Lakes and Phosphorus Inputs
A Focus on Management

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Contents

1 Highlights
   1 Introduction
2 Role of Phosphorus in Lake Ecosystems
3 Sources of Phosphorus
   Time of Measurement
   Dissolved versus Particulate Phosphorus
   Sources of Dissolved Phosphorus
      Sewage from treatment plants
      Unsewered households
      Agricultural activities
4 Alternatives and Costs of Control
   Ban of Phosphates in Detergents
   Sewage Treatment
      Wastes from unsewered households
   Agricultural Runoff
7 Lake Management
   A Reversible Process
   Lake Restoration
   A Note of Caution
11 The Human Factor in Nutrient Management
   Who Is in Charge of a Watershed?
12 Survey Results and Implications
   The Study
   Public Awareness
   Public Willingness
   The Gap between Attitude and Behavior
   Sources of Financial Support
   The “Yuk Effect”
   Failure to See “the Big Picture”
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Highlights

Dissolved phosphorus is the element that most influences the productivity of freshwater lakes and impoundments. Algae affect the quality and appearance of water. They affect the level of fish production. They also affect the costs of filtering water supplies for domestic and industrial use. Ultimately, the level of algae found in most temperate latitude lakes is dependent upon the amount of dissolved phosphorus discharged to the lake. The emphasis on dissolved rather than total phosphorus inputs to lakes represents an extremely important distinction, one to be kept in mind by anyone measuring phosphorus inputs, identifying sources, or making management and policy decisions about water quality.

In the watersheds studied the dissolved phosphorus came from sewage (55%), agricultural runoff (18%), forest runoff (15%), residential runoff (6%), and atmospheric fallout (6%). Studies of control measures showed that after a ban on phosphate detergents, lowest costs per unit of dissolved phosphorus prevented from entering lakes were associated with tertiary treatment of sewage. Next lowest costs were markedly higher and were for control of dissolved phosphorus from unsewered populations and from barnyard runoff.

Drawing on data that show that lakes vary widely in their natural state and that lake changes caused by inputs of soluble phosphorus are reversible, the scientists made extrapolations for 13 lakes in central New York State. These demonstrated the feasibility of using control policies flexibly and gradually. The policies included: (a) no action for lakes in which algae are not a problem, (b) a ban on phosphate detergents in areas where there are water quality problems, (c) tertiary treatment of sewage to remove phosphorus, and (d) control of agricultural and residential runoff. A fifth policy of removing all human activity from a watershed would be impractical on a large scale but might be necessary in certain rare instances.

Introduction

This is a brief account of research findings to help protect and improve the water you and I drink, swim in, fish in, and use in so many other ways.

Objective:
The objective of this publication is to help decision makers concerned with lakes assess management proposals.

By 1970, scientists, pollution control experts, health authorities, and informed laymen had all recognized that one cause of deteriorating water quality was the introduction of excessive quantities of nutrients, such as nitrogen and phosphorus, into streams and lakes. These nutrients acted to stimulate the production of algae. Because of accumulations of these minute plants, the water became more expensive to filter, unpleasant to swim in, and, in some cases, so short of oxygen that production of some game fish was inhibited. Also, excessive quantities of nitrates in water were a potential health hazard.

The Water Pollution Control Act of 1972 (PL92-500) focused additional attention on these
issues. This act required the development of information, including: "(1) guidelines for identifying and evaluating the nature and extent of non-point sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from . . . agricultural and silvicultural activities, including runoff from fields and crop and forest lands . . . ." The legislation forced a recognition of the need for procedures for identifying and evaluating "non-point" sources. It underlined the need for unambiguous data defining the contribution agriculture was making to the nitrogen and phosphorus content of water.

An interdisciplinary group of scientists at the New York State College of Agriculture and Life Sciences at Cornell University began an investigation of some of these problems in 1972 with financial support from the Rockefeller Foundation. Among the questions they addressed were how nutrients affected plant growth in lakes, how nutrients reached the lakes, sources of nutrients in the landscape, ways in which agricultural sources could be reduced, and the effects of controlling agricultural sources on food production and food costs. The Cornell team included aquatic biologists concerned with physical, chemical, and biological conditions in freshwater lakes and ponds; agricultural engineers with understandings of manure handling, waste disposal, fertilizer application, and drainage problems; agronomists experienced in movement of chemicals and water in various soil types; economists skilled in cost analysis and in measuring benefit-cost relationships, and sociologists with years of experience in sampling public attitudes, beliefs, concerns, and predispositions.

A major part of the research was a study of 13 lakes in central New York and an intensive study of the 80,000-acre Fall Creek watershed which is a tributary of Cayuga Lake.

The important generalizations resulting from these specific studies and other information in the scientific literature have been published in a 372-page book cited in the acknowledgement.

This bulletin summarizes the results with respect to phosphorus and some social and political aspects of pollution control.

Role of Phosphorus in Lake Ecosystems

A historical review of scientific literature concerned with lake eutrophication shows a rather dramatic focusing in recent years on phosphorus supply as the critical factor. Initially, this was in part due to the realization that of the nutrients essential for plant growth, carbon, nitrogen, and phosphorus, phosphorus was the only one that could feasibly be controlled in most cases. Increasing evidence has been accumulating that phosphorus is indeed the substance that limits the productivity in most temperate latitude lakes.

Arguments concerning the unique importance of phosphorus fall into three general categories. The first recognizes that, relative to the needs of aquatic plants for substances to support their growth, phosphorus is the element of greatest geochemical rarity. This factor is enhanced
in the aquatic environment by the insolubility of many phosphorus compounds and the tendency of phosphates to be adsorbed to soil particles and hence to settle to the bottom of lakes where they become unavailable to algae. The second category addresses the questions of sources of nitrogen and carbon available to algae. Some (the blue-greens) can use N\textsubscript{2} directly and hence are able to draw on the almost limitless reserves of this gas in the biosphere. Many algae can use the bicarbonate ion as a source of carbon. This, together with the high solubility of CO\textsubscript{2} in water, suggests that carbon is never likely to be more than temporarily limiting to the growth of algal communities. Finally, as shown in the present study and its later extension to lakes in temperate regions in other areas of the world, algae are present during the summer at concentrations closely proportional to the annual inputs of dissolved phosphorus per volume of water in the upper layers of lakes. This relation holds true even for most of those lakes characterized by persistently low nitrate concentrations which might tend to limit algal production.

Recognition that the amount of phosphorus introduced into a lake acts as the primary factor in controlling algae growth raises numerous questions: How does this nutrient function? How does it come into lake water? What are the various sources of phosphorus? Are there alternatives for removing it from water or keeping it from entering a lake? What are the techniques and the costs involved?

The research summarized here offers reasonably clear answers for many of these questions and has suggestions about others. However, the measurements involved and their interpretation are complex. The following sections highlight the principal findings that can have meaning in public discussions and decision making.

**Sources of Phosphorus**

**Time of Measurement**

Efforts to measure phosphorus in streams led to the discovery that samples taken at some predetermined interval or frequency (e.g., once per week) are not likely to provide accurate estimates of the amounts carried by a stream over a period of time. It is essential that measurements include the periods of high run-off during and immediately after rains or snow melt. These high runoff intervals contain most of the water leaving the watershed, including most of the surface run-off, since the latter occurs almost exclusively during periods of rain or snow melt. In addition, the concentration of dissolved phosphorus changes greatly with rate of flow.

**Observation:**

Most of the dissolved phosphorus carried by streams is transported during or immediately after rainstorms or snow melt.

**Implication:**

Measurements of dissolved phosphorus must be made during periods of high stream discharge if the contributions of dissolved phosphorus from watersheds are to be estimated correctly.

**Dissolved versus Particulate Phosphorus**

Phosphorus in runoff occurs in three general forms: dissolved organic, dissolved inorganic, and particulate (most of which is attached to soil particles). With which, then, should researchers and water quality managers be concerned? With total phosphorus or with only one or two of
the chemical forms? This study, along with information already in the scientific literature, led to the important conclusion that “dissolved” phosphorus (organic and inorganic) has a far more important influence on algal growth than has the phosphorus attached to soil particles. Dissolved phosphorus controls the quantities of algae occurring in most temperate latitude lakes during the summer months. The study of 13 New York lakes led to quantitative expressions of the relations between phosphorus loading and concentration of algae. Furthermore, the yield of fish from lakes has been shown to be a function of the crop of algae and so is indirectly dependent on dissolved phosphorus loading. This research project has emphasized the sources and transport of dissolved phosphorus because this phosphorus is of biological importance to receiving lakes.

**Observation:**
The levels of algae in a lake are determined by the dissolved phosphorus present in the water entering the lake rather than on other forms of the chemical, such as the particulate phosphorus attached to soil particles.

**Implication:**
Studies and management practices should concentrate on dissolved phosphorus.

**Sources of Dissolved Phosphorus**
What are the sources of the dissolved phosphorus reaching a lake? The dissolved phosphorus reaching the 13 lakes studied in central New York was calculated to be from the following six major sources:

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage</td>
<td>55%</td>
</tr>
<tr>
<td>Agricultural runoff</td>
<td>18%</td>
</tr>
<tr>
<td>Forest runoff</td>
<td>15%</td>
</tr>
<tr>
<td>Residential runoff</td>
<td>6%</td>
</tr>
<tr>
<td>Atmospheric fallout</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

These relative contributions contrast sharply with land use in the area; 50% of the land was in forest, 48% in agriculture, and only 2% in residential use. The residential area included scattered houses as well as the concentrations in communities of various sizes. If one adds the dissolved phosphorus from sewage to that from agricultural and residential runoff, human activity accounts for nearly 80% of the dissolved phosphorus reaching the lakes in these watersheds.

**Observation:**
Dissolved phosphorus in the 13 lakes studied was from sewage (55%), agricultural runoff (18%), forest runoff (15%), residential runoff (6%), and atmospheric fallout (6%).

**Implication:**
Human activities are responsible for 75 to 80% of the dissolved phosphorus reaching the lakes in central New York.

**Sewage from treatment plants.**
As indicated, sewage is one of the principal sources of the dissolved phosphorus that finds its way into our freshwater systems. The sewage may be discharged from municipal treatment plants, or it may leak from the disposal systems of unsewered households. In either case, the phosphorus content of domestic sewage ranges from 1 to 2 kilograms per capita per year depending primarily on whether laundry detergents containing phosphates are being used by householders. More information about detergents and effects of a ban on use of phosphatic detergents will be included in a later section of this report.
Aside from the size of a treatment plant, the amount of dissolved phosphorus that a particular installation contributes to a lake depends upon the level of treatment (primary, secondary, or tertiary) the plant provides. Most sewage treatment plants in New York State are designed for primary or secondary treatment. Secondary treatment removes approximately 20% of the phosphorus in the influent. With tertiary treatment for phosphorus removal, 75 to 90% of the influent phosphorus is taken out. **Unsewered households.** Estimates of phosphorus contributed to lakes by unsewered households vary from 50% of that contained in domestic sewage to as low as 10%. The higher figures represent inputs from unsewered households in populated areas. These tend to be concentrated near streams and lakes and may have less area for disposal fields. The lower figures represent inputs from dispersed housing units in rural areas. These are more likely to be located farther from streams or lakes. Regardless of which estimate is chosen, on a per capita basis, septic tank disposal fields appear to "leak" less phosphorus to lakes than most municipal sewage collection and disposal systems. Even when home disposal systems are not well designed and maintained, they may put relatively less phosphorus in the streams and lakes than municipal treatment plants with only secondary treatment. Much of the phosphorus from septic systems becomes adsorbed to soil particles whereas that from secondary plants is deposited in lakes or streams. **Agricultural activities.** Farming operations use large amounts of phosphorus. For example, farmers in the United States annually apply about 2 million tons of phosphorus as fertilizer, which is roughly 5 times the amount in household detergents. Farm animals excrete manure containing 2.5 million tons of phosphorus each year. Such data justify a searching study to discover what happens to this phosphorus. The effects of farming operations in central New York on dissolved phosphorus in streams were determined by a comparison of the dissolved phosphorus in streams draining farmland with that in streams draining forested land. The average concentration of dissolved phosphorus from farmed land was about double that from forested land. As stated earlier, about 18% of the soluble phosphorus reaching the lakes in central New York was from farmed land.

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**Alternatives and Costs of Control**

After identifying the principal sources of dissolved phosphorus in streams, the researchers turned their attention to alternatives for controlling the quantities reaching lakes. They also studied the costs that might be involved in implementing some of the alternatives.

**Ban of Phosphates in Detergents**

In recent years, biologists and others have pointed out that household laundry detergents containing phosphates are an important contributor to the phosphorus content of sewage. New York State, in June 1973, imposed a ban on the use of such detergents. A similar ban was imposed earlier in Erie County, New York. A study of three large sewage plants near Buffalo in that county indicated a reduction of 50 to 60% in effluent phosphorus (most of which was dissolved) as a result of the ban. If a similar reduction occurred at other New York sewage plants, the ban would result in about a 30 percent reduction in the total amount of dissolved phosphorus entering.
the 13 central New York lakes from all sources.

Observation:
Laundry detergents have contributed heavily to phosphorus input in the watersheds studied. The 1973 New York ban on such detergents appears to have brought a marked reduction in phosphorus loading to water.

Implication:
Bans on phosphate detergents may be an efficient way to reduce dissolved phosphorus supplied to lakes.

The research did not attempt to assess the costs associated with the ban on phosphate detergents. Consumers may have “paid” something in terms of loss of convenience and reduced whiteness in the family wash, but the effectiveness of the ban in reducing phosphorus inputs to streams and lakes suggests that it was a good policy.

Sewage Treatment
An analysis of other alternatives for reducing the dissolved phosphorus finding its way into lakes revealed that the lowest costs for removing dissolved phosphorus are associated with the largest source—sewage. This is illustrated for the Fall Creek watershed in table 1. The source of dissolved phosphorus least costly to control is that from the sewage treatment plant, followed by that from barnyard runoff. The other sources are much more expensive to reduce. In addition to cost considerations, a greater reduction in dissolved phosphorus input could be made from the sewage treatment plant source than from any other listed in table 1, except possibly for barnyard runoff. This conclusion is based on data for the period after the New York ban on phosphate laundry detergents.

Tertiary treatment to remove phosphorus from the Dryden sewage treatment plant effluent would cost $9,600 annually and would remove about 18% of all dissolved phosphorus transported by the creek to the lake. Because this is a relatively small plant, the cost would be about $12 per kilogram of phosphorus removed. Larger plants, such as some of those discharging directly to lakes, can operate at costs as low as $5 per kilogram removed.

Observation:
In this study, tertiary treatment of sewage for phosphorus removal was the most economical step in controlling dissolved phosphorus inputs to lakes—after phosphate detergents had been banned.

Implication:
Tertiary treatment of sewage plant effluent should be the second step in phosphorus control in many watersheds.

Data collected from the watersheds of 13 lakes in central New York suggest that the Fall Creek situation (table 1) can be extrapolated, to some extent, to other watersheds. As in Fall Creek, many lake watersheds include a city or village that discharges sewage effluent into a stream. Others, of course, may discharge directly to a lake. In fact, sewage represents a greater part of the total problem in the 13 lakes as a group than it does in the Fall Creek watershed.

Wastes from unserved households. Removal of phosphorus from wastewater by the collection and treatment of wastes from the currently unserved population would be quite expensive. Costs were estimated to be between $15 and $50 per kilogram of phosphorus removed. Not all of the costs of such a system should be charged to phosphorus removal, for there are also public health benefits. The estimated cost of removing half of the soluble phosphorus reaching the lakes from unserved populations would be higher than that for the removal of phosphorus from the discharges of existing sewage treatment plants. Recall that only a fraction of the soluble phosphorus in the wastes from unserved systems is presently entering the lakes. Collection and treatment of such wastes will not

<table>
<thead>
<tr>
<th>Method of phosphorus reduction</th>
<th>Reduction in dissolved phosphorus loading</th>
<th>Annual cost to watershed</th>
<th>Cost per kg of reduction in dissolved phosphorus loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in corn acreage</td>
<td>680</td>
<td>278,000</td>
<td>409</td>
</tr>
<tr>
<td>Avoidance of winter spreading of manure</td>
<td>385</td>
<td>398,000</td>
<td>1,034</td>
</tr>
<tr>
<td>Liquid storage</td>
<td>385</td>
<td>221,000</td>
<td>574</td>
</tr>
<tr>
<td>Stacking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control of barnyard runoff</td>
<td>300 to 1,500</td>
<td>45,000</td>
<td>30 to 150</td>
</tr>
<tr>
<td>Tertiary treatment of Dryden sewage</td>
<td>800</td>
<td>9,600</td>
<td>12</td>
</tr>
</tbody>
</table>

reduce phosphorus inputs as much on a per-capita or per-dollar basis as removing phosphorus from existing sewage treatment plants.

**Agricultural Runoff**

A substantial reduction of the soluble phosphorus input from agriculture could be achieved by controlling barnyard runoff but at a cost of $30 to $150 per kilogram of phosphorus removed. Reduction also could be achieved by modification of manure handling practices but at much greater costs.

**Observation:**

Costs for removing phosphorus inputs from unsewered and agricultural runoff were higher — ranging from $15 to $150 or more per kilogram of phosphorus removed — than for detergent bans or tertiary treatment.

**Implication:**

Management practices for reduction of phosphorus from unsewered wastes or barnyard runoff may necessitate installation of sewage treatment facilities in thinly populated areas or retention ponds for barnyard runoff. The costs are relatively high.

No attempt was made to estimate the cost of reducing the phosphorus inputs from human activities to zero. So far as is known, there is no practical means of doing this. Removal of all human activity seems the only way to achieve such a reduction. This would be both drastic and impractical in all but a few unusual cases.

**Lake Management**

**A Reversible Process**

Nutrient enrichment of lakes due to human activities is a process that accelerates the production and accumulation of algae in lakes. Despite statements in the news media and by some scientists suggesting that this process may be irreversible, considerable evidence gathered in recent years shows that if nutrient loadings to lakes are reduced, the lakes can, in large measure, be restored to their former conditions.

For example, a 14-year study of Lake Washington in Seattle, Washington, suggests two conclusions: (1) summer chlorophyll (a measurement of algal concentration) in a lake will increase if the phosphorus content of the water is increased, and (2) a reduction in the phosphorus content of the water (in this case as indicated by phosphorus measured during the winter) will be followed quickly by a reduction of chlorophyll in the water. Between 1957 and 1963, inputs of phosphorus to this lake from domestic sewage were high and increasing. Starting 1963, sewage was diverted, and in February 1968, it ceased to enter the lake. Figure 5 shows the buildup of chlorophyll in summer as phosphorus content of the water increased from 1957 to 1963. After a peak in 1964, chlorophyll concentration dropped off as phosphorus inputs decreased. The final measurement in 1971 shows less chlorophyll than was present at the beginning of the study in 1957.

**Observation:**

Phosphorus enrichment of lakes appears to be a reversible process. Effects of a particular source of phosphorus can be reversed when the source is removed.

**Implication:**

A delay in the introduction of control measures is not likely to cause irreversible changes in lakes. Reversibility suggests an evolutionary policy for phosphorus control in which controls are instituted on a source-by-source basis.

![Figure 5. This graph shows the changes in phosphorus (measured during the winter when biological activity was minimal) and changes in chlorophyll concentration (averaged for the upper 10 meters of the water column) corresponding to changing inputs of sewage to Lake Washington. Data were taken from studies by Prof. W. T. Edmondson, a scientist at the University of Washington.](image-url)
Lake Restoration

Five specific policies that might affect the dissolved phosphorus input and the resulting clarity of water in lakes were examined. They are:

I. No control. Return to pre-1973 conditions by removing the ban on phosphorus in laundry detergents.

II. Maintain the ban on phosphorus in laundry detergents. This would be a continuation of present policy.

III. Remove 80% of the phosphorus from the effluent of sewage treatment plants. If this treatment were universally applied, the ban on phosphorus in laundry detergents could be eased.

IV. Establish community collection and treatment systems (including phosphorus removal) in unsewered areas, and control barnyard runoff.

V. Control all sources of phosphorus associated with human activity in the watershed.

Table 2. Alternatives, policies, and costs for controlling dissolved phosphorus inputs to lakes

<table>
<thead>
<tr>
<th>Policy</th>
<th>Costs per kilogram of phosphorus controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. No ban on phosphate detergents</td>
<td>No cost to municipalities or agriculture</td>
</tr>
<tr>
<td>II. Ban on phosphate detergents</td>
<td>(cost to consumers was not estimated)</td>
</tr>
<tr>
<td>III. Tertiary sewage treatment</td>
<td>$5 to $12/kg</td>
</tr>
<tr>
<td>IV. (a) Collection and treatment of unsewered waste</td>
<td>$15 to $50/kg or more</td>
</tr>
<tr>
<td>(b) Limit barnyard runoff</td>
<td>$30 to $150/kg</td>
</tr>
<tr>
<td>V. Removal of all human activity</td>
<td>Impractical in most situations</td>
</tr>
</tbody>
</table>

The costs of implementing such policies were described in previous sections and are summarized in Table 2. The sequence of policies is such that after the first policy of no control, the least expensive source is controlled first, followed successively by the next least expensive method.

Observation:
Dissolved phosphorus input to a lake can be reduced by a series of incremental policies.

Implication:
Since costs vary among policies, decision makers should examine alternatives carefully before taking action.

The effect of each of the five policies on clarity of the water in three New York lakes was estimated by using a three-step pro-
procedure. First, the input of dissolved phosphorus to each lake was calculated for each policy on the basis of coefficients for sewered and unsewered populations, agricultural land, and land in the absence of human activity. Second, the chlorophyll concentration in the lake water (a measure of the concentration of algae), as related to dissolved phosphorus input, was estimated for each policy by an equation developed from a study of 13 central New York lakes. Finally, the Secchi disc transparency (a measure of water clarity), as related to chlorophyll concentration, was estimated for each policy by another equation developed from data on 13 New York lakes and Lake Washington. This relationship and the approximate situation for each of the 13 lakes prior to the ban on phosphatic household laundry detergents are shown in figure 7. The expected results of incrementally applying the five policies to the three lakes are shown in figure 8.

For example, with policy II, ban on phosphatic laundry detergents, the Secchi disc transparencies in the three lakes would be approximately:

<table>
<thead>
<tr>
<th>Lake</th>
<th>Secchi disc transparency, meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadarago</td>
<td>1.5</td>
</tr>
<tr>
<td>Cayuga</td>
<td>2.6</td>
</tr>
<tr>
<td>Skaneateles</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Figure 9 suggests that a set of policies producing desired results for one lake may be insufficient for another or represent unnecessary costs for a third. For ex-

2. Measuring the clarity of lake water as Secchi disk transparency involves lowering a reflective target (Secchi disc) into the water on a calibrated line. A reading is taken just as the disc disappears from view because of the turbidity in the water. Low readings indicate large quantities of algae as long as readings are taken when the water is not turbid from suspended particles of sediment. Higher readings indicate clear water with less algae.

![Figure 8](image1.png)

**Figure 8.** Responses of the three lakes to the five management policies, showing the expected increases in the clarity of the lake waters.

![Figure 9](image2.png)

**Figure 9.** Comparison of (1) a policy of attempting to achieve the same water quality in all lakes vs. (2) a policy of requiring the same regulations in all lake watersheds.
ample, the application of all five policies (including the removal of all inputs caused by human activity) in the Canadarago Lake Basin would improve water clarity to a point less than the clarity found in Skaneateles before policies were applied. This difference is due, primarily, to the size of the watersheds relative to lake volume. Skaneateles has a small watershed relative to lake size and greater depth. Consequently, it gathers fewer nutrients in relation to volume, and algae are less dense.

In the judgment of the researchers, this discussion represents the most reasonable interpretation of what is known about the relationships between phosphorus inputs from human activities and chlorophyll in the lakes in central New York. Any major improvements in reliability of the relations will result only from the collection of more data. Refinements of the methods of analysis of data now available might improve the relationships somewhat, but such refinements are not likely to make a major change in the general conclusions. What, then, is a reasonable course of action?

First, substantial evidence now in the literature indicates that over a period of years, the phosphorus available to algae is not conserved; that is, high levels of algal growth appear to depend upon continuing inputs of dissolved phosphorus. The effects of a particular source of phosphorus appear to be reversible whenever a control measure is implemented. Therefore, delay in introducing controls will probably not cause irreversible changes in the lakes.

The reversibility of changes suggests an evolutionary policy in which controls are gradually instituted on a source basis. Information obtained about selected study lakes could be applied to others.

The first step of the evolutionary process is now in progress. The New York ban on phosphorus in detergents was instituted in 1973. Tertiary treatment for phosphorus removal is being installed in several sewage plants that discharge effluent to lakes. As the detergent ban and the removal of phosphorus from sewage take effect, it is essential that corresponding changes in the lakes be adequately monitored and assessed. The knowledge gained could be applied in the formulation of further management policy not only for the lakes directly affected, but also for similar lakes elsewhere.

If policies were based on such systematic use and transfer of information between lakes, a framework would be established to assess the costs of reducing nutrient inputs to lakes. For example, figure 7 shows the relation between Secchi disc transparency and chlorophyll in the lakes of central New York in the period prior to the ban on phosphatic household detergents. With this relation, the costs could be stated in the terms that it would probably cost $X dollars to transform conditions in lake Y to those existing in lake Z. This would provide a graphical basis for evaluating the effects of management policies proposed for the lakes. With appropriate data, further relations between the levels of phosphorus input to lakes and their use, such as for fish production and water supply, could be derived and used in an analogous manner.

Should the goal of management policy be to achieve uniform water quality in all lakes or to apply equal restrictions in the watersheds of all lakes? Uniform water quality (e.g., Secchi disc transparency of 5 meters) in the three lakes would require policy V in Canadarago Lake, policy IV in Cayuga Lake, but only policy I (no restrictions) in Skaneateles Lake (fig. 9). On the other hand, if the same policy, say II, was applied in all watersheds, transparency would be high (6 meters) in Skaneateles, medium (2.5 meters) in Cayuga, but less than 2 meters in Canadarago Lake. Perhaps neither uniform quality nor uniform restrictions should be the goal of lake management policy. It is probably not possible to achieve the same quality in the three lakes with any set of management policies. On the other hand, uniform application to all lakes of a policy needed for Canadarago may be a waste of resources.

No attempt has been made to estimate the benefits of reductions in phosphorus inputs to lakes. Such estimation is compli-
cated; reduced phosphorus inputs will make lakes more valuable for some purposes such as swimming and water skiing, but the same reductions may make these lakes less valuable for fishing, as would be the case for most, if not all, of the Finger Lakes. For a given lake, the cost of instituting a particular policy can be estimated and compared with the likely change in chlorophyll and transparency. Policy makers can then make a judgment of whether they think the benefits justify the cost. For example, the cost of moving from policy II to policy III on Canadarago Lake would be about $10,000 per year, based on a severed population of 1,500 people. For Cayuga Lake with 50,000 severed population in the watershed, the cost for the same policy would be about $280,000 per year. In these examples, one must keep in mind that the surface area of Cayuga Lake is more than 10 times, and the volume more than 100 times, that of Canadarago Lake. In either case, although no good estimate of the dollar value of benefits is available, policy makers would at least have some basis for comparing costs with likely changes in algal production in the lake.

A Note of Caution

The lake restoration discussion centers on the supposition that minimizing the concentration of algae in a lake is universally desirable. However, fish production is ultimately dependent upon algal production in all but a few special cases. Quantitative relations defining this have now been developed for a wide variety of lakes located throughout temperate regions of the Northern Hemisphere. Translated in terms of this report, such findings mean that fish yields to anglers and commercial fishermen are greater at higher rates of dissolved phosphorus supply as long as plant growth is not so great as to deplete oxygen. As a management consideration, the question of the kinds, as well as the total amounts, of fish produced must be addressed. Nevertheless, the relations of fish to phosphorus supply and algal concentration provide a cautionary “look-before-you-leap” note to those who would institute wholesale programs of phosphorus control.

Implications:

Policies for phosphorus removal can be applied selectively to reduce total costs.

Identical policies applied to different lakes will not produce water of similar quality.

Appropriate water quality can be achieved at lowest cost by selective use of policies.

The Human Factor in Nutrient Management

The presence of the human population was identified as a major source of nutrient input to the streams and lakes of watersheds. More specifically, the introduction of nutrients into streams and lakes is often the result of the disposal of solid waste, sewage, kitchen and laundry detergent, barnyard waste, and other agricultural runoff.

Analyzing a stream or lake watershed from a social and ecological perspective reveals that a stream like Fall Creek traverses social, economic, and political boundaries which are just as real as the physical and geographical terrains. These invisible man-made boundaries have important implications for nutrient management. One clear implication is the complex nature of the administrative problems created by these various boundaries. Questions arise as to where responsibilities rest for nutrient disposal problems of individual homes, barnyards, or farm land on the one hand and for villages, townships, or municipalities on the other.

Who Is in Charge of a Watershed?

A populated watershed constitutes both an ecological and sociological unit, but seldom is there a recognized administrative authority to govern. The Fall Creek watershed, though modest in size, traverses sections of three counties. Within these three counties the watershed cuts across eight townships and six villages. Each of the three county health departments legislates and supervises its own separate standards for installation and use of septic tanks. Likewise, three separate county planning offices proceed with independent policies. In addition, there are three county boards of legislators and multiple village councils and township governments. Furthermore, several organizations with peripheral interests, such as county environmental councils, the Cayuga Basin Board, the New York State Department of Environmental Conservation, and the Soil Conservation Service, all legitimately claim some responsibility for the planning and control of land and water use within the watershed.

Such a situation suggests that many features of social and environmental systems are not meaningfully organized. Additional evidence for this hypothesis was provided by residents of the watershed who, when interviewed in a formal study, indicated they were at a loss to know to whom to turn for violations or remedial action in safeguarding the streams and lakes.
Survey Results And Implications

The Study

A sociological investigation was made by interviewing one out of every six household heads in the Fall Creek watershed. Similar samples were studied in the Owasco and Canadarago watersheds for the purpose of comparing and verifying the findings. The major purpose of the investigation was to determine the levels of awareness and concern of residents of the watersheds held about the streams and lakes and their propensity to act or support action to safeguard those resources.

Public Awareness

It was clear from the survey that the public was sensitive to environmental issues. Half the respondents in the watersheds considered water quality to be a serious problem. One-third of all respondents believed that water quality was deteriorating, and 98% felt that the quality of the environment should be improved. Interestingly, 80% of the people interviewed in the Owasco and Canadarago lake watersheds were optimistic that improvements could be made, whereas less than 50% of the Fall Creek respondents shared this optimism.

Public Willingness

The best indicator of a cumulative impact of environmental awareness that had been built up was the expression from three-fourths of the residents that all available pollution control techniques should be applied despite the cost. This response is even more surprising when it is realized that one-third of the people believed the costs of pollution control to be high. Two-thirds of the respondents stated they would pay an average of 8.5¢ more per half gallon of milk or per dozen eggs if it would permit farmers to produce these products without polluting the environment.

The Gap between Attitude and Behavior

A note of caution needs to be sounded, however, in terms of what respondents said they would do and what they actually may do. Two examples will serve to illustrate this point. First, when residents were asked their reactions about a neighbor’s septic tank being defective or overflowing into the stream, strong feelings were expressed that immediate remedial action should be required at the owner’s expense. When the same residents were subsequently asked whether their own septic systems had ever been inspected, nearly all indicated no inspection had been performed since the original installation, even though in some cases 20 or 30 years had elapsed. In the second example, at a time when there was a lot of publicity about the beneficial effects to the environment of using low-phosphate detergents, homemakers were asked whether or not they were using low-phosphate detergents. Forty-three percent said they were, but a subsequent check on the available brands in the kitchen and laundry revealed that only 21% were actually using low-phosphate products. Another 27% reported they weren’t sure but thought they were using low-phosphates whereas the brand checks showed they were using high-phosphate detergents.

This apparent dissonance between stated attitude and the actual behavior is explained by social psychologists as residing in the realm of perception. In other words, the respondent does not relate the general case to her or his specific situation. The respondents tend to respond that “pollution” is undesirable (the general case) without relating that perception to whether or not the detergent brand on hand (the specific case) is in opposition to the stated belief. Socially acceptable or normative attitudes are usually expressed in terms of what respondents feel or think is the expected or appropriate response. Only when confronted with the behavior–attitude dichotomy do respondents tend to perceive or redefine the real behavior as internally inconsistent with the stated intent.

The gap between stated belief and actual behavior may be great or small. Whether it is great or small has important implications for trying to forecast future behavior. In general, there are a number of factors that, when present, usually indicate there will be little difference between stated belief and actual behavior. The greater the background of individuals on an issue, the higher their education, the greater their motivation, the more they understand the technical, economic, social, and political feasibility of alternatives, then the more likely it is that these factors will undergird and support their grasp of the full spectrum of the issue and that their actual behavior will tend to conform to their stated attitude.

Sources of Financial Support

The watershed residents believed certain groups should receive more financial assistance than others in their efforts to combat water pollution. One-third supported aid for businesses, one-half thought households should receive aid, and two-thirds supported help for farmers. However, there was no consensus on the source of these funds. Increases in income taxes, property taxes, and food prices; reordering of governmental bud-
get priorities; and special water-use taxes all received about equal support. It was evident that people supported the notion of fair distribution of costs as well as clear delineation of expenditures. The findings related to public interest and concern about water quality, and expressed willingness to pay to protect or improve it were in keeping with national opinion surveys completed in the early 1970s by Erskine and published in the Public Opinion Quarterly.

The "Yuk Effect"

Interestingly the viewpoint of the respondents in the three watersheds was found to be in agreement on another point: sewage disposal was viewed as a more important pollution control problem than farm runoff of fertilizers or insecticides. Related to the concern about sewage disposal and its effect on water quality was a discovery of what the investigators came to identify as the "yuk effect." This was the expression people would utter at the notion of drinking other people's sewage effluent. The interesting thing about this reaction was that from any given individual's perspective there was more concern about the impact of sewage disposal upstream than downstream.

Failure to See "The Big Picture"

The study suggested that few people yet comprehend the existence and functioning of the larger ecosystem of which they are a part. They fail to recognize that, insidiously, their "little bit" of wastewater joins other waste disposal to cause the pollution they know instinctively must be avoided. They accept and verbalize the concept that people must learn to live in harmony with nature. But they have not fully grasped the conceptual implication that neighbor must live in harmony with neighbor, community with community, and larger political entities must learn to work with one another to ensure that people are not drinking others' untreated sewage and that watersheds are not being despoiled.

Observations:

The study of the residents in three rural watersheds revealed that:

The social, political, and administrative boundaries do not correspond with the physical and geographic boundaries of the watersheds.

People are aware of, and concerned about, water pollution.

They feel that water quality improvement and protection cannot be left to individual action and that government action is required.

They prefer government action to be subject to local control.

They believe costs of maintaining or improving water quality will be high but expressed willingness to help pay the bill.

Individual actions are not perceived as having any significant effect on the overall status of a watershed. The feeling expressed is that all residents must act in concert to assure desired results.

Contrariwise, there is evidence of a kind of wilderness psychology in which people seem to feel that their small contribution to water pollution won't hurt anyone. They are more concerned, however, about drinking someone else's sewage than they are about where their own sewage is going.

Despite a feeling that water quality is declining and that action is important, there appears to be a lack of comprehension that the total ecosystem must be in balance. There may be a growing understanding that people's activities must be brought into harmony with nature, but it is offset by a protective sense of individual rights and a feeling of futility over what one can do by oneself.

Some Implications:

The administration of uniform regulations and controls for residents of watersheds is more likely to produce desired results toward safeguarding water quality than dependence upon uncoordinated individual action.

An administrative unit fitted to the watershed boundaries will be better able to address the needs of the watershed; however, its source of economic, political, and social powers will have to be carefully spelled out.

Respondents are willing to participate in environmental management. They are willing to pay more to safeguard water quality. What is lacking is the necessary coordinated governmental effort to capitalize on the willingness of the watershed residents to follow necessary environmental controls and guidelines.

Watershed administrative units that face long delays in undertaking needed action to safeguard water quality in streams or lakes will tend to leave the local residents in an uneasy state of uncertainty. Environmental educational-motivational programs with little or no structured or prescriptive action tend to produce a kind of burned-over territory wherein it is more difficult to ignite sparks of interest the next time around.

With the updated guidelines of the Federal Water Pollution Control Act contained in the 1972 Public Law 92-500, it will be interesting to observe whether the desired ends of clean waters can be achieved. The provisions of section 208 which address the nonurban, undesignated areas, such as the rural watersheds included in this study, will not come under the proposed comprehensive planning process until the late 1970s. Public interest and participation, if properly mobilized along viable administrative options, can make significant contributions.