosphorus for the Rollingwood site, and 1.88 lbs per acre for the Northwest Austin site.

The differences in the pollutant mass loads from the two test watersheds were quite distinct. The Northwest Austin site produced runoff pollutant loads per acre of surface 5-10 times greater than those of the Rollingwood watershed. The primary factor determining the quantity of pollutants in stormwater was the relative area of impervious cover. Quality data for the "conventional pollutant" parameters were obtained for the Turkey Creek watershed for both background (previous USGS and City of Austin sampling programs) and storm event conditions, but due to equipment malfunctions and floods, it was not possible to calculate mass loads.

Storm event oriented water quality sampling data from Town Lake and Lake Austin indicated that the short-term effects of $PO_4$ on receiving water quality can be significant, although chronic water quality impacts were not apparent.

A summary of total phosphorus loading values is presented in Table 9.

**Table 9. Phosphorus Loads for Selected NURP Watersheds**

| Lake Name | Watershed Area (acres) | Total Phosphorus (lbs/ac/yr) |
|---|---|---|
| Lake Quinsigamond, MA | 15,993 | 0.65 |
| Upper Mystic Lake, MA | 17,912 | 0.41-1.75 |
| Lake Austin, TX | | |
| Rollingwood | 60 | 0.27 |
| Northwest Austin | 378 | 1.88 |
| Turkey Creek | 1,297 | * |

* Due to problems with flow measurements, it was not possible to calculate phosphorus loads.

Nutrient loads from urban runoff have not been extensively studied in Illinois. Lake Ellyn, located in Glen Ellyn, Illinois is in a watershed comprised of a typical urban mix of high-density residential, low-density residential, commercial and institutional land uses. No point sources were identified in a 1980 NURP study. The watershed's total drainage area is 534 acres, and the lake is 9.4 acres in size. The watershed contains 181 acres of impervious area, or 34 percent of the total. Population density is 5,000 persons per square mile. Land use information follows.

| Land Use | Percent of Drainage Area |
|---|---|
| Low density single family residential | 80 |
| High density residential | 3 |
| Commercial | 5 |
| Under construction | 0 |
| Wetland | 2 |
| Parkland | 5 |
| Institutional | 5 |
| Total | 100 |

The NURP study monitored atmospheric deposition, vegetation, soils, domestic and public works chemical use, roof runoff, road dirt, catch basins, lake influent, sediment, water column and effluent for the study year July 1, 1980 through June 30, 1981. Materials budgets were prepared for six constituents, including phosphorus, at key points in the watershed - roof tops, pervious areas, impervious areas, catch basins and the lake. The materials budget for phosphorus in the watershed in thousands of pounds is presented in Table 10.

Land use patterns in Washington County are representative of many areas in the Great Lakes Basin which are adjacent to rapidly expanding metropolitan areas. The northern tier of the county is relatively stable and consists mainly of dairy farms averaging about 40 milk cows per farm. Patchwork residential development is more common in the southern part of the county and surrounds the major urban centers of West Bend and Hartford. Farming in these areas more often is a transitional activity; dairy farms have frequently been converted into cash-crop operations.

**Table 10. Lake Ellyn Materials Budget - Phosphorus, 1980-1981**

| | TP Loads (1000 lbs.) | % of Total |
|---|---|---|
| Loads in | | |
| Roof Runoff | 14.2 | 1.9 |
| Stormwater | 388.0 | 51.6 |
| Baseflow | 300.0 | 39.9 |
| Vegetation | 28.5 | 3.8 |
| Animals | 14.2 | 1.9 |
| Precipitation | 1.3 | 0.2 |
| Dryfall | 5.6 | 0.7 |
| Total | 751.8 | 100.0 |
| Loads out | | |
| Stormwater (wet conditions) | 197 | 70.1 |
| Baseflow (dry conditions) | 83.8 | 29.8 |
| Total | 281 | 99.9 |
| Accumulation | 471 | |

Accumulated material settled to the lake bottom as sediment. The study concluded that no direct interaction occurred between groundwater and the lake. Stormwater and baseflow were cited as the most significant sources of solids and constituents, including phosphorus.

Paved surfaces such as streets and parking lots were other sources of phosphorus inputs to Lake Ellyn. Table 11 presents phosphorus loads in pounds from streets and parking lots for the study year. Inputs from atmospheric deposition, pervious runoff, traffic, decomposition of paved surfaces, animals, vegetation, roof runoff and road salt were calculated for the watershed. Materials were removed from these areas by street sweeping and stormwater washoff. Export of materials on streets and parking lots was calculated.

The budget was derived from streets and parking lots directly connected to watershed storm sewers. The area was estimated to be 68.6 acres. All other paved areas are included in the balance for pervious areas.

Animal contributions provided the second highest source of phosphorus, after runoff from pervious areas. The animal population of the watershed was estimated based on survey results, actual observation and urban animal surveys. Phosphorus loads from wild animals were estimated from data supplied by the Illinois Natural History Survey. The principal source of the phosphorus was thought to be geese and ducks.

**Table 11. Phosphorus Loads (in pounds) from Streets and Parking Lots, Lake Ellyn Watershed, Illinois**

| | TP (lbs) | Percent of Total |
|---|---|---|
| **Loads in** | | |
| Precipitation | 8.9 | 1.8 |
| Dryfall | 37.2 | 7.7 |
| Pervious Runoff | 270 | 55.9 |
| Traffic | – | – |
| Paved Surface Decomposition | – | – |
| Animals | 91.7 | 19.0 |
| Vegetation | 61.0 | 12.6 |
| Roof Runoff | 14.2 | 2.9 |
| Road Salt | | |
| Total | 483 | 99.9 |
| Loads out | | |
| Street sweepings | 78.3 | 16.2 |
| Washoff | 406 | 83.9 |
| Total | 484.3 | 100.1 |
| Export | 1.3 | |

## Wisconsin studies

Piwoni (1974) conducted a study of ten south-central Wisconsin impoundments. All of the lakes were in rural, predominantly agricultural watersheds (except for Stewart Lake which receives some urban runoff). The lakes were classified by the author into two groups: Real estate lakes (R.E.) and public recreation lakes (P.R.). Six of the lakes were considered real estate lakes, bodies of water created in an urban environment for the enhancement of real estate values. The lakes in the study were created in the 1960s and early 1970s by private developers, to facilitate high density lakefront development. The remaining four lakes were created for various public recreational uses and were free of significant lakefront development.

All of the lakes were small (under 700 acres) and shallow (6-18 feet in depth). Available data for Lakes Camelot North, Camelot South and Sherwood were grouped for the study to form the Camelot-Sherwood complex.

Figure 8 shows the locations of the studied impoundments found in central and southern Wisconsin.

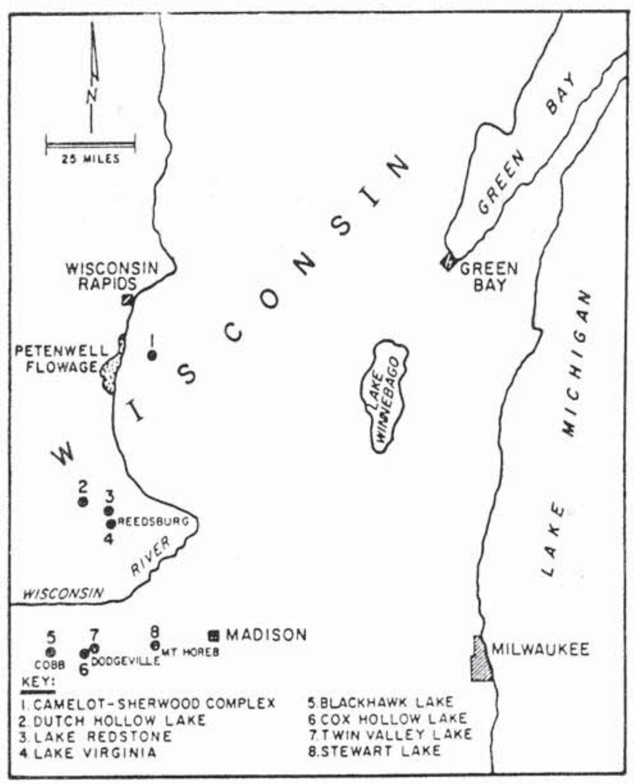



**Figure 8. Impoundment locations in central and southern Wisconsin.**

Piwoni (1974) evaluated land uses in the watershed between 1971-1972 to correlate phosphorus loads with these values. Most of the impoundments were in rural areas dominated by agricultural land uses. The greatest source of phosphorus proved to be agricultural runoff in most of the lakes. Rural runoff also contributed large amounts of phosphorus. Real estate lakes were estimated to receive phosphorus inputs from septic tanks.

Table 12 shows a breakdown of land uses in the watersheds and the estimated phosphorus contributions from land uses to the lakes.

**Table 12. Estimated Phosphorus Loads in Pounds for Land Uses in Eight South-Central Wisconsin Watershed,**

| Land Use | Real Estate Lakes<br>Redstone | Virginia | Dutch Hollow | Camelot-Sherwood | Blackhawk | Public Recreation Lakes<br>Stewart | Cox Hollow | Twin Valley |
|---|---|---|---|---|---|---|---|---|
| Baseflow | 410 | — | 350 | 3,520 | 430 | 51 | — | — |
| Forest | 0 | — | 0 | 0 | 0 | 0 | — | — |
| Agriculture | 7,960 | — | 900 | 9,410 | 2,150 | — | — | — |
| Pasture | 2,840 | — | 110 | 3,360 | 2,510 | — | — | — |
| Precipitation | 120 | 10 | 80 | 140 | 40 | 1 | — | — |
| Dry Fallout | 440 | 35 | 120 | 490 | 150 | 4 | — | — |
| Septic Tanks | 210 | 15 | * | 150 | — | — | — | — |
| Rural | — | 815 | — | — | — | 46 | 1,760** | 2,684 ** |
| Urban | — | — | — | — | — | 358 | — | — |
| Open Area | — | — | 200 | — | — | — | — | — |
| Total | 11,980 | 875 | 1,760 | 17,070 | 5,280 | 460 | 1,760 | 2,684 |
| Watershed Size (in acres) | 18,940 | 1,600 | 3,100 | 22,400 | 8,960 | 510 | 3,970 | 7,680 |
| Annual load lb/ac/yr | 0.63 | 0.55 | 0.57 | 0.76 | 0.59 | 0.90 | 0.44 | 0.35 |

*The lake was still filling at the time of the study. Septic tanks were expected to contribute P to the lake.

**Little data were available. Author estimated a 100 percent rural watershed.

Unlike the real estate lakes the public recreation lakes showed wide variations in annual loads. Stewart Lake, the only impoundment in an urban area, had the highest loading rate. Twin Valley Lake, a rural public recreation lake, evidenced the lowest estimated phosphorus loading rate at 0.35 lbs/ac/yr. These values fall within the range of total phosphorus loading rates for Illinois lakes (see Table 7).

Lopez and Lee (1975) conducted a study of the Lake Mendota, Wisconsin watershed. Land use estimates, developed by Sonzogni and Lee (1974), are presented in Table 13.

Lake Mendota is the largest lake in a five-lake chain of the Yahara River in south-central Wisconsin. Figure 9 shows the location of the five lakes. Approximately 200,000 people lived on the southeast side of the lake at the time of the study. The largest portion of the drainage area was in agricultural uses (dairy farms, mixed crops, etc.).

The most significant source of phosphorus, rural runoff, contributed 63 percent of the loads. Agricultural land uses were estimated to be the greatest source of phosphorus. Runoff from combined urban and rural sources contributed 78 percent of the phosphorus imputs.

Another Wisconsin study performed by Rast and Lee (1975) examined nutrient loads to Lake Wingra, the smallest of the five Yahara River lakes. Lake Wingra's watershed is 5,200 acres. Unlike the more urbanized areas around Lake Mendota, the area surrounding Lake Wingra includes coniferous and deciduous forests, prairies, gardens and marshes

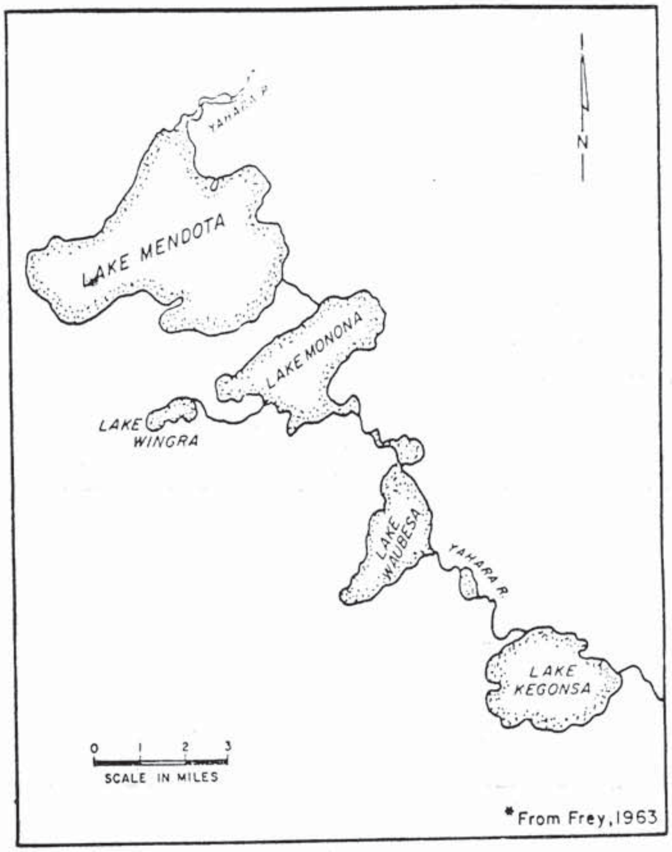



***Figure 9. Lakes of the Yahara River chain, Madison, Wisconsin (Frey 1963)***

within the University of Wisconsin arboretum. The arboretum constitutes approximately 15 percent (800 acres) of a portion of the urban region of southwest Madison, approximately one-third of which drains directly into the lake. Lake Wingra flows into Murphy Creek, which then flows into Lake Monona, the lake downstream of Lake Mendota in the chain. A portion of the watershed area drains directly into Murphy Creek, bypassing Lake Wingra.

Land uses for the Lake Wingra watershed are presented in Table 15.

Lake Wingra is used mostly for sports, fishing and recreation. No sewage or industrial discharges had occurred, according to the authors, except for occasional sewer overflows.

Nutrient sources for Lake Wingra were assessed for the study. Data for estimated total phosphorus loads are presented in Table 16. Urban runoff was estimated to contribute 82 percent of the total phosphorus inputs to the lake.

### Construction erosion

Construction erosion is another potential source of sediment and nutrient loads associated with development in urban areas. Washington County, located in southeastern Wisconsin, northwest of the Milwaukee metropolitan area, was chosen for a 1979 study on urban development (USEPA 1979). In 1975, the county population was 76,577, half of which resided in 13 unincorporated towns, the remainder in two cities and five villages. Farms accounted for 60 percent of the land area in Washington County but only 6 percent of the county's population lived on farms.

**Table 13. Estimated Land Uses/Lake Mendota Watershed, Wisconsin**

| Land Use | Acres | Percent |
|---|---|---|
| Rural | 115,000 | 83 |
| Urban | 16,000 | 12 |
| Marshland | 6,000 | 4 |
| Woodland | 1,000 | 1 |
| Total | 138,000 | 100 |

**Table 14. Phosphorus Loads/Lake Mendota, Wisconsin**

| | Total Estimated Phosphorus Loading | | |
|---|---|---|---|
| Source | lbs/yr | lbs/ac/yr | Percent |
| Domestic Wastewaters | 1,998 | 0.014 | 2 |
| Urban Runoff | 15,981 | 0.115 | 15 |
| Rural Runoff | 68,917 | 0.499 | 63 |
| Atmospheric | 8,989 | 0.065 | 8 |
| Groundwater | 999 | 0.007 | 1 |
| Baseflow | 11,986 | 0.087 | 11 |
| Total | 108,870 | 0.787 | 100 |

**Table 15. Land Uses/Lake Wingra Watershed, Wisconsin**

| | Area (acres) |
|---|---|
| Lake Wingra Basin | 5,200 |
| Area Draining to Lake Wingra | 3,800 |
| Residential | 2,600 |
| Arboretum | 775 |
| Lakes and Ponds | 337 |
| Area Draining to Murphy Creek | 1,400 |

**Table 16. Phosphorus Loads to Lake Wingra, Wisconsin**

| | Total Estimated Phosphorus Loading | | |
|---|---|---|---|
| Source | lbs/yr | lbs/ac/yr | Percent |
| Precipitation | 71 | 0.013 | 3 |
| Atmospheric | 242 | 0.046 | 9 |
| Springs | 169 | 0.033 | 6 |
| Urban Runoff | 2,156 | 0.415 | 82 |
| Total | 2,638 | 0.507 | 100 |

The overall goal of the institutional unit of the Washington County project was to design and implement programs to control sediment pollution in Washington County. It was estimated that agricultural nonpoint sources contributed about 65 percent of both the sediment and phosphorus to Washington County waterways; construction sites accounted for about 20 percent; and urban point and nonpoint sources accounted for the remainder.

Runoff monitoring stations were established in an agricultural area near Kewaskum and two subdivisions under construction near Germantown in Washington County. Samples were collected and analyzed and relationships between precipitation, runoff, land use and water quality were investigated. Farm management practices, both traditional and innovative, were implemented and their effectiveness and acceptability were evaluated. Methods of controlling erosion from residential construction sites were studied and recommendations made on what provisions should be included in a subdivision erosion control ordinance.

The Washington County Project found that:

- Sediment carried most of the phosphorus and nitrogen in runoff from rural and urbanizing sites. However, land management practices could successfully reduce loads of sediment and their associated pollutants, although dissolved loads were often increased.
- Excessive sedimentation and other water quality problems associated with intensive housing construction were documented. Pollutant concentrations and loads diminished as the monitored subdivisions stabilized. Erosion control alternatives were identified but the effectiveness of these was not successfully demonstrated.

The project looked at agricultural sites in the Kewaskum Creek Watershed, which was comprised mainly of farming activities and an urbanizing watershed in Germantown. The Village of Germantown, on the periphery of Milwaukee, was experiencing rapid development of large single and multiple family residential subdivisions at the time of the study.

## Summary

Urban runoff effects are site-specific. Many factors influence the effects of water runoff on receiving waters, including the hydrology of the water body, rainfall, population size, types of pollutants and pollutant concentration. The NURP studies concluded that the effects of urban runoff on lakes vary, but accelerated eutrophication may result.

Of the NURP studies cited, all concluded that urban runoff had a detrimental effect on receiving waters. Of those projects with urban lakes as receiving waters, Lake Quinsigamond, Massachusetts identified urban runoff as the main contributor of phosphorus. The Austin, Texas study found that urbanization within the watershed contributed to runoff pollutant loads. The Lake Ellyn, Illinois NURP study found that loadings to the lake were attributable to nonpoint sources, as no point sources existed in the watershed. Stormwater runoff was found to be the main source of phosphorus (51.6 percent).

The NURP study Executive Summary concluded that nutrients are generally present in urban runoff, but overall loads do not appear to be high in comparison with other possible sources. The report also concluded that geographic location, land uses, or other factors (slope, population density, precipitation characteristics) were of little assistance in consistently explaining site-to-site variability, or predicting the characteristics of urban runoff in a community. In addition, the NURP report concluded that the larger the urban area which drains into a lake of a given size, the greater the annual loadings, and the higher will be the lake phosphorus concentration and the eutrophication effects produced.

Although the report concludes that land use categories are of little general use in predicting urban runoff quality at unmonitored sites or for extensive site to site variability at monitored sites, load comparisons for land uses were estimated and evaluated. Annual total phosphorus loads for residential areas were 1.16 lbs/ac/yr, for commercial areas 3.02 lbs/ac/yr, and for all urban areas, 1.33 lbs/ac/yr. On a unit area basis, total phosphorus loads were higher for commercial areas because of the higher degree of imperviousness typical of such areas. Total loads were strongly influenced by runoff volumes.

For this literature review, total loads were chosen, to facilitate comparison with other data summaries of nonpoint source loads which state results in this manner. A comparison between land uses and total phosphorus loads for urban and agricultural runoff was thus possible.

## Point Source Factors

Factors which determine loading from domestic and industrial point sources have been previously mentioned in the Section entitled "Phosphorus Forms, Sources, and Availability." Some important factors will be expanded upon here.

### Population served

The major factor involved in determining phosphorus loads from domestic waste is the number of people served by the sewage systems.

**Table 17. Phosphorus loadings per unit area for human excrement and detergent phosphorus (after Vollenweider 1971)**

| Population Density | | Phosphorus Load | |
|---|---|---|---|
| caput/km$^2$ | caput/mi$^2$ | g/m$^2$/yr | lbs/acre/yr |
| 50 | 19 | 0.04 | 0.006 |
| 100 | 39 | 0.08 | 0.011 |
| 150 | 58 | 0.12 | 0.028 |
| 200 | 77 | 0.16 | 0.023 |
| 300 | 116 | 0.24 | 0.034 |
| 500 | 193 | 0.40 | 0.057 |
| 1000 | 386 | 0.80 | 0.091 |
| 2500 | 965 | 2.00 | 0.283 |
| 5000 | 1930 | 4.05 | 0.573 |

Phosphorus loading estimates from human waste alone are generally based on a basic physiological value of 1.5 grams/caput/day. To arrive at values reflecting detergent use and, in some regions, use of phosphorus in water softening, effective loading values of 2.25 and 3.0 g/caput/day have been used. Loadings of phosphorus per unit area have been calculated by Vollenweider (1971) using these values. Table 17 below presents loadings for various population densities based on a loading value of 2.25 g/caput/day (caput = capita).

According to the USEPA Process Design Manual for Phosphorus Removal (1976), 10 to 20 percent of the raw wastewater phosphorus can be removed upon sedimentation of particulate phosphorus during primary clarification and biological processing through a trickling filter or activated sludge.

### Industrial waste

Industrial wastewater inputs, especially those associated with food processing can be very large. In Corrina, Maine, phosphorus from potato processing accounted for 66 percent of the approximately 11,500 lbs of total phosphorus/year for 500 people. A woolen mill accounted for 16 percent and domestic and other sources accounted for 18 percent (Keup 1968). Other industrial sources of phosphorus may be (1) fertilizer manufacturing, (2) metal finishing, (3) flour processing, (4) dairy wastes, and (5) slaughter house waste (USEPA Design Manual for Phosphorus Removal 1976). Industrial water is commonly treated with phosphates in order to soften it and avoid corrosion in pipes and boilers (Vollenweider 1971), but the contribution to wastewater is generally small relative to other sources. Industrial loading values are not reported here because values are subject to local conditions and type of industry.

### Detergents

The contribution of detergents to the wastewater phosphorus load depends upon whether there is a phosphate ban in effect or not.

In the early 1970s, before action was taken on the detergent issue, detergents contained seven to 12 percent phosphorus by weight and contributed 50 percent of the total wastewater phosphorus. In many areas, especially in the Great Lakes region, the phosphorus content of detergents has been reduced to five percent or less (down to trace amounts) resulting in a much lower contribution to wastewater phosphorus (Lee et al. 1978). In regions outside of the phosphate bans (and the distribution range of the wholesalers supplying ban areas) the contribution of detergent phosphorus remains significant.

Michigan enacted a detergent phosphate ban in 1977 which resulted in a decrease in wastewater phosphorus by 20 to 35 percent. For some cities, like Detroit, a decrease was not apparent, possibly because of the predominance of the phosphorus from industrial sources (Lee et al. 1980).

There is still some question as to the effectiveness of a detergent ban. Lee et al. (1980) could find no documented cases where there were measureable improvements in lake water quality after a ban. Wisconsin allowed its ban to expire after four years when no changes in stream or lake levels were found in two years of monitoring. Proponents of the ban said that changes in water quality may take up to 10 years to be seen, but the "grass roots response" generated by opposing lobbyists citing washing machine failures, the cost of extra hot water, extra cycles in clothes washers, etc. persuaded the legislature to drop the ban (Flynn 1982). After further consideration, the ban has been reinstated.

### Waste treatment

The type of waste treatment at municipal plants can influence the amount of effluent phosphorus. In a conventional secondary treatment plant, five to ten percent of the phosphorus is removed to the sludge in primary clarifiers. An additional 10 to 20 percent removal of the waste phosphorus can be accomplished through either trickling filter or activated sludge as secondary treatment. These removal levels occur only in properly designed and managed plants which are not overloaded. In order for the settling and biological processing to be effective, the residence time of the waste in the system must be controlled (USEPA Process Design Manual for Phosphorus Removal 1976).

Additional treatment of waste with flocculating and precipitating agents can increase phosphorus removal to a range of 70 to 90 percent in primary treatment and 80 to 95 percent in secondary treatment. Chemical and biological removal of phosphorus from wastewater will be discussed in more detail in the subsection VIII B, titled "Wastewater Treatment."

## *PHOSPHORUS AND IN-LAKE PROCESSES*

In order to understand the importance of phosphorus in lake systems it is necessary to consider the on-going processes within a lake and how lake and watershed morphology can affect those processes. This section is meant to provide a simplistic overview of a lake system that is actually very complex.

### Eutrophication

Eutrophication is the term used to describe the decline in water quality of a lake. Wetzel (1975) defines eutrophication as "the **unnatural** acceleration of productivity due to perturbation of the system." He states that the best criterion of eutrophication is the increasing rate of photosynthesis by algae and larger plants per unit area. Confusion in use of the term still exists because some people think of eutrophication in the classical sense of natural aging of a lake. This aging is associated with the filling of lakes over time and is caused by erosion of clastic materials from the watershed (Lee et al. 1979). In either case, the rate of eutrophication is heavily influenced by human activities in the watershed. By our land and water use practices we can speed lake filling and the decline of water quality or we can slow the decline so as to obtain the maximum long term benefit of the resources. In some cases we can also restore the water quality or depth of a lake but it usually requires a concentration of effort and money.

A eutrophic lake is not necessarily a lake of poor water quality. Moderately high levels of algal and macrophytic productivity can be desirable traits for a water body. As the base of the food chain, high plant productivity can ultimately yield high fish productivity. However, there comes a point at which algal and macrophytic productivity can create nuisance conditions and become deleterious to fish production and other water uses. Excessive nutrient additions which increase plant production can disrupt the natural oxygen balance of the system by increasing the amount of plant respiration and decomposition demanding more oxygen. The equation below, from Stumm and Morgan (1981), illustrates the chemical equilibrium involved.

Excessive algal and oxygen production near the surface of lakes often parallels an extensive oxygen depletion in the bottom waters (Stumm and Morgan 1981). If these anoxic conditions extend over large areas of the lake, the survivability of the fish and their invertebrate food can be impaired. Late season die off of large macrophyte beds can also cause a large oxygen demand.

$$106\,CO_2 + 16\,NO_3^{-1} + HPO_4^{-2} + 122\,H_2O + 18\,H^+ + \text{trace elements} + \text{light} \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} C_{106}H_{263}O_{110}N_{10}P_1 + 138\,O_2$$

As the above equilibrium equation indicates, algae and macrophytes need nutrients in specific quantities for growth and reproduction. Phosphorus, nitrogen, and carbon, singularly or in combination, have all been determined limiting under various conditions. After extensive study most researchers agree that phosphorus is the nutrient whose input must be controlled for control of algal and macrophytic production in the majority of waters in the midwestern U.S. Schindler (1977) used whole lake experiments to demonstrate that natural mechanisms could compensate for nitrogen and carbon deficiencies in some eutrophic lakes. Atmospheric carbon dioxide is constantly incorporated into the water. Blue-green algae and some genera of bacteria can fix atmospheric nitrogen. Waters with excessive phosphorus loading can become nitrogen limited for a period but the blue-green algae which can fix nitrogen will outcompete the green algae, diatoms and other algal phyla. Nitrogen contained in blue-green algae is released as ammonia through metabolic waste products or through decomposition and can be used by more algae. High algal productivity is maintained under these conditions but the diverse algal community is replaced by a large number of a few species of undesirable blue-green algae such as **Aphanizomenon**, **Anabaena** and **Nostoc**. When phosphorus is low, algal productivity is generally low.

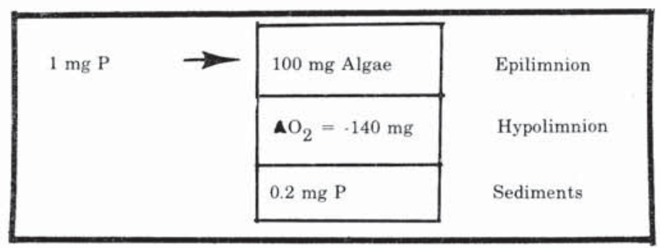
Not only do excessive algal growths, or blooms, disrupt the natural balance of the lake system, they also impart undesirable tastes and odors to the water, interfere with water treatment, cause unpleasant scums and alter the chemistry of the water supply (USEPA 1976a). Blue-green algal blooms are most commonly cited as the main cause of the above problems.

Beds of aquatic macrophytes can be a boon to fish production since weeds provide habitat for fish and their prey. On the other hand, excessive growth of aquatic weeds may lead to sunfish overabundance and cause problems in recreational use by fouling boating, fishing, and swimming areas. Another problem that may occur is oxygen depletion with die off of the plants. The relation of nutrients and macrophytes has not been studied as thoroughly as that of nutrients and algae. Since macrophytes obtain all or part of their phosphorus from sediments, any increases in phosphorus input are likely to cause increases in macrophytic growth (Lee et al. 1979). Macrophytes and algae are known to compete for light and nutrients so, in some cases, dense macrophytic growth can shade out planktonic (open water) algae until the macrophytes die off. With release of nutrients from the decaying macrophytes and the break up of the shade-effect, the algae can quickly grow to bloom proportions. In the reverse fashion, dense algal growth in the upper layers of water can cut down the amount of light available to macrophytes and restrict their biomass.

## Nutrient Recycling

Based on stoichiometric calculations, Stumm and Morgan (1981) estimated that one milligram of phosphorus added to a lake during summer stratification could lead to the synthesis of 100 mg of algae (dry mass) which, upon mineralization, leads to an oxygen consumption in the hypolimnion of 140 mg.

Stumm and Morgan continue with their simple compartmental model saying that of the organic phosphate mineralized in the hypolimnion, 0.6 mg is assumed to accumulate during stratification. Of this 0.6 mg, 0.2 mg is assumed to be absorbed and transferred to the sediments, while another 0.2 mg is returned to the epilimnion by eddy diffusion. However, the process is much more complicated than the above model; there is continual inflow and outflow from the system, there are often other factors such as light availability, temperature, zooplankton grazing and micronutrient availability




that may affect the amount and type of algae produced. In addition, the release and subsequent regeneration of phosphorus from the sediments is a more complex process dependent on several factors.

The simple model above serves to illustrate the basic process of nutrient recycling. A portion of the inflowing nutrients, phosphorus in this case, is taken up by growing algae. This uptake is very fast. In one study (Rigler 1956 as cited in Wetzel 1975), over 95 percent of the added ortho phosphorus was taken up by plankton within 20 minutes of the time it was added. Upon death of the phytoplankton, this phosphorus is released again to the open water to be taken up again or to settle to the hypolimnion. Major sites of phosphorus recycling in a lake area are in a) open water organisms in epilimnion, b) littoral organisms, and c) in the hypolimnion and sediments (Wetzel 1975).

## Relationships Between Algal Productivity and Other Lake Parameters

In order to study relationships between levels of algal production and other factors, a measure of algal production has to be chosen. The most common measurement used is that of chlorophyll **a** which is the major pigment involved in photosynthesis. The assumption made when using this measurement is that more chlorophyll **a** directly relates to a greater number of actively growing algal cells. This is not entirely true since all algal groups do not contain the same amount of chlorophyll **a** in their cells, but the relationship generally holds.

Significant correlations, similar to Figure 10 obtained by Dillon (1975), have been found between total phosphorus and chlorophyll **a** in many lakes (Dillon 1975, Jones and Bachmann 1976, Vollenweider 1976, Rast and Lee 1978, Riley and Prepas 1985). However, others have found little correlation between the two parameters with much scatter in the plotted lake data (Sefton et al 1980, Canfield and Bachman 1981, Lambou et al 1982). Lambou et al listed factors which could interfere with the correlation between total phosphorus and chlorophyll **a** such as :

1. availability of light.
2. biological availability of total phosphorus.
3. limitation of phytoplankton growth by nutrients other than phosphorus.
4. domination of the aquatic flora by vascular plants.
5. temperature.
6. lake hydraulic retention time.
7. lake morphometry.
8. grazing on phytoplankton.
9. presence of toxic substances.

Light availability appears to be the factor of most significance in the predominantly artificial lakes of Illinois. Light attenuation by suspended particles limits the amount of light available for algal growth. In addition, the suspended soil particles tend to be rich in phosphorus so, the phosphorus concentrations tend to be elevated while chlorophyll **a** concentrations remain low due to light limitation. The weakness of the correlation between total phosphorus and chlorophyll **a** makes it difficult to predict the reduction in algal biomass as measured by chlorophyll **a**. Predicted values of this type may or may not be born out by data taken for any individual lake.

In recent years researchers have begun to address the need for definition of the levels of algal production that cause problems. Walker (1985) noted that instantaneous chlorophyll **a** concentrations exceeding 20 to 30 ug/l tend to pose problems for water use. He also defined chlorophyll **a** levels above 30 ug/l as severe nuisance conditions. In another study by Smith (1985) blue green algal biomass was found to be a better indicator of water quality problems than chlorophyll **a**. A correlation was found between taste and odor problems and blue-green biomass, and a critical value of 1.5 gm/$m^3$ for a mean summer blue green biomass was determined. Above this value nuisance odors are likely.

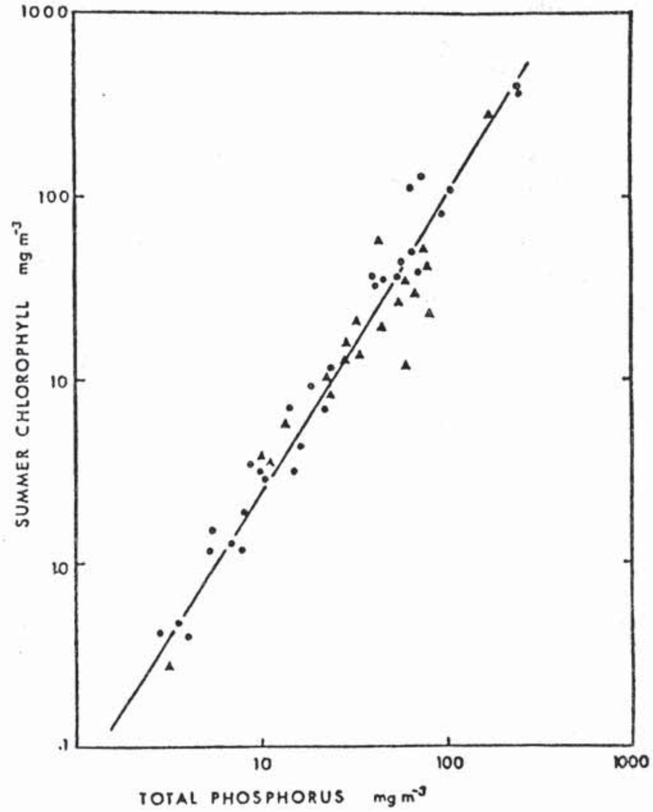



**Figure 10. Plot of total phosphorus concentration at spring overturn vs average chlorophyll a concentration in summer for a number of lakes. Circles represent data from Sakamoto (1966), triangles are for other lakes in the literature. Line is regression line for Sakamoto's points. Correlation coefficient (r) is 0.97. (Dillon 1975)**

In terms of phosphorus measurements, the suggestion of basing water quality decisions on the amount of available phosphorus (orthophosphorus) in a lake has been made (Baker 1980). The limitation to this approach lies in the fact that it ignores the potential availability of particulate phosphorus. Total phosphorus measurements account for both the immediately and potentially available phosphorus. The subsection on "Particulate and Sediment Phosphorus" found in Section III discusses the interchange between dissolved and particulate phosphorus forms over time.

Since in-lake phosphorus concentrations can vary throughout the season and are difficult to directly control, the use of phosphorus loading values instead of concentration has been encouraged for lake management (Lee et al. 1979). Vollenweider (1976 as cited in Vollenweider and Kerekes 1980), using a large data base of global lakes, has derived a loading equation and a classification of lake trophic state based on the loads, morphometric characteristics and their relation to algal biomass. Rast and Lee (1978) in adjusting the model for U.S. data made a slight modification in the loading formula by adding a variable for "hydraulic load" or annual water loading ($q_s$) which results in the following formula:

$$(L(P)/q_s)/(1 + \sqrt{t_w}) = \text{annual, areal TP loading (mg P/m}^3)$$

$L(P)$ = annual load of phosphorus (metric tons/m$^2$yr)
$q_s$ = "hydraulic load" = mean depth/hydraulic residence time (m/yr)
$t_w$ = hydraulic residence time (yr)

This equation was used to develop permissible or critical loading values that would allow maintenance of oligotrophic state in some cases or lead to increased eutrophication in others. Table 18 from Lee et al. (1979) lists these values with their respective depth and residence times.

**Table 18. Permissible and Critical Phosphorus Loading Rates. Based on Rast and Lee's (1978) modification of relationships developed by Vollenweider (1976)**

| Mean Depth/Hydraulic Residence Time (m/yr) | Eutrophic or Critical Loading (g/m$^2$/yr) |
|---|---|
| 0.25 | 0.205 |
| 0.50 | 0.210 |
| 1.00 | 0.220 |
| 2.50 | 0.250 |
| 5.00 | 0.300 |
| 7.50 | 0.350 |
| 10.00 | 0.400 |
| 25.00 | 0.700 |
| 50.00 | 1.200 |
| 75.00 | 2.200 |
| 100.00 | 2.200 |

Some approximate total phosphorus concentration ranges based on annual mean whole-lake values were suggested in Vollenweider's (1968) lake trophic status and revised based on observations made by various investigators (Vollenweider and Kerekes 1980). The original and revised ranges are presented below.

| | Original | Revised |
|---|---|---|
| oligotrophic | 5-10 ug/l | $<$10 ug/l |
| mesotrophic | 10-30 ug/l | 30-80 ug/l |
| eutrophic | 30-100 ug/l | $>$80 ug/l |
| hypereutrophic | 100 ug/l | |

These ranges were meant to be used for a general indication of lake status for purposes of making management decisions.

Extreme caution has been advised in using Vollenweider's model or any of the other vaious models on a regional basis without consideration of characteristics of the individual water bodies (Smith and Shapiro 1981). The smallest confidence interval for any of the models tested by Canfield and Bachmann (1981) with US data was 31-288 percent of the calculated total phosphorus value.

We use critical loading values in a future section (VII A) for comparison to agricultural loading with the understanding that the critical values represent approximate loading rates, below which water quality declines.

In the discussion of loading rates some factors affecting phosphorus loading and ultimately concentration are mentioned. Depth is one factor that must be taken into account since depth along with volume determines the amount of dilution. Lake depth, volume, and basin shape also affect the hydraulic retention time of a lake. This retention period is the time it would take for all the water in the lake to be replaced by inflowing water, again, influencing the amount of dilution or concentration of nutrients by incoming water.

In lakes where pollutant inputs are sporadic, incoming water is often of higher quality than that in the lake. In these cases short retention time can keep the pollutant load from heavily impacting the lake. Short retention time may also prevent algal communities from building up to bloom levels if the lake is a run-of-the-river reservoir with a very short summer retention time (Sefton and Little 1984). In shallow impoundments with short retention time and a large watershed to surface area ratio, the dilution and washout effect is over-ridden by the large loads that are being delivered at high rates. In Illinois lakes retention times range from 0.01 to 15.26 years (Sefton and Little 1984).

# INTERNAL REGENERATION

Internal as well as external sources of phosphorus must be considered in the determination of lake trophic status. Many impoundments, built on fertile land such as that in Illinois, have high sediment phosphorus levels at their inception. Phosphorus release from the sediments of these lakes can cause eutrophic conditions from the beginning. Input from point and nonpoint sources serves to aggravate the eutrophic conditions (R. Raman, personal communication).

Natural lakes and impoundments on less fertile soils can also obtain phosphorus from the sediments. Lakes with hydraulic residence times of greater than a few months tend to accumulate phosphorus in the sediments (Lee et al. 1978). This accumulated phosphorus as well as phosphorus contained in algae and macrophyte biomass may be regenerated.

Dissolved phosphorus may become associated with particulate inorganic or organic material before entering a lake or it may become associated with inorganic and organic particles within the lake. Some of this phosphorus associated with particles is recycled within the water column. The dissolved and particulate phosphorus which is not taken up by algae and macrophytes settles to the lake sediments. Although this sedimented phosphorus is not immediately available to algae and plants under conditions discussed below, it may still be regenerated as orthophosphorus and brought back into the phosphorus budget of a lake.

The amount of phosphorus and the processes involved in its release have been studied in both hypolimnetic and epilimnetic sediments. Sediments of the hypolimnion release phosphorus in its soluble reactive form when the hypolimnetic waters become anoxic, and to a lesser degree, under oxygenated conditions. When lakes undergo spring and fall overturn, the hypolimnetic water containing the orthophosphorus is then brought to the surface where it becomes available to algae and macrophytes.

## Factors Influencing Sediment Phosphorus and Anoxic Release

The contribution of hypolimnetic sediments to the overall phosphorus budget is dependent upon several factors. These factors which influence the concentration of phosphorus in the sediments are:

1. forms and amounts of phosphorus entering the lake,
2. amount of biological activity in the overlying water column,
3. hydraulic retention time, and
4. lake depth.

The forms of phosphorus entering a lake influence concentration within the sediments in the sense that orthophosphorus is more likely to be taken up by algae and macrophytes than by particulate phosphorus. High levels of biological activity in the water column can initially tie up the dissolved phosphorus, but when the plankton and macrophytes die off, they increase the organic phosphorus content of the sediments.

Hydraulic retention time and lake depth influence the amount of time the phosphorus has to settle. The retention time, defined as the lake volume divided by total annual discharge, represents the length of time for lake water with its nutrient and sediment load to be completely flushed from the lake. Due to a long retention time, Green Lake, Wisconsin retains regenerated phosphorus over winter to be reincorporated into the budget at spring overturn (Stauffer 1985). Lake depth determines the distance settling particulate phosphorus must drop and the amount of turbulence reaching the sediments. In a deep lake there is less wind-driven turbulence reaching the bottom than in a shallow lake so there is a greater likelihood of the sediments becoming anoxic, thereby, releasing large amounts of phosphorus. In shallow lakes anoxia can develop during calm periods and then, wind mixing can bring phosphorus up to the photic zone.

Factors which influence the amount of phosphorus released under anaerobic conditions include:

1. temperature,
2. area of sediments that becomes anoxic, and
3. duration of anoxic conditions.

Temperature affects the rate of microbial decomposition resulting in anaerobic conditions and the release of phosphorus due to iron reduction (Holdren and Armstrong 1974, Theis and McCabe 1978).

Temperature can also affect the activity of the biota in the sediments. Gallepp (1979) found phosphorus concentrations above sediments with chironomids to increase by 10 fold with an increase in temperature from 10 to 20$^{o}$C, while aerobic sediments without chironomids showed no change in phosphorus levels with temperature. Unfortunately, the presence of benthic organisms in sediment cores was not mentioned in most studies surveyed, so the effect of biota has yet to be completely defined.

The amount of decomposing organic material in the sediments influences both the area and duration of anoxic conditions. High nutrient inputs stimulate lake productivity which gives rise to high concentrations of organic material and phosphorus in the sediments at die-off and, subsequently, a substantial amount of phosphorus release from sediments due to anoxia created by decomposition of phosphorus-rich organic sediments.

In thermally stratified, eutrophic lakes, oxygen declines to zero in the hypolimnion by mid-summer because there is no mixing of oxygenated waters from above and oxygen-demanding decomposition removes the remaining oxygen (Welch 1980). Lack of oxygen at the sediment-water interface produces an environment favoring reductive chemical reactions. One of the reductive reactions most often discussed as the main source of phosphorus release from sediments is the reduction of ferric ($Fe^{3+}$) to ferrous ($Fe^{2+}$) iron, freeing the phosphates which had been bound to the iron (Stumm and Morgan 1971, Wetzel 1975, Welch 1980). Upon release, some of the dissolved phosphorus is found in a layer of water just above the sediments; the rest of the dissolved phosphorus is found in the pore spaces between the sediment particles. The dispersion of the released phosphorus to the overlying water is then accomplished by diffusion from areas of high concentration at the sediment surface (Theis and McCabe 1978) and in the pore spaces (Meals and Cassell 1978) to the lower concentration of the overlying water.

In unstratified, shallow, eutrophic lakes, phosphorus release by the aforementioned process occurs under calm conditions when organic decomposition removes the oxygen from the water near the sediments. Release of phosphorus from the sediments in deep oligotrophic lakes is usually small since the hypolimnion remains oxygenated (Welch 1980).

Breakdown of phosphorus-bearing organic material and some inorganic precipitates by bacteria such as those from the genera **Pseudomonas**, **Bacterium**, and **Chromobacterium** is expected to free phosphorus from the sediments. However, they are presumed to play a minor role relative to the chemical reactions taking place (Wetzel 1975).

## Aerobic Phosphorus Release

Phosphorus is also released under aerobic conditions in the hypolimnion but usually, at a much slower rate as compared to release under anaerobic conditions. Burns and Ross (1972) found that only 25 percent of the phosphorus in an algal bloom in Lake Erie was recycled in the hypolimnion under aerobic conditions. Aerobic release can be mediated by pH, temperature and through sediment reworking by bacteria, fungi and benthic invertebrates (Jacoby et al. 1983). Turbulence at the sediment surface caused by wind and wave action also promotes aerobic release through diffusion. Phosphorus bound to iron and aluminum is released at pH's of less than five or greater than nine, while phosphorus associated with calcium is released at a pH of less than 7.5 (Kamp-Nielson 1974 as cited in Meals and Cassell 1978).

## Upward Transport of Released Phosphorus

Phosphate ions released from the sediments must be transported upward to the euphotic zone (region of sufficient light penetration for algal growth) to complete the regeneration process. In deep, stratified lakes this may occur at spring and fall turnover when the thermal stratification is lost and water from all depths is mixed. However, during these periods of mixing, oxygen is also circulated throughout the water column so a portion of the dissolved phosphorus is re-precipitated by the oxidized ferrous iron $Fe^{3+}$ (Wetzel 1975). Phosphorus brought to the surface waters during fall turnover is less likely to be taken up by algae since the growing season is nearly over. If temperature and light conditions are suboptimal for algal growth, most of the phosphorus made available at this time either returns to the hypolimnion or, if retention time is short, is flushed out of the lake (Stauffer 1985). Spring overturn, on the other hand, comes at a time when available phosphorus can be taken up by growing algae.

Temporary disruptions of the thermocline by wind turbulence or rapid temperature changes results in significant inputs of dissolved phosphorus to the epilimnion from the waters below (Welch 1978, Jacoby et al. 1983, Lazoff 1983). Stauffer and Lee (1973) found an increase of 70 percent in the total phosphorus content of the epilimnion for Lake Mendota in a two day period when the thermocline migrated 1.2m during a major wind event.

## Sediment Release Rates

There have been several studies regarding the release rate of phosphorus from the sediments. Table 19 lists values for rate of release from aerobic and anaerobic sediments. Release rates for both conditions vary over a wide-range demonstrating the variety of lake environments. A few values come from **in situ** measurement but most come from cores incubated in the laboratory. The laboratory values are believed to be overestimates of the **in situ** rates (Lazoff 1983), but the laboratory values are most readily attained and replicable.

## Table 19. Measured Rates of Phosphorus Release from Sediments

| SRP Release Rate (mg/m2/day) | Temp. °C | Sediment Source | Citation |
|---|---|---|---|
| Aerobic Sediments | | | |
| -9.3 | | Baldeggersee (Central Europe), in situ[a] | Vollenweider (1971) |
| -1.4 | 7 | Lake Esrom (Denmark), 3m | Kamp-Nielsen (1975) |
| 0.68 | 11 | Lake Erie, **in situ** | Burns & Ross (1972) |
| 0.03-0.80 | 4-10 | Lake Ontario | Bannerman et al. (1974) |
| 1.2 | 24-30 | Lake Warner (Mass.) | Fillos & Swanson (1975) |
| -1.9-68 (5.1-omitting high July samples) | 2-23 | Lake Mendota (Wisc.) w/high densities of emerging chironomids) | |
| -0.56-2.5 | 4-21 | Lake Wingra (Wisc.) | Holdren & Armstrong (1974) |
| -0.49-0.77 | 7-14 | Lake Wingra, littoral | |
| 0.02-0.16 | 3-18 | Lake Minocqua (Wisc.), mesotrophic | |
| 0.02-0.55 | 4-16 | Little John Lake (Wisc.) | |
| 0-9 | 20 | Lake Mendota, depending on chironomid density | Gallepp (1979) |
| Anaerobic Sediments | | | |
| 9-10 | | Baldeggersee (Central Europe), in situ | Vollenweider (1971) |
| 12.3 | 7 | Lake Esrom (Denmark) | Kamp-Nielsen (1975) |
| 15 | 4.4-14 | Lake Trummen (Sweden), before restoration | Bengtsson et al. (1975) |
| 7.6 | 11 | Lake Erie, **in situ** | Burns & Ross (1972) |
| 26 | 20-30 | Lake Warner (Mass.) | Fillos & Swanson (1975) |
| 0.67-65[b] (11-omitting high July samples) | 2-23 | Lake Mendota (Wisc.) | |
| 0.95-2.9[b] | 4-21 | Lake Wingra (Wisc.) | Holdren & Armstrong (1974) |
| 0.03-3.1[b] | 3-18 | Lake Minocqua (Wisc.), mesotrophic | |
| 0.02-0.98[b] | 4-16 | Little John Lake (Wisc.) | |
| 11.9 | 24 | Cedar Lake (Ind.) | Jones (1985) |

[a]Unless stated as **in situ** data were taken from samples incubated in the laboratory.
[b]$N_2$-treated cores with 2-3 mg/l dissolved oxygen in overlying water.

The largest value for aerobic sediment release, 68 $mg/m^2$/day, was measured in late July sediment cores incubated at 22°C. The July sediments of Holdren and Armstrong's (1974) study had the highest release rates overall. Their initial interstitial reactive phosphorus levels were two to 50 times greater than samples taken at any other time. Aerobic and anaerobic laboratory release rates for these sediments were similar (38-68 $mg/m^2$/day). These similarities were attributed to high densities of tubificids and emerging chironomids. It is also possible that interstitial phosphorus had built up under low oxygen conditions in the lake before samples were taken. Gallepp (1979) also found chironomid activity to increase the rate of phosphorus release, however, his values were much lower (0-9 $mg/m^2$/day). Differences in the rates between the two studies may be due to differences in immediate use of intact sediment cores and Gallepp's microcosms in which sediments were sieved, reassembled and stored until used. Phosphorus flux under aerobic conditions was two times greater in the presence of benthic invertebrates than predicted by diffusion alone in intact cores from a Connecticut lake (Starkel 1985).

Omitting the extremely high July rates from Holdren and Armstrong and the microcosm values of Gallepp, aerobic release rates ranged from -9.3 to 9.0 $mg/m^2$/day and anaerobic release rates ranged from 0.02 to 26 $mg/m^2$/day. Maximum rates were obtained under summer temperatures. Maximum anaerobic rates ranged from approximately two to 20 times greater than maximum aerobic rates for individual lakes.

## Littoral Phosphorus Regeneration

Internal regeneration in the littoral zone can be a major source of phosphorus, especially since phosphorus released from littoral sediments is spatially available as soon as it is released since it is already in the euphotic zone. Sediments in the littoral region receive major phosphorus inputs from the decay of aquatic weeds and algae as well as settling of phosphorus from the overlying water. Aquatic plants take up phosphorus and nitrogen through their roots. At the end of the growing season, the plants die and phosphorus is released during microbial decomposition. Stauffer (1985) suspected that phosphorus releases from littoral sediments contributed more total phosphorus to the Green Lake budget in mid to late summer than external sources or vertical flux from the sediments. It was calculated that at least 50 percent of internal loading of Lakes Louisa and Marie, Minnesota came from aerobic release from the littoral zone (Miller and Erdman 1985).

Over 75 percent of the phosphorus leached from decaying macrophytes is in a form (soluble reactive phosphorus) which is available to plants (Carpenter 1983). This phosphorus is released within days of plant die-off; it can either be taken up by bacteria or algae or it returns to the sediments. Jaynes and Carpenter (1985) found that living macrophytes can supress the release of phosphorus from sediments since oxygen released by the roots prevents anaerobic conditions favorable to release.

## Regeneration and Lake Restoration

The importance of internal regeneration in the nutrient budget of lakes has come to light with lake restoration activities of the last 20 years. Diversion of point source inputs of phosphorus has had limited success due to the large phosphorus contribution of the sediments in some lakes. Lake Sammamish (mean depth = 18m), near Lake Washington (mean depth = 33m) in Washington did not show a significant response in five years following diversion of one third of its external phosphorus load.

It was determined that unlike Lake Washington, Lake Sammamish experienced anaerobic hypolimnetic conditions which allowed for sufficient phosphorus release from sediments to maintain the same lake concentrations as before diversion (Welch et al. 1972).

Internal loading was identified as a major eutrophying factor in another, much shallower (mean depth = 2m) lake — Long Lake (Jacoby et al. 1983). With drawdown and alum treatment of this unstratified lake, total phosphorus levels dropped from over 100 mg/m$^3$ to 29 mg/m$^3$ and chlorophyll **a** dropped from over 60 mg/m$^3$ to 7 mg/m$^3$ in two years following treatment. Alum binds to phosphate ions and sinks to the sediment in a heavy precipitate.

Lake Trummen, Sweden (mean depth = 2m) did not respond over a 10 year period to sewage diversion but after sediment was dredged and the lake treated with alum, total phosphorus of the lake dropped from highs of 0.85 mg/l to highs of 0.1 mg/l. Algal biomass dropped from annual highs of over 100 mg/l to highs of approximately 12 mg/l (Bengtsson et al. 1975 and Cronberg et al. 1975 cited in Welch 1980).

## Regeneration in Illinois Lakes

As previously mentioned, the contribution of phosphorus from the sediments can be high in Illinois impoundments built on fertile soil. Illinois lakes in which the contribution of internal loading has been estimated show a wide variation in the role of sediment regeneration.

Lake Le-Aqua-Na in Stephenson County receives much of its phosphorus (86 percent dissolved and 92.6 percent total) as runoff from the watershed; internal regeneration accounts for 13.8 percent dissolved and 7.3 percent total phosphorus (Kothandaraman and Evans 1983a). Inclusion of internal regeneration in the phosphorus budget of Skokie Lagoons nets a dissolved phosphorus contribution of 6.3 percent from the sediments (Kirschner 1983). This was second only to the 89 percent contribution from a sewage treatment plant. Estimates of regeneration from the sediments in Johnson Sauk Trail Lake reveal that regeneration was the dominant source of dissolved (75 percent) and total phosphorus (60.2 percent of net phosphorus input). There is no point source contribution to the lake and, in this case, the tributaries accounted for 17.1 percent dissolved and 27.1 percent of the total phosphorus load (Kothandaraman and Evans 1983b). The values for Illinois lakes are estimates based on literature values for release rates and represent the low end of the ranges cited so the rates in these lakes may be underestimated. However, in the absence of values for the proportion of released phosphorus that is brought back into the photic zone, the low estimation may be closer to the actual regeneration rate.

Although intensive studies have not been done on other Illinois lakes, it is likely that internal regeneration contributes to their phosphorus budgets. Most of the 353 lakes considered in an assessment and classification project exhibited dissolved oxygen deficiencies (less than 1.0 mg/l) in the bottom waters regardless of the occurrence of stratification. Exceptions were usually lakes with maximum depths of less than five feet (IEPA 1978).

## Summary

Although there is still much to be learned about internal regeneration of nutrients, it can be concluded from the existing literature that regeneration from the sediments and plants within lakes can be an important source of nutrients. Anoxia near the sediments causes the greatest phosphorus release rate although phosphorus may also be released under oxic conditions. A general comparison shows anaerobic release to be approximately 10 times greater than aerobic release (Welch 1980).

The quantity of released phosphorus that makes its way from the sediment-water interface depends upon the coefficient of eddy diffusion defined by the steepness of the concentration gradient from sediment surface to overlying water (Vollenweider 1971). Characteristics of the gradient, in turn, are affected by the lake surface area to volume ratio (Welch 1980). The amount of phosphorus that is actually recycled (rather than dropping back to the sediments) depends upon the extent and timing of mixing from overturn, wind events, or temperature changes.

Depth is an underlying factor influencing many of the above conditions. Lakes of moderate to shallow depth tend to receive more input from internal sources than deep lakes of similar surface areas since the released phosphorus would have less distance to travel in order to become positionally available to algae in the photic zone. The longer time lakes experience high phosphorus inputs from point and nonpoint sources, the greater the sediment phosphorus concentration and the greater the potential for influence of sediment phosphorus on lake productivity.

With reduction in point and nonpoint sources, it is likely that the phosphorus levels in highly eutrophic lakes will remain high due to release of phosphorus from the sediments. In-lake management practices, such as artificial destratification, hypolimnetic aeration or treatment of the sediment with alum or dredging would be necessary to prevent the release of sediment phosphorus. Reduction of phosphorus input from point and nonpoint sources would reduce the amount of phosphorus stored in the sediments. In some lakes, this could decrease the need for intensive in-lake restorative practices.

# *NONPOINT SOURCE CONTROL STRATEGIES*

## Agricultural Best Management Practices

Efforts to control erosion and thereby sedimentation in Illinois are widespread. Soil and Water Conservation Districts (SWCDs) work together with the Soil Conservation Service (SCS) field offices to promote soil conservation practices and to provide the technical expertise needed to apply those practices to the land. The Agricultural Stabilization and Conservation Service (ASCS) offers annual and special Agricultural Conservation Payment (ACP) programs designed to help defray the cost of sometimes expensive soil conservation practices to the landowner. The Watershed Protection and Flood Prevention Act (PL 83-566) provides federal cost-share funding through SCS for large scale watershed protection projects which reduce soil erosion and lake sedimentation to water bodies. As part of Governor Thompson's "Build Illinois" program, the Illinois Department of Agriculture (IDOA) will oversee a $20 million state cost-share program to be spent over the next five years to build enduring soil conservation practices and to reduce sedimentation to critical watersheds. Private and local funds are also being spent to protect lakes from sedimentation. For example, Springfield, Illinois' public utility has provided the local SWCD with $45,000 over the past three years (1983-1985) to protect Lake Springfield, the City's water supply source.

In 1977, the Illinois Erosion and Sediment Control Program and Standards law was passed by the General Assembly, which led to the establishment of Illinois' "T by 2000" plan. This plan took effect on January 1, 1983. The plan was created to provide for a workable set of guidelines in order to achieve tolerable soil loss levels on all lands in Illinois by the year 2000. Therefore, it is evident that a great deal of attention and financial support, relative to years past, has been given to help solve the soil erosion and sedimentation problems in Illinois.

Phosphorus is an essential element for the production of crops such as corn and soybeans so it is widely used in Illinois. Phosphate fertilizers are applied mechanically to the land making phosphorus readily available for plant use. Because phosphorus has low solubility and high affinity for mineral soil particles, most phosphorus in surface runoff waters is thought to be associated with eroded soil particles (USEPA 1973). Therefore, the common assumption has been that reducing soil erosion and sedimentation to Illinois water bodies would naturally mitigate phosphorus related problems. An overriding question then arises as to whether or not intensive "T by 2000" soil erosion control efforts in lake watersheds will improve the eutrophic situation within lakes by reducing inputs of phosphorus laden sediments and runoff waters.

Soil conserving Best Management Practices (BMPs) established in a lake watershed should not only reduce the amount of sediment transported to its lake, but also the sediment associated phosphorus, which may be as much as 70-90 percent of the total phosphorus load. Most soil conservation BMPs also reduce the dissolved phosphorus load to lakes associated with a reduction in total surface runoff, however, the DP fraction of the TP load should increase, since PP losses are dramatically reduced with a reduction in soil loss. Obviously, reductions in phosphorus loading received by lakes due to BMP application will not have an equivalent effect on the in-lake phosphorus concentration. Many other point and nonpoint sources contribute to the concentration including, but not limited to, precipitation, waterfowl contributions, septics, sewage treatment facilities and internal regeneration.

From the literature reviewed, the following conclusions can be drawn about the use of BMPs for phosphorus control.

1. **Terraces**: Terraces can reduce sediment associated phosphorus (PP) loads by as much as 95 percent, while reducing dissolved phosphorus losses from 30-70 percent. Water ponds behind terraces allowing time for soil particles to settle out of suspension and can increase water infiltration, reducing the amount of surface runoff. Sediment transport can also be reduced by 95 percent.

2. **Contouring**: Contouring can reduce sediment losses by 50-60 percent. Particulate phosphorus loads can be reduced by an average 45 percent. Because contouring also retards water runoff, increased infiltration and reduced runoff of water and sediment result, reducing dissolved phosphorus losses by 20-50 percent.

3. **Sod Rotations**: Sod rotations of small grain or legume crops improve soil structure, increase organic matter content and increase soil porosity relative to continuous row cropping, thereby increasing water infiltration which reduces runoff and erosion. Particulate phosphorus loads can be reduced by 65 percent and dissolved phosphorus loads from 30-75 percent when sod rotations are utilized.

4. **Conservation Tillage**: Conservation tillage systems require that a minimum 30 percent residue cover be left on the soil surface after secondary tillage operations are completed and the crops have been planted. Crop residues provide protection from erosion and improve water infiltration. Literature reviewed shows that the use of conservation tillage can reduce particulate phosphorus losses by an average of 50 percent (ranged from 25-70 percent) and dissolved phosphorus losses from 25-42 percent.

   In some cases, dissolved phosphorus concentrations under conservation tillage systems can be higher than that found under conventional tillage because residues left on the soil surface can impede the attachment of applied phosphorus fertilizers to the soil. However, because runoff is reduced, a decrease in dissolved phosphorus loads will most often be noticed.

5. **No-till**: No-till is a method of planting crops that involves no seedbed preparation and all residues remain on the soil surface other than those displaced when readying the soil for seed placement. No-tilled soils reduce erosion substantially and therefore reduce particulate phosphorus by an average 55 percent (range from 33-81 percent). Because large amounts of residues and broadcast phosphate fertilizers remain on the soil surface in no-till situations, increased dissolved phosphorus loads in surface runoff will be noticed (up to 100 percent). However, even though dissolved phosphorus loads increase, the TP loads are reduced substantially when compared to the total phosphorus lost with conventional tillage, because dramatic reductions in both soil loss and runoff occur under no-till conditions.

6. **Diversions and Grassed Waterways**: A diversion is defined as a channel with a supporting ridge on the lower side constructed across the slope for the purpose of diverting excess water from areas to sites where it can be used or disposed of safely. Similarly, grassed waterways are natural or constructed waterways or outlets, shaped or graded, and established in suitable vegetation to provide for the disposal of excess surface water from terraces, diversions, or from natural concentrations without damage by erosion or flooding (USDA - SCS 1979). Both practices are designed so that soil in the channel does not erode nor does the sediment settle out of suspension.

   According to Haith (1979) both diversions and waterways concentrate the flow of water, giving the water less chance to infiltrate into the soil; therefore these two practices increase runoff volume rather than decrease it. However, according to S. Black (personnal communication), the statement that grassed waterways increase runoff volume is not accurate. He states that grassed waterways are located in areas where water is already concentrated and that vegetation reduces the flow velocity from what the velocity would be on base soil, allowing for some water infiltration.

   Other than controlling soil loss originating from gully erosion, and regardless of whether water runoff is increased or decreased, it cannot be concluded at present that waterways or diversions control any pollutant until more research is done (Haith 1979).

7. **Sediment Basins and Filter Strips**: Sediment basins and filter strips can be effective management practices in reducing phosphorus loads. Although they do not affect the amount of runoff from a watershed, they do slow the movement of water and allow sediment to settle out. Because sediment basins and filter strips vary in size, shape and proximity to water bodies, the extent to which these practices reduce pollutant loadings is uncertain. However, it can be assumed that since sediment is allowed to filter out of suspension, the sediment associated phosphorus (PP) loads will be reduced.

8. **Stripcropping**: Stripcropping is a conservation practice in which grass or small grain crops are planted on the contour next to row crops in a systematic, alternative arrangement. The purpose of the practice is to reduce erosion and improve water control. Runoff volume will not be affected. However, slowing the downhill movement of water will reduce its capacity to pick up and transport soil particles in suspension. Because contour stripcropping reduces soil erosion, particulate phosphorus loads will be reduced (to what extent is unknown according to the literature reviewed).

9. **Others**: Other BMP's that are often overlooked are: (a) soil testing, (b) liming, and (c) timing of fertilizer application. According to the North Carolina Agricultural Extension Service (1982), these practices affect fertilizer uptake efficiencies which can eliminate excess fertilizer, a logical first step in nutrient control. Use of these practices will also reduce the farmers' fertilizer costs.

   A. **Soil testing** will minimize the error between optimum and actual rates of fertilizers needed during application. It is recommended to take one soil sample per 30-45 acres. Tests should be taken once every three to four years on cropland, and once every five years on pasture land.

   B. **Liming** acidic soils to raise pH to optimum levels will improve the plant's ability to uptake phosphorus fertilizers. If liming is not practiced, excessive phosphorus will be applied to counter low plant uptake efficiencies which will cause greater surface runoff losses of phosphorus and phosphorus buildup in the soil.

   C. **Timing of fertilizer application** may be the most important factor in determining nutrient utilization efficiency and crop yields. Applying phosphorus and other fertilizers at the time of maximum growth and demand of the plant will reduce nutrient losses. Because soil type, crops, date of planting, etc., affect the optimum timing of fertilizer application, proper management by each individual farmer must take place.

Any soil and water conservation BMP will serve to reduce phosphorus loadings if: (a) soil erosion is reduced, (b) water runoff is reduced, and/or (c) increased plant nutrient uptake efficiency is achieved. In some cases, soil erosion practices will increase the amount of phosphorus in solution, however, these losses are low compared to the total phosphorus reductions that take place when soil losses are reduced.

### Watershed land treatment programs

Because of various local, state and federal programs, many lake watersheds in Illinois are receiving funds to reduce erosion and sedimentation. This is accomplished primarily by sharing the cost of soil conservation BMP application with the land user. This cost-share process reduces the financial burden to the land user since some needed conservation practices can be expensive to apply on the land. When funds are made available for accelerated BMP application in lake watersheds, they are commonly referred to as Watershed Land Treatment Projects (WLTPs).

Information on ten Illinois lake watersheds was reviewed to show estimates of reduced gross erosion and sedimentation that would arise should the area receive cost-share funding. The USDA Soil Conservation Service Water Resource Planning staff provided most of the data gathered, as they commonly predict during the PL83-566 watershed review process on-site and off-site benefits which would occur. Other data were obtained from reports written by the Illinois State Water Survey (ISWS) and the Richland County Soil and Water Conservation District.

Table 20 shows the gross erosion and sedimentation reductions expected during BMP application over the indicated time period. Watershed and lake surface acres are also given. Reductions in gross erosion ranged from 26.7-68.4 percent (mean was 45.7 percent) and reductions in sedimentation ranged from 25.2-68.2 percent (mean was 45.8 percent). In all cases, estimated gross erosion and sedimentation were very closely related, in fact almost identical to each other. This can be explained since the most erosive areas, which lie adjacent to tributaries of lakes and around lakes themselves are prioritized and treated with conservation practices (BMPs) first. These lands often erode at rates above 2T, and this eroded soil is often deposited directly as lake sediments. Upland portions of the watershed, which drain to the lake but have erosion rates below or slightly above T, are treated last (if at all), since eroded soil losses and related sediment delivery rates are comparatively small. Since the most critically eroding and sediment delivering lands receive prioritized conservation applications, the best results are obtained for both soil erosion and water quality programs.

It should be mentioned that these watersheds reviewed are best case scenarios, as thousands and sometimes millions of dollars are being spent, or proposed to be spent, in these areas to reduce erosion and sedimentation by the indicated amounts. Ongoing county level soil conservation programs, because of limited availability of cost-share monies and manpower, could not possibly achieve such results unless the watershed was very small in size.

As a result of reductions in sedimentation, it is assumed that each lake will receive smaller total phosphorus loads after implementation of BMPs than before implementation. Because the average time period of implementing large scale watershed projects is from five to ten years, and because long term extensive water quality monitoring programs are time consuming and extremely expensive, concrete data showing before and after phosphorus loading rates are scarce.

However, work conducted by the ISWS in the Lake Le-Aqua-Na watershed in Stephenson County showed that the expected reduction in sedimentation would be 29.6 percent (Kothandaraman and Evans 1983). Likewise, the expected reduction in total phosphorus loading to the lake was 29.6 percent. This reduction assumes 75 percent implementation of the most practical BMP options including conservation tillage, terracing, and contour strip cropping. Work

**Table 20. Estimated Erosion and Sedimentation Reductions in Lake Watersheds (1000 tons)**

| Citation | Lake Name | Wshd Ac.[1] | Surface Ac. | Gross Erosion B[2] | Gross Erosion A[3] | Percent Reduc. | Sedimentation B[2] | Sedimentation A[3] | Percent Reduc. | Project Period (yrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA-SCS 1985b[5] | Springfield | 165,366 | 4,024 | 601.0 | 393.9 | 34.4 | 130.0 | 79.8 | 38.6 | 10 |
| USDA-SCS 1983a | Decatur | 587,700 | 2,348 | 2,645.5 | 1,727.3 | 34.7 | 385.3 | 241.5 | 37.3 | 10 |
| USDA-SCS 1985e | Shabbona | 12,570 | 320 | 65.7 | 33.1 | 49.6 | 14.4 | 7.4 | 48.9 | 10 |
| USDA-SCS 1983b | Spring | 12,726 | 240 | 90.7 | 49.5 | 45.4 | 35.6 | 18.8 | 47.3 | 10 |
| USDA-SCS 1985f | Waverly | 5,791 | 109 | 38.1 | 19.9 | 47.9 | 17.2 | 8.9 | 48.5 | 10 |
| USDA-SCS 1985c | Raccoon | 30,035 | 685 | 176.5 | 76.5 | 56.7 | 32.4 | 15.1 | 53.3 | 10 |
| USDA-SCS 1985d | Sara | 7,140 | 760 | 24.5 | 17.9 | 26.7 | 10.0 | 7.5 | 25.2 | 10 |
| Richland SWCD 1985 | Olney E. Fork | 5,445 | 934 | 38.7 | 14.0 | 63.8 | 13.6 | 5.2 | 61.8 | 5 |
| USDA-SCS 1985a | Kinkaid | 39,590 | 2,750 | 394.6 | 124.8 | 68.4 | 129.4 | 41.1 | 68.2 | 10 |
| Kothandaraman 1983 | Le-Aqua-Na | 2,348 | 40 | 8.1 | 5.7 | 29.6 | 3.8 | 2.7 | 29.6 | .4 |
| | | | | | | mean = 45.7 | | | mean = 45.8 | |

1 Watershed acres.

2 **Before** conservation land treatment practices are established.

3 **After** conservation land treatment practices are established and 75-80 percent of the acres have been treated to below "T" levels.

4 When 75 percent of the watershed is protected below "T" levels.

5 USDA-SCS 1985b only gave gross erosion and sedimentation reduction figures for the Lick Creek portion of the Lake Springfield watershed. However, the figures shown above were proportionately extrapolated to reflect gross erosion and sedimentation reductions for the entire Lake Springfield watershed.

conducted by the Illinois State Water Survey (1983) found that implementation of proposed protection/restoration measures in the Lake of the Woods watershed (Champaign County, Illinois) would likely result in a sediment loading reduction of 50 percent, while the TP load would be reduced by 45 percent. It is evident that the reduction in TP is very closely related to the reduction of sediment entering a given lake.

These findings correlate to what has been mentioned previously in that the PP fraction of the TP load is approximately 70-90 percent, according to the literature reviewed. Therefore, since the mean average sediment load reduction found in Table 20 is 45.8 percent, and assuming a 70-90 percent phosphorus loading reduction, a 32.1-41.2 percent state average TP load reduction from agricultural nonpoint sources would take place in lakes where watershed protection projects are implemented. Obviously however, percent load reductions will vary throughout individual watersheds in the State.

Actual total phosphorus loads and estimated loads after implementation of watershed land treatment projects (WLTPs) are presented in Table 21. Critical loads for approximating levels which cause declining water quality conditions in terms of algal production are also presented in the table for comparison. In reviewing this information it must be kept in mind that the critical loads were developed with a large data set of U.S. lakes so the relationships may not provide an accurate measure of determing potential success of phosphorus control for Illinois lakes. Further study of phosphorus loading and algal biomass for Illinois lakes would refine the critical loading levels for Illinois. Actual loads for several years of record would also be instrumental in clarifying lake water quality trends.

None of the loads for these lakes is predicted to fall under critical levels after WLTP implementation. Buildup and maintenance applications of phosphorus fertilizers lost during the erosion process are the main sources contributing to lakes from agricultural nonpoint sources. However, even though fertilizer applications are limited in the Johnson Sauk Trail Lake watershed (only 6.2 percent cropland), loading rates exceeded the critical loading rate. This may be due to the inflow of inherent soil phosphorus to the lake. Since approximately 80 percent of the land area in the Johnson Sauk watershed is currently in an eroded

**Table 21. Actual and Calculated Critical TP Loading Rates for Five Illinois Lake Watersheds**

| Lake Name | Mean Depth (meters)[1] | Hydraulic Retention Time (yrs)[1] | "Hydraulic[4] Load" (meters/yr) | Actual Load (lbs/ac/yr) | Estimated[5] Load with WLTPs (lbs/ac/yr) | Critical Load (lbs/ac/yr)[2] |
|---|---|---|---|---|---|---|
| Highland Silver L. | 3.05 | 0.518 | 5.89 | 0.670 (1975) | 0.39-0.45 | 0.045 |
| Johnson Sauk Trail L. | 2.29 | 0.796 | 2.88 | 0.130 (1981) | 0.08-0.09 | 0.037 |
| L. Le-Aqua-Na | 3.32 | 0.284 | 11.69 | 1.600 (1981) | 0.94-1.09 | 0.062 |
| Lake of the Woods | 3.41 | 0.634 | 5.38 | 0.230 (1981) | 0.14-0.16 | 0.042 |
| L. Pittsfield | 3.75 | 0.554 | 6.77 | 0.060 (1980)<br>12.900 (1981)<br>0.220 (1982)[3] | 0.03-0.04<br>7.58-8.76<br>0.13-0.15 | 0.047 |

1 Mean depth and hydraulic retention time from Assessment and Classification of Illinois Lakes (1978).

2 Vollenweider's Critical or Eutrophic Load taken from Table 18 of this report.

3 Data only shows TP loadings from April 1982 - September 1982.

4 Hydraulic load = Mean Depth Divided By Hydraulic Retention Time

5 Assumes 70-90 percent phosphorus load reduction.

or critically eroded state, much of the topsoil is gone, allowing erosion to take place directly on the subsoil. These subsoils, which were formed from loess parent materials in forested areas, contain substantial amounts of inherent phosphorus, and when eroded, can be a significant source of excessive phosphorus loads.

Although the loading rates of the lakes are predicted to remain above critical loading levels, the reductions which do take place are likely to improve lake water quality conditions. As noted by Rogers (1977), eutrophic lakes cover a range of water quality conditions from very desirable recreational lakes that support excellent warmwater fisheries to lakes with undesirable aesthetics and water use limitations.

Any reduction in the total phosphorus load to water bodies by reducing sedimentation will not have an equivalent effect on the total phosphorus concentration (mg/l) in lake water samples. For example, the SCS Water Resources staff estimated that 53.3 percent and 68.2 percent reduction in sediment yields would result in Lakes Raccoon and Kinkaid, respectively, due to BMP application during ten year PL83-566 watershed protection project implementation (USDA Soil Conservation Service 1985). Assuming a 70-90 percent reduction, total phosphorus loads from agricultural nonpoint sources would be reduced by 37.3-48.0 percent and 47.7-61.4 percent, respectively. However, SCS, in cooperation with IEPA, estimated that reductions in total phosphorus concentrations would be only 6-12 percent for both lakes (reductions were estimated by extrapolating CREAMS model results). The reduction in total phosphorus loads will not be equivalent to reductions of in-lake phosphorus concentrations because; (1) phosphorus attached to bottom sediments is often released during the internal regeneration process, (2) the application of conservation tillage systems can increase the dissolved phosphorus load to lakes, and (3) contribution of phosphorus from other point and nonpoint sources such as waterfowl excrements, septic systems, rainfall, wastewater treatment facilities, etc., regularly occur. However, if runoff is not significantly reduced a higher reduction in loading will mean a greater reduction in concentration.

Although this review primarily emphasizes the particulate phosphorus fraction of the total phosphorus load, this does not mean that dissolved forms are unimportant. In fact, because dissolved phosphorus forms are readily available for aquatic plant utilization, it is very essential that control measures be taken for this form. In areas where subsurface flow is a major portion of the total runoff, dissolved phosphorus may comprise much of the loading. However, the literature reviewed indicated that total phosphorus loads in surface runoff are associated largely with sediment.

## Summary

Because individual lake watersheds differ dramatically throughout Illinois, it is difficult to assess on a statewide basis the effects that the "T by 2000" program and intensive watershed land treatment projects will have on reducing nonpoint source phosphorus loads to Illinois lakes. Soil types, watershed sizes and shapes, sediment delivery ratios, land uses within the watershed, annual amounts and intensities of rainfalls, degree of conservation practices applied and many other factors vary greatly within individual sites. Because no two watersheds are the same, they must be looked at on an individual basis to accurately assess current phosphorus loading rates, and those rates which could be expected after BMP implementation. Since specific phosphorus monitoring programs are expensive and time consuming, little information was available to show before and after relationships for entire watersheds.

The following conclusions can be drawn from this study of agricultural nonpoint source phosphorus contributions:

1. Phosphorus is often the major limiting nutrient contributing to the eutrophication process. In most cases, particulate phosphorus was found to be approximately 70-90 percent of the nonpoint source total phosphorus load with the dissolved phosphorus forms contributing approximately 10-30 percent or less. Because dissolved phosphorus is readily available for algae and macrophyte utilization, it may be the most critical fraction of the TP load causing eutrophication. However, as mentioned previously in Section VI, Internal Regeneration, both sediment associated phosphorus (PP) and dissolved phosphorus not utilized by aquatic plants which settle to the lake sediments, can still be regenerated as readily available dissolved phosphorus and brought back into the phosphorus budget of a lake. Hydraulic retention time, lake depth, temperature, amounts and forms of phosphorus entering a lake and amount of biological activity within the lake are all factors influencing this regeneration process.

2. Any land use reduces erosion and water runoff should reduce phosphorus loads. Pastureland and ungrazed forestland are two such land uses.

3. Watershed size was not found to be an accurate measuring device to predict phosphorus loading rates. Micro-relief (percent slopes), watershed shape and field conditions are more important factors to consider.

4. Sediment yields vary in amount throughout Illinois watersheds and are very important

factors to consider when predicting phosphorus loading. Watersheds that contain areas of steep eroding lands adjacent to waterways or tributaries of lakes will produce high sediment yields and associated phosphorus delivery rates.

5. Phosphorus yields vary greatly throughout Illinois and its neighboring states. In the Illinois lakes reviewed, phosphorus loads ranged from 0.13-12.90 lbs/ac/yr (0.15-14.5 Kg/ha/yr). Loading rates were found to be very dependent on land use, and the amounts and intensities of rainfalls, which relate to the amount of erosion and related particulate phosphorus being lost.

6. BMPs utilized in Illinois generally reduce phosphorus loads by reducing erosion and surface runoff. Some practices such as conservation tillage and no-till can increase the dissolved phosphorus fraction of the total phosphorus load. However, losses are small when compared to total phosphorus reductions that take place when soil losses are minimized. Additionally, BMPs should be utilized to increase fertilizer uptake efficiencies of individual crops. These BMPs include soil testing, liming of acidic soils, and timing of fertilizer application.

7. As shown in Table 20, intensive watershed land treatment programs (WLTP) can greatly reduce both gross erosion (mean = 45.7 percent) and sedimentation (mean 45.8 percent). These reductions will relate directly to an approximate 32.1-41.2 percent State mean average reduction in phosphorus loading rates, as phosphorus is associated primarily with the transport of sediment.

   Of the WLTPs reviewed, the maximum projected phosphorus loading reduction would take place in the Lake Kinkaid watershed (Jackson County, Illinois) as a 68.2 percent sediment yield reduction would correspond to an approximate 47.7-61.4 percent phosphorus loading reduction from agricultural nonpoint sources. This reduction, as with the others found in Table 20, assumes that 75-80 percent of the critically eroding acres would be treated to below "T" erosion rates. These programs are designed to treat critically eroding lands adjacent to lake tributaries and watercourses where sediment delivery ratios can be high. Because high level cost-share assistance is made available to help the land user apply BMPs, these programs are considered to be best case examples in reducing erosion, sedimentation, and associated phosphorus losses in the state, and would far exceed what the "T by 2000" program could accomplish in and of itself. Even with these seemingly large reductions, phosphorus loading rates are predicted to remain above critical loading levels. However, the reductions which do take place are likely to improve water quality conditions (i.e. decreased frequency of nuisance algal blooms).

8. Although the Illinois "T by 2000" program is not a specific water quality program, the process of saving soil acts as a surrogate water quality management tool by reducing phosphorus contributions to Illinois lakes. Should "T by 2000" be 100 percent successful (all lands in Illinois below "T" by the year 2000), it can be safely assumed that gross erosion, sedimentation, and related phosphorus loads would be reduced equivalent to or greater than those estimated in Table 21 which only assumes 75-80 percent of the land will be treated below "T." However, because this program is based on a voluntary, non-cost-shared program of soil conservation, the success of it depends upon the willingness and financial capability of the land user to apply the necessary BMPs. Without financial incentives during the current poor farm economy, it seems unlikely that the major goals of the program will be obtained and exceed the results of financially supported WLTPs.

## Urban Best Management Practices

The NURP studies reported selective best management practices for the control of urban runoff. Technologies were chosen for the individual studies by various agencies and were considered the most attractive and practical at a localized level. General conclusions were drawn for the NURP Final Report from evaluating these practices.

The NURP Final Report (1983) discussed four types of control techniques used by the projects. These four categories were as follows:

1. **Detention Devices** – These include normally dry detention basins (typically designed for runoff quantity control), normally wet detention basins, dual purpose basins, over-sized drain pipes, and catch basins.

2. **Recharge Devices** – These include infiltration pits, trenches and ponds, open-bottom galleries and catch basins, and porous pavements.

3. **Housekeeping Practices** – Principally streetsweeping, but also includes sidewalk cleaning, litter containers, catch basin cleaning, etc.

4. **Other** – So-called "living filters" such as grassed swales, wetlands, etc.

Detention basins were one of the most popular practices used by the NURP projects. Nearly all of the facilities studied were already in place or required slight modifications. The NURP report concluded that, in general, the practices provided a highly effective approach to control urban runoff, although design of the techniques significantly influenced performance results.

Dry basins are designed to control flooding and erosion in areas downstream of new development. They normally hold excess flows for a short period and are, thus, usually dry. Performance of these basins for pollutant removal efficiency was insignificant to very poor. Wet basins, on the other hand, were shown to be highly effective in general at removing total pollutant masses. The Lake Ellyn, Illinois NURP study (1983) found that substantial reductions in suspended stormwater pollutants resulted from detention basins. Reductions of over 80 percent for suspended solids and metals were measured. Total phosphorous reductions were over 50 percent.

The Final Report concluded that the size of the basin relative to the urban area served, as well as local storm characteristics, strongly influenced removal results. Some basins exhibited substantial reductions in soluble phosphorus, as well as particulate phosphorus. Results showed that biological processes could produce reductions of 50 percent or more for soluble phosphorus.

Dual-purpose basins, dry basins modified to extend detention time, were considered effective at reducing urban runoff loads, although limited data were available from the individual NURP studies.

Recharge devices, the second major category, are measures used to increase infiltration of urban runoff. These methods were shown to be practical and effective at removing pollutants. Performance capabilities were judged according to the extent to which urban runoff was "captured" and prevented from discharging directly to surface waters. Removals were reduced in direct proportion to the runoff volume intercepted and recharged. The issue of groundwater contamination from infiltration was discussed, and based on the NURP studies, the Final Report concluded that significant contamination of groundwater would not result from recharge practices. The report emphasized however, that this practice should be restricted to areas where conditions are favorable.

Porous pavement, another recharge device, refers to a porous asphaltic paving material with a high void aggregate base which allows for rapid infiltration and temporary storage of rain falling on paved surfaces (Maryland Department of Soil and Water Conservation 1985). It is used to reduce stormwater runoff and water pollution. This practice is applicable as a substitute for conventional asphalt pavement on parking areas and low-traffic volume roads provided that the grades, subrock drainage, and groundwater table conditions are suitable. The water table should be deep enough to prevent contamination. Figure 11 presents a typical section of porous pavement.

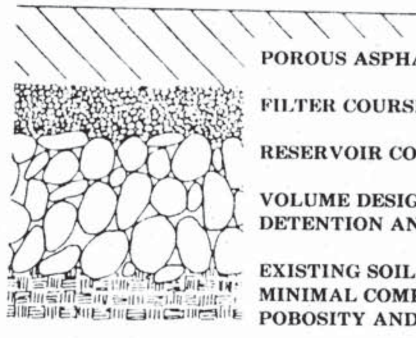



**Figure 11. Porous asphalt paving typical section.**

A study by the Virginia Division of Soil and Water Conservation (1985) rated wet ponds and porous pavement as the most effective urban BMPs, whereas dry ponds and grassed swales were judged the least effective.

Streetsweeping, included in the third category of housekeeping practices, was found to be generally ineffective at improving the quality of urban runoff. The Lake Ellyn study stated that catch basins and streetsweeping were ineffective urban stormwater pollutant management techniques.

Only three NURP projects assessed the performance of grassed swales. Based on these limited data, the Final Report concluded that the techniques can provide moderate improvements in urban runoff quality. Additional study was recommended, as this technique was considered very promising. Design considerations to improve performance of grassed swales (slope, vegetation type) were cited to improve load reductions.

Wetlands were also considered a promising technique. Only one study evaluated wetlands, and results showed it had good potential for improving the quality of urban runoff. The Final Report recommended that additional attention would be useful, and that factors such as the need for maintenance harvesting to prevent constituent recycling should be examined. The use of wetlands may prove very beneficial. Recent research has shown that the runoff from drained marshes and wet meadows (which, when normally functioning, act as traps for nutrient-rich sediments) is so rich in phosphorus that it can have as detrimental an impact on its receiving waters as a point source of pollution (Northeastern Illinois Planning Commission 1985).

Not enough complete data were available for control techniques to present reductions in pollutant mass loads for all methods. However, according to the Wtershed Handbook (monteith et al. 1981), selected control measures have the following phosphorus rmoval capabilities (See Table 22).

**Table 22: Average Phosphorus Removal/ Various Stormwater Control Measures**

| Stormwater Control Measure | Percent Unit Area Load Reduction |
|---|---|
| Diversion of first flush materials to a storage/percolation basin | 99+ |
| Detention/percolation | 100 |
| Detention in natural swales/ percolation | 92 |
| Percolation and collection by underdrains | 93 |
| Detention/Sedimentation | 70 |

The following selected studies of urban best management practices and their ability to reduce phosphorus loads are discussed for comparison with the NURP results.

Six types of urban best management practices (BMPs) were evaluated to determine their comparative pollutant removal capability and relative implementation costs in the Washington, D.C. metropolitan area. A two year field monitoring investigation of the pollutant removal efficiency of detention (dry) ponds, extended detention dry ponds, wet ponds with a permanent pond, grassed roadside swales, infiltration pits and trenches, and "popcorn" porous pavement was undertaken in suburban Maryland and Virginia (Schueler et al., 1985).

Statistical analysis of the data indicated that conventional dry ponds and grassed roadise swales were not effective in removing pollutants in urban runoff. Rapid passage of stormwater through the structures resulted in generally low or occasionally negative removal efficiency. By contrast, extending detention times within dry ponds for six to 12 hours produced moderate (40 to 60 percent) removal of sediments, organic nutrients, and trace metals, but only minor removal of biologically available nutrient forms. Biological processes operating in wet ponds effectively removed 60 to 80 percent of the available nutrient forms. The porous pavement site exhibited moderate to high (60 to 98 percent) removal for all pollutants. Porous pavements provide storage, enhancing soil infiltration that can be used to reduce runoff and combined sewer overflow (CSO) volumes. Porous asphalt-cement pavements can be underlain by a coarse gravel base for whatever storage capacity is desired.

Results from a Rochester, NY study showed that peak runoff rates were reduced as much as 83 percent where porous pavement was used (Field 1985). The structural integrity of the porous pavement was not impaired by heavy load vehicles.

The Washington, D.C. NURP study collected data and analyzed these to correlate urban land use and nonpoint pollution loadings in runoff, and to evaluate the effectiveness of urban BMPs (USEPA, Washington Metropolitan Area 1982). The types of BMPs studied were wet and dry ponds, infiltration pits, grassed swales and porous pavement.

Of the BMPs evaluated, wet ponds had typical removal rates for total phosphorus around 55-58 percent. Total dissolved phosphorus rates were higher, between 70-90 percent. Orthophosphorus rates were also high, at 60-99 percent. These rates suggested that algae, wetland vegetation and bottom sediments are achieving relatively high levels of phosphorus removal. Dry ponds evidenced negative or zero total phosphorus removal rates for ten storms. Total phosphorus removal rates for other storms were 20-40 percent. Total dissolved phosphorus removal rates were negative to zero for 11 storms, and were 20-25 percent for three other minor storms. Orthophosphorus removal rates were negative or zero for 12 storms. A comparison between wet and dry ponds showed higher total phosphorus removal rates at wet ponds (55-80 percent) and lowest at dry ponds (negative or zero for almost 2/3 of the storms and 20-40 percent for others).

A study of Lake Eola, an urban lake in downtown Orlando, Florida was undertaken by Wanielista et al. (1982). The major source of phosphorus (560 lbs/ yr) was stormwater. The study evaluated detention as a means of improving the quality of stormwater runoff. Because a significant amount of the phosphorus was in the dissolved state and therefore not removed by detention alone, coagulation with detention was investigated. Alum, ferric sulfate and lime were the primary coagulants used. Overall removal efficiencies are presented below.

Stormwater Management Controls per Impervious Acre, Lake Eola, Florida

| Management Practice | Overall Efficiency (%)* |
|---|---|
| Diversion/Percolation | 99 |
| Percolation Pond | 99+ |
| Swales w/Percolation | 92 |
| Residential Swales | 80 |
| Sedimentation | 64 |
| Advanced Sweeping | 68 |

*Yearly average mass removal of BOD, N, P and SS not discharged to surface waters.

Approximately 30 percent of average total phosphorus was removed after 1-2 hours of detention. P was equally distributed among dissolved and suspended fractions. Sixty percent of suspended phosphorus was removed by detention which resulted in a 30 percent reduction of all TP. The study concluded that even with these reductions, P loads would tend to produce eutrophic conditions.

Alum coagulation plus detention removed an average of 92 percent of initial average TP after 60 minutes. Final TP concentration in the alum treated stormwater was 0.06 mg/l. This practice decreased TP loads an estimated 84 percent.

The existing streetsweeping program in Madison, Wisconsin was evaluated for effectiveness in reducing phosphorus and sediment loading in a primarily residential urban watershed (Ahern 1979). Streets in the 2,030 acre watershed were swept by mechanical sweepers approximately three times per month during the study period.

The effectiveness of the streetsweeping program was assessed by comparing annual amounts of sediment and phosphorus removed by the program to sediment and phosphorus loads from the same urban watershed, without the streetsweeping program. Findings estimated removal rates of 47-59 percent for phosphorus and 76 percent for sediment.

The study concluded that most of the sediment and particulate phosphorus in the stormwater was contributed from sidewalk, street and driveway runoff. Dissolved phosphorus in stormwater was contributed from leaching of lawns, gardens and other areas out of reach of the sweepers, as well as from dust and debris in the streets.

During the program, the amount of phosphorus in stormwater from street loading was estimated at 1,260 to 2,028 pounds per year. Total phosphorus picked up by mechanical sweepers was approximately 1,832 pounds. Thus the annual total phosphorus street loads (the sum of stormwater loads and streetsweeping) were estimated at 3,092 to 3,860 pounds per year. Annual street loadings for sediment were estimated at 3.179 million pounds. On a per acre basis, the loads were 1,566 pounds of sediments and 1.52 to 1.90 pounds of phosphorus.

Maximum total phosphorus loads on the streets occurred during November (1,045 pounds) and October (733 pounds). Another spring peak occurred in May, when approximately 616 pounds of total phosphorus was recorded. The majority of the peak fall total phosphorus loads came from streetsweeping, while the peak spring loads were dominated by stormwater contributions. This was attributed to leaf fall and a dry autumn, while the spring peak loads were due to seed fall and spring rains.

Sediment loads however, peaked in late spring from road sand used to control ice and snow. Peak sediment loads occurred in April and May. In April, an estimated 572,000 pounds of sediment was measured, contributed predominantly by streetsweeping. In May, an estimated 495,000 pounds of sediment was contributed from the streets, largely from stormwater.

The study concluded that the effectiveness of the streetsweeping program with respect to phosphorus removal was greatly enhanced by the efficient removal of leaves. During autumn leaf fall, the sweepers removed an estimated 86-96 percent of the phosphorus on the streets. During the rest of the year, the removal rate was 15-20 percent. To improve the effectiveness of the streetsweeping program, the study recommended vacuum sweepers and alternate side parking ordinances.

## Summary

From the studies that evaluated urban BMPs for the control of urban runoff, general conclusions may be drawn. The NURP program evaluated a limited number of control technique and concluded that, of these, detention basins and recharge devices were very effective at removing pollutants (USEPA/NURP Final Report 1983). Wet detention basins, one type of detention control, were considered to have the greatest performance capabilities. This conclusion was also supported by the Virginia Division of Soil and Water Conservation study which rated wet ponds and porous pavement, a recharge device, as the most effective BMPs.

Grassed swales were considered a promising technique, as were wetlands. The NURP report assessed grassed swales and concluded that moderate improvement in urban runoff quality were possible.

In contrast to the Madison study, the NURP program concluded that streetsweeping was generally an ineffective technique for improving the quality of urban runoff. One NURP report did state however, that in some cases, streetsweeping could be effective during periods following snow melt or leaf fall, although no NURP studies demonstrated this. The Madison project did demonstrate this however.

# POINT SOURCE CONTROL STRATEGIES

We have considered management strategies designed to reduce phosphorus loads from nonpoint sources; now, we will consider strategies for reduction of point source loads. It should be noted that the quality of all lakes would not be significantly improved by reduction of point sources. In many watersheds, agricultural nonpoint loads predominate and in some cases other factors are causing declines in water quality. With reduction in point source loading, recovery of a lake is likely to be slow because of the release of phosphorus stored in sediments by internal regeneration. However, there are water bodies - lakes, arms of large impoundments, or pools in streams - that would benefit from control of point source phosphorus loads.

## Standards in Other States

First we will consider standards currently being used in states to regulate point source phosphorus inputs.

A variety of approaches to phosphorus limitations have been taken by other states to meet the conditions mandated by the USEPA under Public Law 92-500. Twenty-five states have specified criteria for phosphorus control (EPA 1980). Fourteen states, including Illinois have numeric criteria, six states have narrative criteria, two states have a combination of numeric and narrative criteria, and three states have criteria calling for maintenance of natural nitrogen to phosphorus ratios. In addition, Kansas has narrative criteria for all nutrients and North Carolina has a chlorophyll **a** criterion which can lead to regulation of phosphorus input.

Numeric lake standards for total phosphorus range from 0.02 mg/l in Hawaii to 0.1 mg/l in some Pennsylvania lakes. These two states, as well as Maine and California, have different standards for different lakes depending on the lake classification. Arizona has separate standards for specific river stretches. Their standards are for total phosphate, not total phosphorus, and are based on annual means with a stipulation that samples not exceed the 90 percent value more than ten percent of the time. Four states, including Illinois have a 0.05 mg/l lake (and reservoir) water quality standard for some, if not all, lakes. North Dakota has a goal of 0.025 mg/l for its lakes which appears to leave some room for interpretation on a case-by-case basis.

Several states have chosen to leave their criteria open for interpretation by using narrative criteria. Most often these criteria state that phosphorus values shall not be so great as to cause nuisance growths of algae, weeds, and slimes that may impair the use of the water.

Two states, Indiana and Ohio, have a combination of numeric and narrative criteria. Indiana has a narrative criterion, much like other narratives described above, for most state waters but for waters in and around Lake Michigan there are specific values set. Ohio has a similar narrative criterion but proceeds to state that in areas of nuisance growths, phosphorus discharges from point sources determined significant by the Ohio EPA will be limited to a daily average of 1.0 mg/l as Total P.

Michigan and Minnesota have criteria for effluents only. In Michigan's case it is a 1.0 mg/l monthly average effluent concentration goal (which appears to leave it open for compliance or non-compliance). Minnesota has an effluent limit of 1.0 mg/l where the effluent affects a lake or reservoir.

Arkansas is one of three states using natural N:P ratios as a criterion for levels not to be exceeded. The Arkansas criterion also stipulates that total phosphorus should not exceed 1.0 mg/l in streams or 0.05 mg/l in lakes and reservoirs due to any municipal, industrial, agricultural or other waste discharges.

Some states, such as Florida and Wisconsin, are in the process of updating their standards. Wisconsin has plans of classifying its lakes into two categories — Type I lakes being high quality lakes designated for protection against increased phosphorus loading or lakes in which control of phosphorus inputs could improve the lake quality; Type II lakes being impoundments and lakes in which control of external loading would not significantly improve the lake or phosphorus is not the main factor determining water quality (Schrank et al. 1983).

Maine has a two level lake classification system which is used to prioritize lakes for quality control. Class A lakes have the most stringent standards of 0.015 mg/l TP, 0.008 mg/l chlorophyll **a**, and secchi disk of greater than two meters as averages over the open water season. Class B lakes have less stringent standards (TP of 0.05 mg/l). The Maine criteria have been developed from calculations of loading rates based on the Dillon-Rigler model (Dillon and Rigler 1974). Using the flushing rates for each lake, a phosphorus loading rate is calculated which would maintain in-lake phosphorus levels controlling algal blooms. Maine is also working on a Lake Vulnerability Index to flag those watersheds that may be susceptible to water quality declines and make the public aware of the consequences of new developments before they are initiated (M. Scott, personal communication).

North Carolina, in addition to its standard of 40 mg/l chlorophyll **a** for a maximum limit during the growing season, has instituted a Nutrient Sensitive Classification of watersheds. This classification system allows the appropriate State agency to scrutinize lakes in which the chlorophyll **a** standard is exceeded to determine if noxious (blue green) algae predominate, what the limiting nutrient is and what the major sources of nutrient loading are. Public input is also solicited in making the decision as to whether a lake should be classified as nutrient sensitive.

Once the Nutrient Sensitive Classification is made, alternatives to nutrient control are studied. In the case of nonpoint source control, voluntary compliance to implement best management practices is sought with the idea that if compliance isn't voluntary then regulatory action may be taken in the future. For point sources the effluent standard is background concentration but, based on technological and economical feasibility, 1.0 or 1.5 mg/l is used. The complete system has not been tested yet as compliance deadlines have not been reached.

## Wastewater Treatment

Once a means of phosphorus regulation has been adopted, a choice must be made as to which method of wastewater treatment will be used to meet the standard. Contrary to the complexity of strategies necessary for nonpoint phosphorus reduction, the strategies for point source control are relatively straightforward.

The most common method of reducing wastewater phosphorus concentration is the addition of a precipitation-flocculation material such as aluminum salts, iron salts, or lime (USEPA 1976b). The metallic ions react with orthophosphorus to form insoluble phosphate precipitants. Some polyphosphates and organic phosphorus compounds are also removed by other reactions and sorption onto floc particles (Black 1979).

Precipitation with alum is often used in phosphorus removal. The alum can be added before the primary settling tank in the aeration basin or following aeration before final sedimentation. Alum can also be added to the waste in a trickling filter but the practice has not been shown to be particularly effective and is not recommended (USEPA 1976b). Black (1979) recommended the effluent channel of the aeration basin which carries the mixed liquid to the final clarifier as the best point of alum addition. At this point, much of the particulate phosphorus has settled out and organic and polyphosphates have been broken down to orthophosphates which are most effectively precipitated.

Iron salts, especially in the oxidized ($Fe^{+3}$) form, are also of common usage. Ferrous salts ($Fe^{+2}$) can be used, but only with aeration to oxidize to the ferric form (Black 1979). In Ontario, Canada, 70 percent of the treatment plants in 1979 were using iron salts for phosphorus removal, compared to 26 percent using aluminum sulfate and two percent using lime (Rupke 1979). Iron salt can be cheaper to use than alum because the dosage is smaller (Table 23) and because waste pickle liquor may be used.

**Table 23. Average Doses of Commonly Used Chemicals and Their Costs (Rupke 1979)**

| Chemical | Average Dosage (mg/l) | Chemical Costs ¢/lb | $/Mgal |
|---|---|---|---|
| Alum | 65 mg/l as $Al_2(SO_4)_3 \cdot 14\,H_2O$ | 5.1 | 33.15 |
| Iron Salt | | | |
| $Fe^{2+}$ | 11 mg/l as Fe | 17 | 18.70 |
| $Fe^{3+}$ | 11 mg/l as Fe | 25 | 27.50 |

The costs in the above table are figured for treatment plants in Ontario. Costs in other locations may vary due to distances and means of transport and sources of free material. Problems with solid deposits blocking feed pumps, high toxic contamination, and concentration variations have kept the use of iron salts from becoming predominant in other areas.

Lime is used to precipitate phosphorus in some cases. Since a high pH (greater than 9) is caused by lime addition, care must be taken to ensure that the high pH does not interfere with biological activity in secondary treatment. Carbon dioxide production from biological activity has been found to be sufficient for moderating pH levels in activated sludge when the pH resulting from lime addition was raised to 10 (USEPA 1976). Lime addition was not recommended during trickling filter treatment. While lime may be inexpensive compared to metal salts ($18 to $22 per ton compared to $39 per ton for ferric sulfate, and $60 per ton for liquid alum in 1974) there are added facility costs for flow and pH controls (USEPA 1976b).

Sludge production is greatest with the use of lime. A three-fold increase in sludge production has been measured in an Ontario secondary treatment plant with the addition of lime for phosphorus removal (Black 1979). The advantage of lime sludge lies in the case of dewatering and the suitability for land application compared to metal sludges (Schmidtke 1979).

Removal of phosphorus by increased uptake by sludge biota has also been investigated. One method, called Phostrip, developed by Union Carbide, has been tried in pilot plant studies (Black 1979). This method subjects sludge microorganisms to anaerobic conditions as a stressant which promotes luxury uptake of nutrients by the microbes once they are returned to the aeration basin. The microbes are settled in a secondary clarifier, part of the phosphorus - rich sludge is returned to the aeration basin, part is wasted, and part is sent to a stripper tank where the microbes release phosphorus under anerobic conditions. The phosphorus-poor microbes at the bottom of the tank are returned to the aeration basin completing the cycle. The phosphorus-rich supernatant from the stripper is sent to a lime mix tank to precipitate the phosphorus and the mixture is sent to the primary clarifier to settle. In pilot scale, the system has been shown to produce effluent of less than 1.0 mg/l total phosphorus at a cost 34-37 percent lower than systems employing ferric chloride or alum.

The phosphorus removal methods mentioned above can remove 70 to 90 percent of the total phosphorus from effluent (USEPA 1976b). It was calculated from data taken over five years in the Sandusky River Basin that compliance to 1.0 mg/l effluent standard by all major sewage treatment plants in the system would reduce the total phosphorus loading from the watershed to Lake Erie by 14 percent from 445 to 382 metric tons per year (Baker 1980).

Wastewater diversion is a different approach to phosphorus control that deserves consideration. It may be possible to route wastewater from a community to a watershed that does not include a vicinal lake or, one in which the receiving stream is judged to be less sensitive. After the initial cost of diversion have been met, maintenance costs would be low compared to those for continuous phosphorus precipitation in wastewater.

As previously mentioned, diversion of Round Lake Sanitary District effluent from a tributary of Long Lake in 1979 resulted in a significant decline in levels of total and dissolved phosphorus in the lake. Mean chlorophyll **a** has also decreased from 68 ug/l prior to diversion to 34 ug/l in 1984-85 (IEPA 1986).

Diversion may not be appropriate in all cases, however. Care should be taken in consideration of diversion projects to ensure that diversion would not, in effect, cause the same problem in a different location.

**Treatment Costs**

Lee et al. (1980) estimated a cost of 91¢/person/year for phosphorus removal to 1.0 mg/l at treatment plants serving over 10,000 people.

The USEPA Financial Systems Unit used a computerized File of Approved Municipal Revenue Systems (FOAMRS) to develop a cost for phosphorus removal in Region V. The average cost for the region, based on 150 municipalities, was estimated at $1.35 per pound of phosphorus treated. The average cost from six municipalities in Illinois was $1.17 per pound.

Using the $1.17 estimate and a rate of phosphorus removal of 0.00296 lbs/capita/day, estimated by consultants for the City of Pana, Illinois, a cost estimate of $1.26/person/year is obtained.

A survey of operators and consulting engineers for several Illinois wastewater plants which have phosphorus removal capabilities resulted in a range of annual cost estimates. Operation and maintenance (O&M) costs (including chemicals) per person ranged from $1.70 to $4.90 in four of the surveyed plants for which information was available. Annual cost per person for chemicals used in precipitation of phosphorus ranged from $0.75 to $2.96 in five plants. Costs per household for yearly O&M ranged from $1.27 to $14.79 for five plants. Cost per household for chemicals ranged from $0.63 to $8.94 for six plants surveyed.

Cost estimate for the plants surveyed varied with the size and design of the plants and chemicals used. Chemical costs were most readily available through invoices. Other O&M costs had to be estimated since costs attributated to phosphorus treatment, alone, were not easily separable from the total costs of waste treatment.

# *DISCUSSION*

In order to relate the information in the preceding review to the issue of phosphorus control in Illinois waters, the discussion has taken the form of question and answer.

**Q: Which form of phosphorus is most important in water quality management - dissolved or total phosphorus?**

A: After review of literature on phosphorus management it has been concluded that total phosphorus is most important in terms of overall watershed management. As reported in Section IIC entitled "Availability of Phosphorus", soluble orthophosphorus (the main component of the dissolved fraction) is immediately available for uptake by algae in lakes. However, the majority of phosphorus load entering a typical lake is in the potentially available, particulate form.

The probability of delivery of dissolved phosphorus is greatest from sources on or near a lake. As distance of the source from the lake increases the likelihood of dissolved phosphorus incorporation into biota or sediments increases, thus, decreasing the amount of dissolved phosphorus entering a lake (see Section III "Phosphorus in Stream Water").

Total phosphorus, as a measure of particulate and dissolved phosphorus provides an estimate of both the amount of phosphorus that can immediately be used by algae and the amount that may become available through release from the sediments, breakdown of organic material, and ion exchange in maintenance of equilibrium phosphorus concentrations.

**Q: How does distance from the lake affect the amount of point source phosphorus delivered to the lake?**

A: The distance a load must travel from a treatment plant to a lake influences the amount, availability, and timing of phosphorus (Section III). As mentioned in the previous answer, the greater the transport distance the less likely that dissolved phosphorus from the point source will make it to the lake in solution.

Flow rate determines the amount of phosphorus transported to a lake in a given time period. Under high flows a large part of the suspended phosphorus load, in addition to load from sediment scour, can be moved downstream. Under normal flows, portions of the load have time to settle out and be taken up by stream biota. The phosphorus which settles out or, is taken up, contributes to later loads during high flows or after die-off of biota.

A plot of total phosphorus concentrations below an Ohio plant under normal flow conditions shows a 75 percent reduction in concentration over approximately four miles (See Figure 3 Section IIIA).

Mean total phosphorus concentration and flux dropped 73 percent within two miles of the Decatur treatment plant on the Sangamon River in August, 1982. Flow conditions were slightly higher than normal due to release from Lake Decatur. Under September low-flow conditions, the total phosphorus remained elevated for a greater distance, declining 74 percent in concentration, 65 percent in flux, after 37.8 miles (Appendix Figures 1 and 2). Although the distance and form of phosphorus (particulate or dissolved) transported varies, more study emphasizing measurement of transport distance will allow development of critical distances beyond which effluent phosphorus becomes a minor component of the total load to the lake.

**Q: Is phosphorus concentration the most important factor limiting algal productivity in Illinois lakes?**

A: Four major factors that may limit algal growth in lakes and impoundments are temperature, flushing rate, nutrient availability and light availability.

Temperature limitation is a seasonal phenomenon in Illinois lakes which generally prevents nuisance algal blooms from occurring in late fall, winter, or early spring.

Flushing rate is another factor which, in a few impoundments, keeps the lake water moving through the system fast enough that there is not time for algal populations to reach bloom proportions.

Nutrient availability is important, at times, in several lakes and impoundments. As discussed in Section VI A, carbon, nitrogen, and phosphorus are essential for algal growth and reproduction. Carbon is limiting only on rare occasions when little atmospheric carbon dioxide is incorporated at the water surface. Nitrogen can be limiting at times, but phosphorus is most often found to be the nutrient controlling algal growth in Illinois lakes.

Light availability is another important factor in determining algal abundance. Comparison of trophic state indices (TSI-Chla and TSI-TP, from Carlson 1977) developed from chlorophyll **a** and total phosphorus data of 1982 and 1983 indicates a deviation from the expected linear relationship (IEPA Water Quality Report 1984). It was suggested that the high potential for algal production, as indicated by values from the phosphorus index was not realized in several central and south-central impoundments because high levels of suspended soil particles attenuated light penetration or short retention times flushing the reservoir before large algal standing crops could develop.

In a survey of observations by IDOC biologists from 1970 - 1977, 68 out of 157 Illinois lakes (43 percent) had a moderate to substantial suspended sediment problem. Thirteen percent (21/157) of the lakes were noted as having a substantial suspended sediment problem. Three of the 21 lakes assessed as having high suspended sediment were also perceived to have substantial algal bloom problems.

Returning to the question of phosphorus as a limiting factor - shading by suspended solids is likely to be more important in limiting algal growth in some Illinois impoundments. However, there are other cases (48/152 lakes) where moderate to substantial algal bloom problems were reported regardless of suspended sediment levels.

Studies focusing on the algal limiting factors in specific Illinois lakes would be necessary before conditions contributing to or prohibiting algal blooms can be determined. However, there are lakes in which phosphorus is the important limiting factor.

**Q: In view of Vollenweider's critical loading values (as modified by Rast and Lee 1983), will we ever be able to bring our lakes out of the eutrophic classification?**

A: Due to natural fertility of Illinois soils, a large number of lakes and impoundments in the state tend to be eutrophic by nature and will most likely remain so, regardless of their management. However, eutrophic conditions do not necessarily indicate a degraded resource. There are many eutrophic lakes which provide potable drinking water, quality fisheries, and quality water recreation.

Critical loading values are used as estimates of phosphorus loadings which produce degraded water quality. As can be seen from Table 17 in Section VIII A, some lakes in Illinois exceed critical loading rates by appreciable amounts. While reduction of loads below critical levels may be our ultimate goal in lakes such as these, our immediate task is to reduce the frequency of nuisance algal blooms and reduce the need for chemical application and weed harvesting in the maintenance of lake water quality. The load reductions necessary to reduce nuisance algae and weeds must be determined with a data base more localized than Vollenweider's global data or Rast and Lee's U.S. data.

The mesotrophic and borderline meso-eutrophic lakes in Illinois presently exhibiting good water quality must also be kept in mind when considering phosphorus loading and standards. Effort must be made to keep phosphorus loading rates low in order to maintain the quality of lakes such as Devil's Kitchen Lake, as valuable recreational resources.

Given the wide variation in lakes and their watersheds, all lakes cannot be considered the same relative to their nutrient levels. Good water quality should be promoted and maintained in lakes of moderate to slight eutrophication with limits placed on phosphorus inputs. It may be determined that phosphorus inputs to other lakes should also be limited by effluent standards based on water supply needs and the public's perception of a water quality problem. A phosphorus standard for the remaining lakes may be costly to maintain and ineffective in producing the desired water quality due to other factors such as suspended sediment.

**Q: How important is regeneration of phosphorus from the lake sediments?**

A: Regeneration of phosphorus can be a very important part of a lake's phosphorus budget. As discussed in Section VII F, some lake restoration efforts, in the past, have had limited effect due to the unexpected contribution of phosphorus from lake sediments.

Estimation of phosphorus release in a few Illinois lakes shows that regeneration can play a major or minor role in the phosphorus budget depending, in part, on the magnitude of the other phosphorus sources.

The fact that phosphorus can be regenerated from the sediments in significant amounts highlights the importance of the contribution of particulate phosphorus to the phosphorus available for algal growth. Continued input of excessive amounts of phosphorus into a lake system will build up the sediment reserve, and so, increase the cost and time for restoration.

**Q: How many Illinois lakes exceed the 0.05 mg/l total phosphorus level in their surface waters?**

A: Data summary from 1984-1985 monitoring of 36 lakes showed 23 lakes (64 percent) to have mean total phosphorus concentrations exceeding the general use standard of 0.05 mg/l in the surface waters (IEPA 1986). Of the 56 lakes monitored by the Illinois EPA in 1982-83, 20 (36 percent) exceeded the State Standard (IEPA, 1984). From 1980-81, 31 out of 65 lakes (48 percent) in the ambient monitoring program had a surface mean total phosphorus concentration exceeding the standard (IEPA 1982).

Actual exceedence may be more or less widespread since time and resources allow for only a fraction of the Illinois lakes (approximaely two percent of the estimated 2,900 with surface area of six acres or more) to be sampled in any year. Also, the data have been summarized as annual means for all sites so exceedence with individual values during the year is likely to be more common. Internal regeneration and seasonal lake exceedance can be expected to create significant deviation above and below the annual mean concentration.

A survey of maximum total phosphorus values from IEPA ambient monitoring data from 1977 to 1983 shows 111 out of 148 (75 percent of the lakes sampled at any time during the period) exceeding the 0.05 mg/l concentration.

**Q: How many dischargers would be expected to come into compliance with the present regulation?**

A: According to our records, at least 32 dischargers would be expected to come into compliance with the present regulation. (See Appendix Table 1).

**Q: What is the estimated cost of wastewater treatment to reduce phosphorus to the 1.0 mg/l level?**

A: Annual operation costs range from \$0.91 to \$4.90 per person, according to literature reviewed and estimates from several Illinois treatment plants. Operation costs per household range from \$1.27 to \$14.79.

**Q: How do agricultural BMPs reduce phosphorus loads to lakes?**

A: BMPs reduce phosphorus losses if soil erosion and water runoff are reduced and plant nutrient uptake efficiencies are increased (refer to Section VIII A entitled "Agricultural Best Management Practices").

Phosphorus has a high affinity for, and is tightly bound to, silt and clay soil particles and is generally an immobile nutrient unless transported by the movement of soil. BMPs are applied to the land to reduce soil movement (erosion) and therefore reduce phosphorus loads to lakes. Approximately 70-90 percent of the total phosphorus losses from agricultural watersheds is associated with eroded soil.

BMPs such as terraces, contouring and others serve to both increase water infiltration and reduce the rate and/or volume of surface runoff. Conservation tillage and no-tillage practices leave crop residues on the surface which provide protection from erosion and also improve water infiltration. Although erosion and runoff are reduced, crop residues left on the soil surface may relate to higher dissolved phosphorus losses produced by the decay and breakdown of the crop residues. However, in almost all cases, BMPs reduce water runoff which reduces soil erosion and subsequent phosphorus losses.

Other BMPs such as soil testing, liming of acidic soils, and timing of fertilizer application affect fertilizer uptake efficiencies of plants and can eliminate excess fertilizer applications. Knowing how much phosphorus an individual plant needs, applying the nutrient when the plant needs it most and providing the proper pH for plant utilization all increase plant nutrient uptake efficiencies.

**Q: How much phosphorus from agricultural nonpoint sources can be prevented from entering Illinois water bodies with the use of BMPs?**

A: Lake watersheds in Illinois vary in size, shape, steepness, WA:SA, etc., and require varying kinds and amounts of BMPs to adequately protect the lakes from sedimentation and large phosphorus contributions. From the literature reviewed, total phosphorus loads to Illinois lakes ranged from 0.13 - 12.90 lbs/ac/yr (refer to Section IV A entitled "Agricultural Loading").

Ten Illinois Watershed Land Treatment Project (WLTP) applications were reviewed to help estimate potential reductions in phosphorus contributions to Illinois lakes. These applications include estimates of reduced erosion and sedimentation that would take place when 75-80 percent of the watershed had been treated with BMPs to below "T" levels.

In the projects reviewed, gross erosion would be reduced by 45.7 percent (range 26.7-68.4 percent) and sedimentation would be reduced by 45.8 percent (range 25.2-68.2 percent). Knowing that approximately 70-90 percent of the total phosphorus lost is associated with the transport of sediment (particulate phosphorus), an average of approximately 32-41 percent of the total phosphorus load from agricultural nonpoint sources could be reduced as a result of BMP application in Illinois lake watersheds.

High level cost-share assistance is made available to the land user to apply the needed BMPs in WLTPs. They are considered to be best case examples in reducing erosion, sedimentation, and associated phosphorus losses in the State, and would far exceed what the "T by 2000" program could accomplish in and of itself in the same given period of time.

**Q: How will the "T by 2000" program reduce phosphorus loads to Illinois lakes?**

A: The goal of "T by 2000" is to reduce erosion on every acre of land in Illinois to "T" levels, or tolerable soil losses by the year 2000. Because eroded soil carries particulate phosphorus to lakes, reducing erosion will reduce both sedimentation and phosphorus loading rates and therefore enhance Illinois lake water quality.

The success "T by 2000" attains will ultimately and proportionately reflect phosphorus loading reductions in Illinois. As previously mentioned, WLTPs reviewed, on average, would reduce total phosphorus loads by approximately 32-41 percent, when 80 percent of the watershed land was treated to below "T" erosion rates. Proportionately, should only 40 percent of the "T by 2000" goal be attained, current phosphorus loading rates would be reduced by approximately 16-21 percent.

The "T by 2000" program in and of itself is based on a voluntary non-cost shared approach to soil conservation relying on the individual land user's willingness to apply the needed BMPs to reduce erosion to below "T" levels. Because financial incentives are lacking in the program during this present poor farm economy, the soil erosion and water quality goals of "T by 2000" may be difficult to attain and deem 100 percent successful. Whatever the success of the program, reduced phosphorus loads will follow with a reduction in soil erosion.

**Q: How significant are urban runoff contributions to phosphorus inputs into lakes?**

A: The NURP Final Report (USEPA 1983) concluded that urban runoff can contribute significant amounts of phosphorus to lakes, resulting in decreased water quality. In Illinois, not enough studies have been completed on the effects of urban runoff on lakes to accurately state that a relationship exists between phosphorus inputs and urban runoff into lakes.

**Q: How can phosphorus inputs from urban runoff best be controlled?**

A: The NURP effort evaluated a limited number of conventional control measures. The study concluded that wet detention basins are very effective for removing many of the pollutants in urban runoff. Wet detention basins were estimated to reduce pollutant concentrations between 60 and 90 percent for most conventional pollutants; somewhat lower efficiencies were noted for nutrients such as phosphorus. However, most lakes and reservoirs in Illinois are fed by watersheds greatly dominated by rural land uses with extremely small portions of urban area.

Dry detention basins, in contrast, showed mixed results. The NURP Final Report concluded that basins designed to only control water quantity may not function well for controlling water quality.

Recharge basins appeared to be an effective and economical technique for reducing both runoff volume and pollutant inputs to surface waters. Recharge basins function by trapping all or part of urban runoff and holding it until it evaporates or percolates away. Concerns raised about groundwater contamination were not supported as NURP studies indicated that pollutants were trapped in the upper soil layers. According to the NURP Final Report, recharge basins appeared to be the most effective BMPs available. The report recommended that their use be considered where space and soil conditions warrant.

**Q: What information can be derived from consideration of the other States' standards?**

A: There appears to be three general approaches to regulation of phosphorus by individual states. One approach is to maintain a phosphorus standard as required by federal law but not pursue regulation. A second apprach is to assign effluent standards and emphasize phosphorus regulation of point sources for all lakes. A third approach is to control point source phosphorus in watersheds where point source contributions predominate over nonpoint contributions.

One idea that several states have used in their criteria is: not all watersheds can be considered in the same light. Watersheds vary in land use, physio-chemical characteristics, and degree of eutrophication. Some states have tried to classify and prioritize lakes and watersheds so that efforts to identify potential and actual problems can be concentrated on those lakes of greatest use and probability of maintenance or improvement. The idea of flagging watersheds that currently meet water quality standards but could easily fall below standards with increased phosphorus inputs is important for protection of the higher quality lakes of the state. Emphasis on strong programs of nonpoint phosphorus control, in addition to point source control is also important.

A review of numerical effluent and lake standards of various states produces several factors that may be useful in the evaluation of a standard. These factors are: the frequency sampling (daily, monthly, annually), position of sample (surface, tributary entrance, lake-proper), and how many excursions, if any, would be allowed (Arizona, for example, stipulates that samples from designated river reaches must not exceed the specified values more than 10 percent of the time).

The use of a critical chlorophyll **a** values to indicate lakes in which nutrient control is necessary (as in Maine and North Carolina) also has merit. However, investigation would be necessary to determine the levels of chlorophyll **a** which would be unacceptable for Illinois lakes ranging from mesotrophic to highly eutrophic.

# RECOMMENDATIONS

Most Illinois lakes and reservoirs are subject to excessive nutrient loading (particularly phosphorus), resulting in periodic, nuisance algae blooms or excessive rooted vegetation infestations. These lakes and reservoirs can be characterized as eutrophic; probably irreversibly so. Nevertheless, practically all of these impoundments support numerous beneficial uses including aquatic life propagation and maintenance, public and industrial water supply and a broad range of recreational opportunities. The extent to which these uses are restricted or will be further degraded is dependent on three primary factors: 1) the character of the impoundment, 2) watershed characteristics (land use activities and management practices within the watershed), and 3) in-lake management practices. Specific recommendations are offered for each of these categories.

### Lake Characteristics

1. Future efforts should be directed toward categorization of lakes according to phosphorus sensitivity and potential for restoration/protection with control of input from various sources.

   Factors such as point and nonpoint loading, seasonal distribution of loading, lake characteristics (retention time, depth, stratification tendency, watershed to lake surface area ratio, algal productivity, suspended solids, historical water quality trends), and lake management practices need to be molded into a classification scheme. This categorization can be built upon the existing classification developed for prioritization of Clean Lakes projects by IEPA. Lake categorization would allow concentration of phosphorus control efforts on lakes which are most likely to benefit from these efforts.

### Watershed and Source Factors

2. In view of the variability of conditions within lakes and their watersheds, adjustment of the current point source phosphorus regulations is in order.

   Wastewater sources discharging directly to or in close proximity to a lake or reservoir constitute a continuous input of readily available phosphorus throughout the year, including the critical summer months. The potential impact of these proximal discharges is greater than their percentage contribution to the total annual phosphorus load since they contribute a large amount of readily available phosphorus during favorable growing periods. Even hypereutrophic lakes can be affected by wastewater discharges with aggravation of aesthetic and nuisance problems, increases in the magnitude of daily D.O. fluctuations and a generally heightened extent of degradation, either locally or throughout the entire lake. Phosphorus removal consistent with the capabilities of currently available technology should continue to be required from proximal sources. Diversion of wastewater effluent outside the watershed or downstream of the reservoir would be the preferred alternative, if feasible. Otherwise, phosphorus removal should be provided.

Sources further removed upstream of the lake do not constitute such a direct threat. In transit from the source, phosphorus may be transformed from dissolved to a particulate state through various instream mechanisms. A portion of the phosphorus becomes bound to stream sediments. As a result, much of phosphorus is retained in stream system (at least temporarily) or reaches the lake as bound phosphorus, unavailable for immediate use by suspended aquatic plants and algae. Point source phosphorus stored in the sediments of the stream system remains there until high flows resuspend the sediments and transport it to the flood plain periphery or downstream to the lake. Phosphorus entering the lake in this fashion is 1) less available 2) arrives intermittently under elevated flow conditions, and 3) has a high probability of settling to the lake bed or flushing through the lake. Thus, point sources in upper reaches of the watershed are not as obvious a threat to lake conditions as sources near the lake. Point sources in this category should not be regulated by blanket phosphorus discharge limitations. Individual discharges may still be regulated by water quality provisions of Pollution Control Board Regulations as warranted by specific conditions. Criteria to be considered include: a) lake condition and sensitivity to incremental load reductions, b) size and relative location of source, c) existing or proposed nonpoint reduction programs and d) in-lake management and restoration initiatives.

3. Governmental and private entities should adhere to and accelerate nonpoint source control programs since these programs constitute a great potential for reducing external phosphorus loads.

   Sediment has been identified as the most signficant pollutant affecting surface water resources in Illinois. Outside of the six county metropolitan area of northeastern Illinois and the southern portion of the state, agriculture dominates Illinois' landscape, including most lake and reservoir watersheds. Most agricultural nonpoint source management practices emphasize reducing soil erosion on the land or redeposition of eroded soil particles prior to entry to the watercourse. Generally, 70 percent to 90 percent of the phosphorus derived from agricultural runoff is associated with particulates, therefore, effective erosion and sediment control programs are also effective phosphorus load reduction programs. Erosion and sediment controls can be further supplemented by prudent phosphorus fertilization rates and livestock waste disposal practices. Control of shoreline and streambank erosion, construction site erosion, and urban runoff would also help to reduce nonpoint source phosphorus input to lakes.

**In-Lake Management**

4. Due to the importance of internal loading from regeneration of lake sediment phosphorus, more effort should be given to development and implementation of in-lake management practices.

   Chemical control of algae and rooted plants through herbicide application is the most common in-lake tool used for dealing with eutrophication problems, but it represents a temporary measure which should not be relied on exclusively. Techniques to maintain aerobic conditions throughout the lake depth and, so, reduce sediment phosphorus release show promise. Aeration and mechanical destratification systems have proven effective in some instances but are limited in application by site conditions. Consolidation of sediments and removal of nutrient-laden sediments are two additonal methods used to reduce resuspension of sediments and their associated phosphorus. Nutrient inactivation by in-lake application of flocculation/precipitation materials similar to those used in treatment plants is another restoration method which has not been used extensively in Illinois, but has potential. Aquatic macrophyte harvesting and biological controls also show promise.

   More research is needed to develop a greater array of in-lake management practices for large, as well as, small lakes and reservoirs.

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# APPENDIX A

## Glossary of Lake and Watershed Management Terms

(Modified from USEPA Clean Lakes Program Guidance Manual 1980)

Aeration: A process in which water is treated with air or other gases, usually oxygen. In lake restoration, aeration is used to prevent anaerobic condition or to provide artificial destratification.

Algal bloom: A high concentration of a specific algal species in a water body, ususally caused by nutrient enrichment.

Artificial destratification: The process of inducing water currents in a lake to produce partial or total vertical circulation.

Background loading of concentration: The concentration of a chemical constituent arising from natural sources.

Benthos: Organisms living on or in the bottom of a body of water.

Best management pratices (BMP): Practices, either structural or non-structural, which are used to control nonpoint source pollution.

Biochemical oxygen demand (BOD), biological oxygen demand: The amount of oxygen used by aerobic organisms to decompose organic material. Provides an indirect measure of the concentration of biologically degradable material present in water or wastewater. Additionally, "5-day BOD" is the amount of oxygen required over a period of 5 days to oxidize the organic and inorganic ($NH_3$, $PO_4$, etc.) compounds present.

Biomass: The total mass of living organisms in a particular volume or area.

Biota: All living matter in a particular region.

Blue-green algae: The phylum Cyanophyta, characterized by the presence of blue pigment in addition to green chlorophyll, which usually have the ability to fix nitrogen.

Catch basin: A collection chamber usually built at the curb line of a street, designed to admit surface water to a sewer or subdrain and to retain matter that would block the sewer.

Catchment: Surface drainage area.

Chemical control: A method of controlling pest organisms through exposure to specific toxic chemicals.

Chlorophyll ("chlorophyll a"): Green pigment in plants and algae necessary for photosynthesis.

Circulation period: The interval of time during which a lake is not stratified, permitting the entire water body to mix.

Combined sewer: A sewer receiving both stormwater runoff and sewage.

Cover crop: A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of permanent vegetation.

Detention: Managing stormwater runoff or sewer flows through temporary holding and controlled release.

Dilution: A lake restorative measure aimed at reducing nutrient levels within a water body by the replacement of nutrient-rich waters with nutrient-poor waters.

Discharge: a volume of fluid passing a point per unit time, commonly expressed in units of cubic meters per second ($1\ m^3/S = 35.3\ ft^3/S = 22.8$ MGD).

Dissolved oxygen (DO): The quantity of oxygen present in water in a dissolved state, usually expressed as milligrams per liter of water, or as a percent of saturation at a specific temperature.

Dissolved solids (DS): The total amount of dissolved material, organic and inorganic, contained in water or wastes.

Diversion: A channel or berm constructed across or at the bottom of a slope for the purpose of intercepting surface runoff.

Drainage basin, watershed, drainage area: A geographical area where surface runoff from streams and other natural watercourses is carried by a single drainage system to a common outlet.

Enrichment: The addition to or accumulation of plant nutrients in water.

Epilimnion: The upper, circulating layer of a thermally stratified lake.

Erosion: The process by which the soils of the earth's crust are worn away and carried from one place to another by weathering, corrosion, solution, and transportation.

Euphotic or photic zone: The region in a lake with sufficient light to permit photosynthesis. Defined as extending from the surface to the depth at which 99% of the surface light has disappeared.

Eutrophic lake: A lake with an abundant supply of plant nutrients accounting for a high concentration of biomass.

Eutrophication: A natural enrichment process of a lake, which may be accelerated by man's acctivities. Usually manifested by one or more of the following characteristics: (a) excessive biomass accumulations of primary producers; (b) rapid organic and/or inorganic sedimentation and shallowing; or (c) seasonal and/or diurnal dissolved oxygen deficiencies.

Grassed waterway: A natural or constructed waterway covered with erosion-resistant grasses, used to conduct surface water from an area at a reduced flow rate.

Green algae: Algae characterized by the presence of photosynthetic pigments similar in color to those of the higher green plants.

Hydraulic residence time: The time (in years) it would take to replace all of the water in a lake. Calculated by taking lake volume/total annual discharge. Its reciprocal is flushing rate.

Hypereutrophic lake: A lake with extremely high level of nutrient enrichment caused by human activities. Nuisance algal blooms and aquatic macrophyte growths are common.

Hypolimnion: The lower layer of a thermally stratified lake which does not mix with the upper layer (epilimnion) while the lake is stratified.

Internal regeneration: The release and subsequent return of dissolved phosphorus or other nutrients from sediments to the euphotic zone of a lake.

Limiting nutrient: The substance that is limiting to biological growth due to its short supply with respect to other substances necessary for the growth of an organism.

Littoral: The region along the shore of a body of water. Often the area of major aquatic plant growth.

Macrophytes: Large vascular, aquatic plants which are either rooted or floating.

Mesotrophic lake: A trophic condition between an oligotrophic and an eutrophic water body.

Metalimnion: The middle layer of a thermally stratified lake in which temperature rapidly decreases with depth (also called the thermocline).

Nitrogen fixation: The biological process of removing elemental nitrogen from the atmosphere and incorporating it into organic compounds.

Nonpoint source: Nonpoint source pollutants are not traceable to a discrete origin, but generally result from land runoff, precipitation, drainage, or seepage.

Nutrient, available: That portion of an element or compound that can be rapidly absorbed and assimilated by growing plants.

Nutrient budget: An accounting for the nutrients entering a lake, leaving from the lake, and accumulating in the lake and its sediment (e.g., input minus output = accumulation).

Nutrient inactivation: The process of rendering nutrients inactive by one of three methods: (1) Changing the form of a nutrient to make it unavailable to plants, (2) removing the nutrient from the euphotic zone, or (3) preventing the release or recycling of potentially available nutrients within a lake.

Oligotrophic lake: A lake with a small supply of nutrients, and consequently a low concentration of biomass. Oligotrophic lakes are often characterized by a high level of species diversification.

Orthophosphate: See Phosphorus, available.

Outfall: The point where wastewater or drainage discharges from a sewer to a receiving body of water.

Overturn, turnovers: The complete mixing of a previously thermally stratified lake. This occurs in the spring and fall when water temperatures in the lake are uniform.

Periphyton: Microorganisms that are attached to or growing on submerged surfaces in a waterway.

Phosphorus, available: Phosphorus which is readily available for plant growth. Usually in the form of soluble orthophosphates.

Phosphorus, total (TP): All of the phosphorus present in a sample regardless of form. Usually measured by the persulfate digestion procedure.

Photic zone: See Euphotic zone.

Photosynthesis: The process occurring in green plants in which light energy is used to convert inorganic compounds to carbohydrates. In this process, carbon dioxide is consumed and oxygen is released.

Phytoplankton: Plant microorganisms, such as algae, living unattached in the water.

Plankton: Unattached aquatic microorganisms which drift passively through water.

Point source: A discreet pollutant discharge such as a pipe, ditch channel, or concentrated animal feed operation.

Population equivalent: An expression of the amount of a given waste load in terms of the size of human population that would contribute the same amount of biochemical oxygen demand (BOD) per day. A common base is 0.17 pounds (7.72 grams) of 5-day BOD per capita per day.

Primary production: The production of organic matter from light energy and inorganic materials, by autotrophic organisms (algae and macrophytes).

Rainfall intensity: The rate at which rain falls, usually expressed in centimeters per hour.

Secchi depth: A measure of optical water clarity as determined by lowering a weighted Secchi disk into a water body to the point where it is no longer visible.

Sediment basin: A structure designed to slow the velocity of runoff water and facilitate the settling and retention of sediment and debris.

Sediment delivery ratio: The fraction of soil eroded from upland sources that reaches a continuous stream channel or storage reservoir.

Soluble reactive phosphorus (SRP): Phosphorus in aqueous solution measured by means of its reactivity with a molybdate solution.

Sub-basin: A physical division of a larger basin, associated with one reach of the storm drainage system.

Substrate: The substance or base upon which an organism grows.

Suspended solids: Refers to the particulate matter in a sample, including the material that settles readily as well as the material that remains dispersed.

Terrace: An embankment or combination of an embankment and channel built across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.

Thermal stratification: The layering of water bodies due to a temperature-induced density differences.

Trace elements: Those elements which are needed in low concentrations for the growth of an organism.

Trophic status: A relative description of a lake's biological productivity. The range of trophic conditions is characterized by the terms oligotrophic for the least biologically productive, to eutrophic for the most biologically productive.

Turbidity: A measure of the cloudiness of a liquid. Turbidity provides an indirect measure of the suspended solids concentration in water.

Urban runoff: Surface runoff from an urban drainage area.

Water quality: A term used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose.

Water quality standards: State-enforced standards describing required physical and chemical properties of water according to designated uses.

Watershed: See drainage basin.

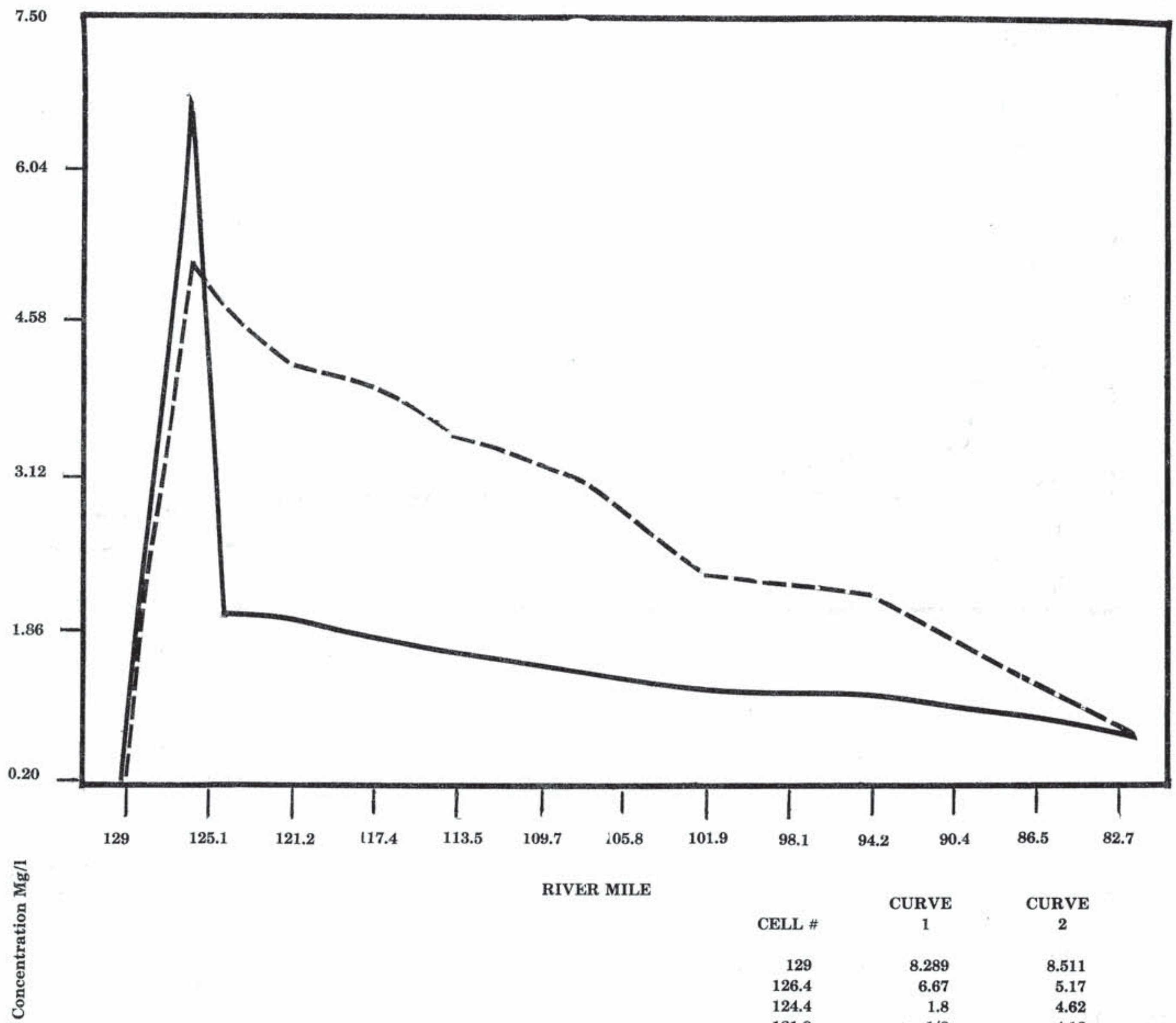
Zooplankton: Protozoa and other animal microorganisms living unattached in water.

# *APPENDIX B*

## Total Phosphorus Concentrations and Loading, Sangamon River Below Decatur

### Appendix Figure 1: Phosphorus Concentration, Sangamon River Below Decatur

### August and September Sampling



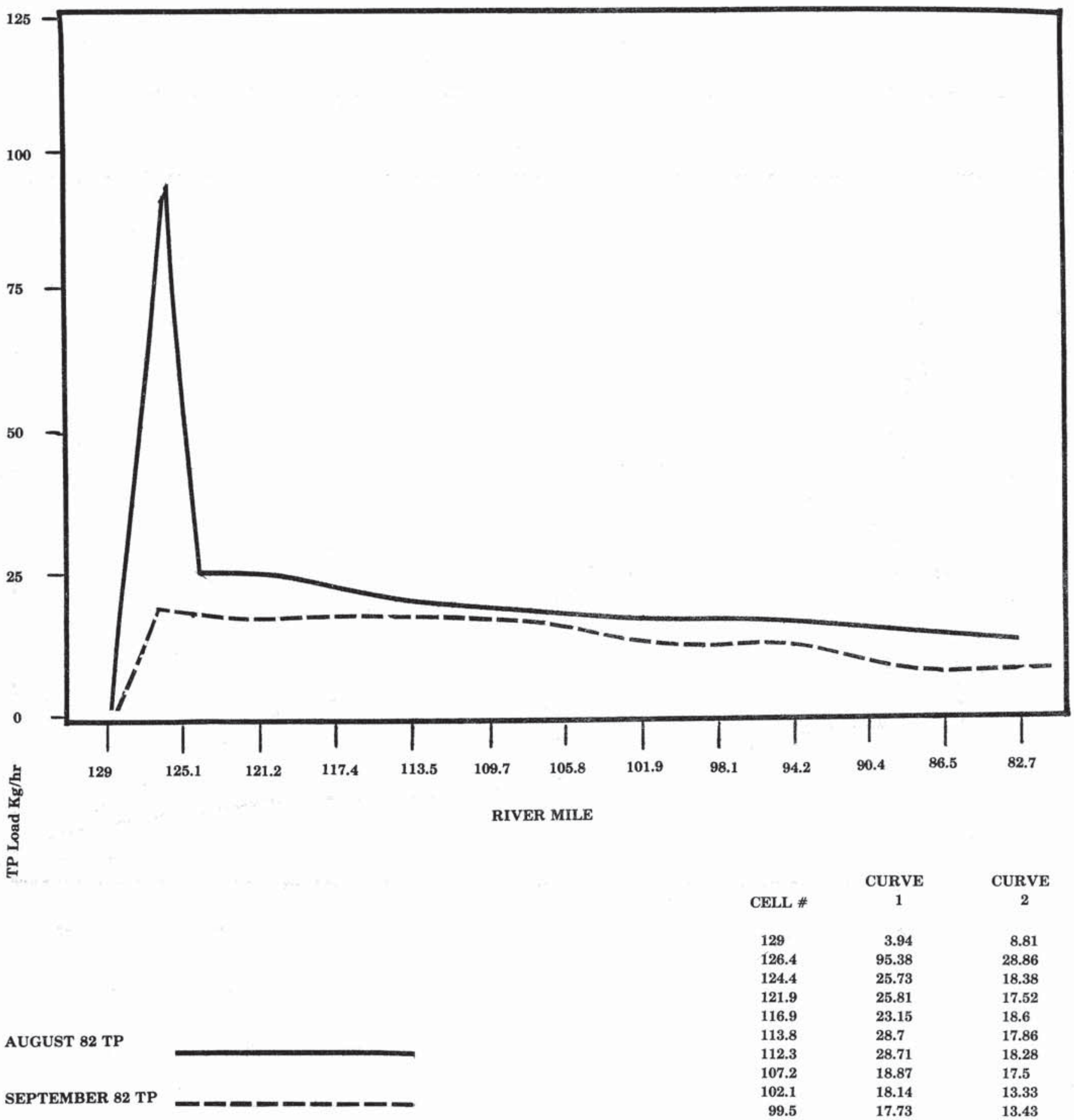

AUGUST 82 TP ————

SEPTEMBER 82 TP – – – – –

| CELL # | CURVE 1 | CURVE 2 |
|---|---|---|
| 129 | 8.289 | 8.511 |
| 126.4 | 6.67 | 5.17 |
| 124.4 | 1.8 | 4.62 |
| 121.9 | 1/8 | 4.18 |
| 116.9 | 1.6 | 3.88 |
| 113.8 | 1.43 | 3.46 |
| 112.3 | 1.43 | 3.42 |
| 107.2 | 1.26 | 3.82 |
| 182.1 | 1.13 | 2.2 |
| 99.5 | 1.89 | 2.11 |
| 94.9 | 1.87 | 2.86 |
| 96.2 | 9.92 | 1.32 |
| 82.7 | 9.71 | 8.82 |

**Appendix Figure 2: Phosphorus Loading, Sangamon River Below Decatur**

**August and September Sampling**




| CELL # | CURVE 1 | CURVE 2 |
|---|---|---|
| 129 | 3.94 | 8.81 |
| 126.4 | 95.38 | 28.86 |
| 124.4 | 25.73 | 18.38 |
| 121.9 | 25.81 | 17.52 |
| 116.9 | 23.15 | 18.6 |
| 113.8 | 28.7 | 17.86 |
| 112.3 | 28.71 | 18.28 |
| 107.2 | 18.87 | 17.5 |
| 102.1 | 18.14 | 13.33 |
| 99.5 | 17.73 | 13.43 |
| 94.9 | 17.44 | 13.87 |
| 96.2 | 15.77 | 9.16 |
| 82.7 | 17.83 | 9.37 |

# *APPENDIX C*

List of Abbreviations

ac: Acre

ACP: Agricultural Conservation Payment

ASCS: Agricultural Stabilization and Conservative Service

BMP: Best Management Practice

BOD: Biochemical Oxygen Demand

C: Carbon

Caput: Capita

$CO_2$: Carbon Dioxide

Creams: Chemicals, Runoff and Erosion from Agricultural Management Systems Model

CSO: Combined Sewer Overflow

DO: Dissolved Oxygen

DP: Dissolved Phosphorus

$Fe^{2+}$: Ferrous Iron

$Fe^{+3}$: Ferric Iron

g: Gram

H: Hydrogen

ha: Hectare

$H_2O$: Water Molecule

$HPO_4$: Monohydrogen Phosphate Ion

IDOA: Illinois Department of Agriculture

IEPA: Illinois Envirommental Protection Agency

IPCB: Illinois Pollution Control Board

ISWS: Illinois State Water Survey

kg: Kilogram

km: Kilometer

l: Liter

lbs: Pounds

m: Meter

mg: Milligram

MGD: Million Gallons per Day

N: Nitrogen

NES: National Eutrophication Survey

$NO_2$: Nitrite

$NO_3$: Nitrate

NPDES: National Pollutant Discharge Elimination System

NRI: National Resource Inventory

NURP: National Urban Runoff Program

$O_2$: Oxygen Molecule

O&M: Operation and Maintenance

OP: Orthophosphorus

P: Phosphorus

SCS: Soil Conservation Service

SRP: Soluble Reactive Phosphorus

SS: Suspended Solids

SWCD: Soil and Water Conservation District

t: Ton

"T": Tolerable Soil Loss Limit

TP: Total Phosphorus

USDA: United States Department of Agriculture

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

USLE: Universal Soil Loss Equation

WA:SA: Watershed Area to Surface Area Ratio

WLTP: Watershed Land Treatment Program

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

In the process of bringing municipalities into compliance with the present phosphorus regulations, questions have arisen regarding the efficacy of point source phosphorus reduction in view of the large contribution from nonpoint sources. This document represents a review of scientific literature and information from Illinois watersheds for the purpose of clarifying the influence of phosphorus on lake water quality and relative contribution of point and nonpoint sources.

17. Document Analysis a. Descriptors

| | |
|---|---|
| phosphorus | nutrients |
| sewage treatment | eutrophication |
| effluents | runoff |
| lakes | nonpoint sources |

b. Identifiers/Open-Ended Terms

Illinois lakes
Illinois
best management practices

c. COSATI Field/Group watershed management

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