EVALUATION OF A WATER QUALITY STANDARD FOR TOTAL PHOSPHORUS IN FLOWING STREAMS IN SOUTHEASTERN WISCONSIN

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INTRODUCTION

To support beneficial water uses, the quality of water must be within a certain range of conditions. The range can be described in terms of the physical, biological, and chemical characteristics of the water. Water quality standards serve to define this range of conditions. Without such standards there would be no way to measure the existing, and no way to predict the probable future, suitability of a given water resource for a particular water use. Moreover, technically sound water resource planning requires that measurable standards be utilized as a basis for the comparison of alternative plan proposals, and for determining the extent to which such proposals meet established water use objectives.

In 1966 SEWRPC published Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin. At that time, the Commission recommended a set of water quality standards to support the numerous categories of water use objectives then recommended for various stream reaches in the Region. Subsequently, the U. S. Public Health Service, operating through the Wisconsin Department of Resource Development, adopted water quality standards for the interstate waters—and later for the intrastate waters—of Wisconsin. These actions provided the basis for the administration of water quality management programs in Wisconsin by the Wisconsin Department of Natural Resources (DNR), which, after 1967, was the successor agency to the Department of Resource Development.

This approach, however, was significantly modified in 1972 when the federal Water Pollution Control Act amendments established as a national goal “the achievement, wherever attainable, of water quality which will provide for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water of the United States.” More simply stated, the attainment of fishable and swimmable waters became a national goal. In 1974, the Regional Planning Commission was formally designated by Governor Patrick J. Lucey to undertake an areawide water quality management program. As part of the program, the Commission established a set of recommended water quality standards to support the recommended water use objectives in the Region. These objectives and standards formed the basis for the development of the regional water quality management plan. Standards were established for water temperature, pH, dissolved oxygen, fecal coliform, residual chlorine, un-ionized ammonia-nitrogen, and total phosphorus.

During the regional water quality management planning effort, the public perception of water quality problems in southeastern Wisconsin was increased by the intensive public participation efforts of the Commission in cooperation with the University of Wisconsin-Extension Service. It was concluded that nuisance aquatic plant growth does represent a real water quality problem in southeastern Wisconsin, and does result in the impairment of the intended water uses. Accordingly, after appropriate technical studies, the Regional Planning Commission staff concluded that an instream total phosphorus standard of 0.1 milligram per liter (mg/l) could be expected to prevent excessive aquatic plant growth in flowing streams in the Region. This article documents the basis for the selection of that phosphorus standard as one of the important standards to be met if the desired water use objectives are to be achieved. For water quality standards to be sound, it must be demonstrated that they properly address the specific pollutants that are significant factors in the water pollution problems concerned, and that the achievement of the recommended level of the pollutants in the streams or lake waters would mitigate the water quality problem sufficiently to achieve the intended water use objectives. Because of the dynamic nature of water resources, particularly the flowing streams, it is not always possible to design a standard that protects all surface waters from adverse impacts under all conditions while at the same time providing a basis for cost-effective controls. This is particularly the case with regard to the establishment of an instream phosphorus standard.

Many streams in southeastern Wisconsin are choked by excessive algae and weed growths that are aesthetically displeasing; interfere with recreational uses such as boating, swimming, and fishing; and create undue stress on the aquatic environment, as these plants die and decompose and thereby reduce the oxygen
content of the streams (see Figure 1). These streams not only become unsuitable for recreational use, but also become unable to support the particular species and populations of fish and other aquatic life that are indicative of healthy, stable environments. Such polluted streams may also cause localized economic hardships and result in a region that is a less desirable place in which to live. The conclusion that these pollution problems are—in a significant part—caused by excessive phosphorus levels in streams is the basis for the phosphorus standard.

The instream effects of nutrient levels have been largely ignored by water quality researchers, such researchers having concentrated their efforts on lake ecosystems. However, K. M. Mackenthun, in Toward a Cleaner Aquatic Environment (1973), states:

A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 μg/l (0.1 mg/l) P at any point within the flowing stream, nor should 50 μg/l (0.05 mg/l) be exceeded where waters enter a lake, reservoir, or other standing water body.

These criteria have not, to date, been adopted as standards by the U. S. Environmental Protection Agency (EPA) or the DNR. However, the EPA's Quality Criteria for Water (1976) and several DNR river basin reports have referred to the 0.1 mg/l total phosphorus level as a desired goal for the prevention of aquatic plant nuisance growths in streams. The Commission, in Planning Report No. 16, A Regional Sanitary Sewerage System Plan for Southeastern Wisconsin, published in 1974, and in Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed, published in 1976, recognized the effect of phosphorus levels on aquatic plant growth and proposed that 0.1 mg/l be designated as the water quality standard for total phosphorus. However, these plans were not designed for the strict achievement of this standard because it was assumed that the background levels of phosphorus in southeastern Wisconsin often exceeded the standard. This assumption was made in Planning Report No. 16 because nonpoint source pollutant loads were not addressed by the plan, and in Planning Report No. 26 because it was determined that nonpoint source pollutant loads could not be reduced sufficiently.

ANALYSIS AND RESULTS

The Commission's areawide water quality management planning program evaluated natural background levels of phosphorus, recognized the advancing state-of-the-art of point and nonpoint source control, and further studied phosphorus as a limiting factor for plant growth. From these studies it was concluded that reduced phosphorus levels were achievable, and that reduced phosphorus levels should reduce aquatic plant growth in most streams.

The water quality simulation model analyses conducted under the areawide water quality management planning program tended to substantiate certain phenomena which previously had only been assumed. The findings concerning these phenomena, and the findings of other studies conducted under the areawide water quality planning program relevant to a phosphorus standard, may be summarized as follows:

1. On a long-term or annual basis, phosphorus-limited algae growth rates are generally assumed to be related to the phosphate-phosphorus concentration. A phosphate concentration of 0.03 mg/l is estimated to

Figure 1

EXCESSIVE ALGAE GROWTH IN THE PEWAUKEE RIVER AT CTH F, WAUKESHA COUNTY: AUGUST 1978

Excessive weed and algae growths interfere with the recreational use of many streams in the Region and result in stressful environments for fish and aquatic life. The Pewaukee River reach depicted here is located downstream of the Pewaukee sewage treatment plant. The phosphorus concentration in this stream exceeds the Commission recommended standard.

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support about one-half of the maximum phosphorus-limited algae growth rate. Thus, the “half-saturation constant” is estimated at 0.03 mg/l or less. On a short-term basis, however, this assumption may not be valid since some algae may accumulate luxury amounts of phosphorus during high concentrations and utilize these nutrients during conditions of limited phosphorus availability.

2. Although seasonal variations occur, the measured water quality data used to calibrate the water quality simulation model indicate that, during the spring and fall, approximately 60 percent of the total phosphorus in streams in southeastern Wisconsin is in the phosphate form. For example, a phosphate-phosphorus concentration of 0.06 mg/l would correspond to a total phosphorus concentration of 0.1 mg/l—the recommended standard. Because the water quality model simulated phosphate-phosphorus and not total phosphorus, simulated phosphate-phosphorus levels were applied to the phosphorus standard in the areawide water quality management plan.

3. The water quality simulation model was used to determine whether light, temperature, phosphorus, or nitrogen is likely to be the factor limiting the algae growth rates. Generally, plant growth rates are limited by that factor that is most critically in short supply. Additional factors, such as zooplankton grazing rates or rates of streamflow for dilution, also affect the amount of plant material or biomass present within a stream. Analyses of simulated hourly water quality conditions indicate that algae growth in nearly all streams of the Region is limited by phosphate-phosphorus during those periods when nuisance growth conditions occur. Therefore, a reduction in the phosphorus concentration may be expected to reduce excessive algae growths in most streams. The model did not have the capability to simulate macrophyte (rooted weed) growth. Macrophytes may assimilate their required nutrients from the water column and/or from the bottom substrate through their roots. It is not known to what extent the macrophytes present in streams in southeastern Wisconsin are limited by phosphorus, although in many lakes in southeastern Wisconsin the macrophytes are considered to be limited by phosphorus.

4. It is important to evaluate phosphate-phosphorus levels on an annual basis. If phosphate-phosphorus concentrations are analyzed only during the growing season, they will be found to be relatively low because the phosphate-phosphorus is utilized and stored as organic phosphorus in the aquatic plant tissue. Therefore, applying a phosphorus standard to phosphate-phosphorus levels only during this period would erroneously lead to the conclusion that phosphorus levels are sufficiently low. However, if a standard is satisfied during the entire year, then the phosphate-phosphorus levels prior to uptake by aquatic plants are usually low enough to prevent excessive growths.

5. Background, or “precultural,” phosphate-phosphorus concentrations are believed to be below 0.1 mg/l in many—if not most—streams in the Region. Figures 2 through 6 show simulated water quality frequency-duration curves for phosphate-phosphorus for selected streams in the Region that neither drain highly urbanized areas nor receive wastes from significant point source discharges. Simulated phosphate-phosphorus concentrations in these streams are well below a level of 0.1 mg/l at least 90 percent of the time, which is the recommended compliance level. This indicates that a level of 0.1 mg/l phosphate-phosphorus can—with adequate point and nonpoint source pollution controls—usually be achieved. Measured water quality values for relatively unpolluted streams in the Region also indicate that total phosphorus levels are often less than 0.1 mg/l. Table 1 presents total phosphorus concentrations measured from 1968 to 1975 for selected streams in the Region that are relatively unaffected by pollution.

6. No single phosphorus standard can reflect the varying effects of physical, hydrologic, hydraulic, and benthic conditions in streams. Impounded or slow-flowing streams, streams that receive long periods of direct sunlight, or streams without excessive turbidity may be expected to support

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excessive plant growths at a lower phosphorus concentration than that required to support the same conditions in fast-flowing streams, streams that are shaded from direct sunlight, or streams that are very turbid. Figure 7 presents an example of excessive plant growth in a stream impoundment with a simulated phosphate-phosphorus level below 0.1 mg/l at least 90 percent of the time. As shown in the figure, plant growth upstream and downstream of this impoundment is limited, presumably by the velocity of streamflow. However, even in impoundments, a reduction in phosphorus concentrations would be expected to reduce the severity and duration of nuisance aquatic plant growths.
Table 1
MEASURED TOTAL PHOSPHORUS CONCENTRATIONS AT SELECTED RELATIVELY UNPOLLOUTED STREAM SITES IN THE REGION: 1968-1975

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Stream Site Location</th>
<th>Measured Total Phosphorus Concentrations (mg/l)</th>
<th>Percent Samples Exceeding 0.1 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Mean</td>
</tr>
<tr>
<td>Fox River</td>
<td>Mukwonago River at STH 83</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>Rock River</td>
<td>Oconomowoc River at STH 83</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>Rock River</td>
<td>Oconomowoc River at USH 16</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

a Water quality measurements at 87 sampling stations were taken under the Regional Planning Commission’s benchmark sampling program for the period of 1964-1975. Total phosphorus measurements were only taken from 1968-1975. These data are documented in SEWRPC Technical Report No. 17, Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975.

b A total phosphorus concentration of 0.1 mg/l is the recommended standard to support a recreational water use objective.
Source: SEWRPC.

7. Phosphorus reductions are technically achievable with stringent controls. Point source treatment systems have been developed that can achieve a 0.1 mg/l total phosphorus effluent concentration. Point source discharges can also be essentially eliminated through land application of effluent. As indicated in SEWRPC Technical Report No. 21, Sources of Water Pollution in Southeastern Wisconsin: 1975, the majority of nonpoint source phosphorus loads are contributed by livestock operations, construction activities, and malfunctioning septic tank systems. These sources are relatively easy to control. Control of these sources is recommended throughout the Region.

8. Reduced phosphorus levels reduce algal growth rates and subsequently reduce concentrations of chlorophyll-a, which provides the green pigment necessary for photosynthesis to occur and is an indicator of algal standing crop. To demonstrate this point, simulated phosphate-phosphorus and chlorophyll-a concentrations are shown in Table 2 for the East Branch of the Milwaukee River at the New Fane impoundment in Fond du Lac County, about one-half mile north of the Region. Water quality at this site was simulated under assumed year 2000 conditions under three alternatives which differed only in the assumed quality of the discharged effluent from the proposed Forest Lake wastewater treatment facility upstream. These three alternatives assumed either 1) no phosphorus removal; 2) conventional chemical precipitation for phosphorus removal; or 3) land application, with no effluent entering the stream (zero discharge). The results, tabulated in Table 2, indicate that lower phosphate-phosphorus concentrations in the treatment facility effluent will lead to lower instream phosphate-phosphorus concentrations that will produce lower concentrations of algal standing crop (measured in units of chlorophyll-a). The conventional phosphorus removal alternative does not result in higher summer instream phosphate-phosphorus levels than those found

\(^2\) See Appendix E of SEWRPC Technical Report No. 18, State of the Art of Water Pollution Control in Southeastern Wisconsin, Volume One, Point Sources.
Impoundments reduce the velocity of streamflow, thereby creating conditions more susceptible to excessive weed and algae growths. The water quality simulation model analyses indicate that the East Branch of the Milwaukee River near New Fane has a phosphate-phosphorus concentration of less than 0.06 milligram per liter (mg/l) at least 90 percent of the time, and therefore, satisfies the recreational use phosphorus standard of 0.1 mg/l. The flowing stream reaches of the East Branch, as shown above, are not affected by excessive aquatic plant growth. However, the impoundment at New Fane does exhibit aquatic plant growths that would interfere with the recreational use of the stream. This indicates that satisfying the phosphorus standard will not prevent excessive plant growths in all stream reaches or impoundments in the Region.

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under the land application alternative, which involves no effluent discharge to surface waters, because the additional phosphate-phosphorus in the effluent is consumed by the increased algal growth, as shown by an increase of 26 percent in the mean summer chlorophyll-a concentration. This phenomenon makes the development of phosphorus control recommendations difficult to analyze. However, review of annual simulated instream phosphate-phosphorus levels indicates that the conventional phosphorus removal alternative does result in a higher average annual phosphate-phosphorus concentration than that which results from the land application
Table 2


<table>
<thead>
<tr>
<th>Alternative Treatment Level</th>
<th>Treatment Facility Effluent Phosphate-Phosphorus Concentration (mg/l)</th>
<th>Stream Phosphate-Phosphorus Concentration (mg/l)</th>
<th>Value Exceeded 10 Percent of Year(^a) (mg/l)</th>
<th>Stream Chlorophyll-a Concentration (ug/l)</th>
<th>Value Exceeded 10 Percent of Year(^a) (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum(^b)</td>
<td>Maximum(^b)</td>
<td>Mean(^c)</td>
<td>Standard Deviation(^c)</td>
<td>Minimum(^b)</td>
</tr>
<tr>
<td>No Phosphorus Removal</td>
<td>5.0</td>
<td>6.0</td>
<td>0.007</td>
<td>0.066</td>
<td>0.20</td>
</tr>
<tr>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phosphorous Removal</td>
<td>0.7</td>
<td>-</td>
<td>0.004</td>
<td>0.004</td>
<td>0.08</td>
</tr>
<tr>
<td>Land Application</td>
<td>No effluent discharge</td>
<td>0.004</td>
<td>0.041</td>
<td>0.016</td>
<td>0.06</td>
</tr>
</tbody>
</table>

\(^a\) Simulated phosphate-phosphorus and chlorophyll-a values are for May through August, when maximum algal growth would occur.

\(^b\) The phosphate-phosphorus level exceeded 10 percent of the time annually is shown because the recreational water use phosphorus standard of 0.1 mg/l was applied to this duration-compliance level under the statewide water quality management planning program.

Source: SEWRPC.

Figure 8


Water quality samples obtained by the Regional Planning Commission in the fall of 1976 further substantiated the assumption that higher phosphorus levels tend to result in larger algae growths. Table 3 sets forth the phosphate-phosphorus, total phosphorus, and chlorophyll-a measurements for the fall of 1976 for eight sites within the Fox River watershed. The chlorophyll-a measurements are given for phytoplankton (algae suspended in the water column) and for periphyton (algae that grow attached to underwater substrates). The data indicate, as shown in Figure 9, that those streams with lower phosphate-phosphorus and total phosphorus levels tend to support lower algal standing crops. This conclusion applies to suspended algae and even more so to attached algae. It should be noted that there are a great many variables—such as stream size, flow, depth, shading, temper-
**Table 3**

PHOSPHATE-PHOSPHORUS, TOTAL PHOSPHORUS, AND CHLOROPHYLL-A MEASUREMENTS IN THE FOX RIVER WATERSHED: FALL 1976

<table>
<thead>
<tr>
<th>Stream</th>
<th>Location</th>
<th>Phosphate-Phosphorus Mean (mg/l)</th>
<th>Sample Period</th>
<th>Total Phosphorus Mean (mg/l)</th>
<th>Sample Period</th>
<th>Algal Standing Crop Mean Chlorophyll-a (ug/l)</th>
<th>Sample Period</th>
<th>Periphyton Mean Chlorophyll-a (mg/cm²)</th>
<th>Sample Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mukwonago River</td>
<td>At STH 83, Waukesha County</td>
<td>0.020</td>
<td>10/11-1/2</td>
<td>0.10</td>
<td>10/11-1/2</td>
<td>1.55</td>
<td>10/12-11/2</td>
<td>0.03</td>
<td>9/15-11/2</td>
</tr>
<tr>
<td>Sugar Creek</td>
<td>At Potter’s Road, Walworth County</td>
<td>0.022</td>
<td>10/11-1/2</td>
<td>0.11</td>
<td>10/11-1/2</td>
<td>2.21</td>
<td>10/12-11/2</td>
<td>0.84</td>
<td>9/15-11/2</td>
</tr>
<tr>
<td>Poplar Creek</td>
<td>At Bluemound Road, Waukesha County</td>
<td>0.031</td>
<td>10/11-1/2</td>
<td>0.11</td>
<td>10/11-11/2</td>
<td>3.78</td>
<td>10/12-11/2</td>
<td>0.26</td>
<td>9/15-11/2</td>
</tr>
<tr>
<td>White River</td>
<td>At STH 11, Walworth County</td>
<td>0.068</td>
<td>9/7-10/6</td>
<td>0.10</td>
<td>9/7-10/6</td>
<td>2.09</td>
<td>9/29</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Honey Creek</td>
<td>At Carver Road, Walworth County</td>
<td>0.101</td>
<td>10/11-11/2</td>
<td>0.19</td>
<td>10/11-11/2</td>
<td>3.40</td>
<td>10/12-11/2</td>
<td>1.14</td>
<td>9/15-11/2</td>
</tr>
<tr>
<td>Fox River</td>
<td>At CTH C, Kenosha County</td>
<td>0.109</td>
<td>9/7-10/6</td>
<td>0.22</td>
<td>9/7-10/6</td>
<td>79.11</td>
<td>9/29</td>
<td>4.41</td>
<td>9/15-11/2</td>
</tr>
<tr>
<td>Fox River</td>
<td>At CTH W, Racine County</td>
<td>0.113</td>
<td>9/15-11/2</td>
<td>0.23</td>
<td>9/15-11/2</td>
<td>83.04</td>
<td>9/29-11/2</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Fox River</td>
<td>At State Street, Waukesha County</td>
<td>0.147</td>
<td>10/11-11/2</td>
<td>0.25</td>
<td>10/11-11/2</td>
<td>4.78</td>
<td>10/12-11/2</td>
<td>2.01</td>
<td>9/15-11/2</td>
</tr>
</tbody>
</table>

Source: SEWRPC.

**Figure 9**

COMPARISON OF PHOSPHATE-PHOSPHORUS AND TOTAL PHOSPHORUS LEVELS TO CHLOROPHYLL-A LEVELS IN THE FOX RIVER WATERSHED: FALL 1976

**CONCLUSION**

Findings of the Commission water quality and biological sampling analyses and of simulation modeling studies indicate that 1) a restriction on phosphorus levels is warranted; 2) reductions in phosphorus concentrations are achievable; and 3) aquatic plant growth in most streams of the Region can be reduced. However, even if the proposed phosphorus standard of 0.1 mg/l is satisfied, many stream impoundments and selected reaches of streams will continue to have excessive aquatic plant growths that will interfere with the use of such waters. However, the duration and severity of these excessive growths will be reduced. Excessive aquatic plant growths in most flowing streams in the Region can be expected to be all but eliminated if the recommended instream standard is achieved.