LONG-TERM (15 YEARS) RESULTS OF NPS CONTROLS IN AN AGRICULTURAL WATERSHED UPON A RECEIVING LAKE'S WATER QUALITY

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ABSTRACT

Nonpoint source controls were installed in a 1215 ha agricultural watershed in northeastern Wisconsin in the late 1970s. Changes were made in handling of animal wastes and cropping practices to reduce runoff of sediment and nutrients. Modelling results predicted a reduction in phosphorus runoff of 30 percent. The water quality of White Clay Lake has worsened since the installation of NPS controls. The lake's phosphorus concentration has increased from a mean of 29 µg L⁻¹ in the late 1970s to 44 µg L⁻¹ in recent years. Water clarity has declined from 2.7 to 2.1 m and the mean summer chlorophyll levels have increased from 9 to 13 µg L⁻¹ with peak values exceeding 40 µg L⁻¹. Increased phosphorus loading is not the result of elevated precipitation but instead the failure of the control measures to sufficiently reduce P loading. Most of the effort was placed on structural changes while most of the P loading comes from cropland runoff. Further, soil phosphorus concentrations have increased because of artificial fertilizers and manure spreading. The White Clay Lake experience is discouraging since the majority of the polluters in this watershed utilized some NPS control practices, including 76 percent of the farms which installed waste management control facilities.

KEYWORDS

Nonpoint source, agriculture, dairy, manure storage, cropland runoff, lake, phosphorus, chlorophyll, water clarity.

INTRODUCTION

Nonpoint source (NPS) pollution of lakes and streams by agricultural runoff is recognized as one of the nation's major water quality problems. The U.S. Environmental Protection Agency reported to Congress in 1984 that six of 10 EPA regions found nonpoint sources to be the principal remaining cause of water quality problems, and that virtually every state reported some kind of problem related to these sources (U.S. Environ. Protect. Agency 1984). The role of phosphorus and nitrogen transported by agricultural runoff in accelerating the biological productivity of surface waters is well documented (Loehr 1974, Schindler 1977, Vollenweider 1980, Sharpley and Menzel 1987, Ryding and Rast 1988).

Many state, federal, and local agencies have recognized this in recent years and programs have been created to control these sources of sediment and nutrients. For example, at the federal level, the U.S. Department of Agriculture created the Rural Clean Water Program in 1980 and the Clean Water Act has been reauthorized. In Wisconsin, the Wisconsin Fund was created to improve and protect water resources by controlling NPS pollution. Much less effort has gone into determining the effectiveness of these control measures. Johengen
et al. (1989) reported that short-term water quality goals were not met in Saline Valley, Michigan because of low landowner participation. Less information is available on the long-term effectiveness of NPS control projects.

One of the early projects in Wisconsin involved the White Clay Lake Watershed. This watershed was the focus of an intensive program of land treatment to reduce agricultural runoff of phosphorus and sediment. Significant NPS control practices were implemented in this agricultural watershed from the period 1974 through 1981 to protect the lake from eutrophication. This paper discusses the long-term effectiveness of these measures to protect the lake’s water quality. Since phosphorus is the limiting nutrient in most lakes (Vollenweider 1968, Schindler 1977), including White Clay Lake, most of the discussion will focus on this parameter.

SITE DESCRIPTION

The White Clay Lake Watershed is located in Shawano County in northeastern Wisconsin. The 1215 ha watershed is a gently rolling glacial till plain and drains into a 95 ha dimictic lake. White Clay Lake has a maximum depth of 13.5 m and a mean depth of 4.2 m. Ninety percent of the shoreline is wetland of the marsh type. The soils are mostly Onaway and Solona series and the watershed has a maximum relief of about 30 m with slopes generally less than 12 percent.

Figure 1. Map of the White Clay Lake Watershed. The East Branch Watershed contributed the majority of the phosphorus loading from the surface water runoff. This subwatershed was the object of the modelling efforts by Persson et al. (1983).
Most of the agricultural activity involves dairy farming. From 1950 to the mid-1970s, herd sizes increased from 75 to 100 cattle. Farmers increasingly held their herds on feedlots rather than on pastures and were emphasizing more corn production and less emphasis on oats and hay in crop rotations. In 1978 there were 20 livestock concentrations in the watershed and five others were spreading animal waste in the watershed. There were 1,960 animal units where one unit equals 1000 pounds of animal liveweight. The average farm size was 105 ha of which 81 ha was cropland. Cropland averaged 28 ha of corn, enough oats to re-establish legume seeding, and the balance was planted in alfalfa. Less than 10 percent of the watershed is forested and there were no point sources.

HISTORY OF NPS CONTROL PRACTICES

In the 1970s, hydrologic and nutrient transport studies indicated that the major nutrient sources were from groundwater and agricultural runoff. A project was implemented to reduce sediment and nutrient delivery from the watershed to the lake with 90 percent cost share money from federal (US E.P.A., Agricultural Stabilization and Conservation Service) and state (Department of Natural Resources) sources. Participation was voluntary with technical assistance offered through the Soil Conservation Service to install NPS control practices. Money was provided by the US E.P.A. and the Upper Great Lakes Regional Commission to monitor the lake's water quality and nutrient and sediment runoff from the watershed. Because it was thought that the greatest reduction in phosphorus runoff could be made with animal waste management, the early emphasis was on this pollution source. In 1976, two animal waste management projects were completed. A typical management plan involved animal waste storage (solid, semi-solid, and/or liquid) and feedlot improvement. These animal waste plans involved keeping unpolluted water clean and diverting and filtering water that did become contaminated. Runoff water from adjacent fields and roof water was diverted so that it did not run through feedlots or manure storage areas. Filter walls, diversions, and grass filter areas were used to filter runoff away from feedlots. Feedlots were concreted so wastes could be more easily collected and either stored or spread on fields. The storage areas were designed to hold from seven to twelve months of animal waste. Animal waste was not to be spread on the land when the soil was frozen or snow covered (mid-November to mid-April). Cooperators were instructed to incorporate manure into the soil as soon as possible, at a rate not exceeding 25 tons per acre. The application of manure was generally on land being planted to corn because it best utilized the nutrients. If necessary, manure could be top dressed in other cropland at rates less than 20 tons per acre.

Cropland runoff was the major contributor of nutrients and sediment in the surface water. Sediment-bound nutrients may account for up to 90 percent of the total amount transported in cropland runoff (Schuman et al. 1973, Sharpley et al. 1987) with a variable proportion of this available for biological uptake in the lake. Improvements to reduce cropland runoff included installation of grassed waterways (with and without tile), contour strips, and changed field boundaries to avoid plowing up and down hills. In addition to these practices, crop rotation was modified in the watershed. A typical crop rotation prior to the initiation of the project was CCCOHHHH (corn, corn, corn, oats, hay, hay, hay, hay). Modified rotation schemes included less years of corn, eg. CCOHHH, CCOHHHH, or COHHHH. A few shallow ponds were installed to act as sediment and nutrient traps (Persson et al. 1983). One practice that was not utilized in the watershed was conservation tillage. The farmers felt that this would not benefit their operations because of the fine textured nature of the soils and the short growing seasons.

Table 1 is a summary of the NPS control practices that were installed in the watershed. Installation of all NPS controls was completed by 1981. Nineteen of 25 livestock concentrations that impacted the watershed installed manure storage facilities and/or barnyard runoff control measures. However, in the East Branch Subwatershed, the barnyard that was closest to the stream was not improved. Participation in cropland management was not as common. For example, in the East Branch Subwatershed, which was the largest source of surface water phosphorus, only about 50 percent of the watershed participated in cropland runoff improvement projects.
Table 1. Summary of NPS Controls in the Watershed

<table>
<thead>
<tr>
<th>Animal Waste Management</th>
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</thead>
<tbody>
<tr>
<td>Storage for 6 to 12 months of manure</td>
</tr>
<tr>
<td>Redesign of feedlots to prevent clean water from entering</td>
</tr>
<tr>
<td>Filter strips between feedlots and stream</td>
</tr>
<tr>
<td>Manure only spread on unfrozen ground</td>
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<table>
<thead>
<tr>
<th>Cropland Management</th>
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</thead>
<tbody>
<tr>
<td>Grassed waterways with and without tile</td>
</tr>
<tr>
<td>Change field boundaries</td>
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<tr>
<td>Change crop rotation patterns so less corn and more hay</td>
</tr>
<tr>
<td>Contour strips</td>
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<tr>
<td>Settling ponds</td>
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RESULTS

During the period from 1974 to 1977, three subwatersheds were monitored for runoff of sediment, nitrogen, and phosphorus and the annual loading computed. Monitoring was continued for an additional two years for the East Branch Subwatershed which contributed the largest annual load (Peterson and Madison 1979). This period of monitoring corresponds to the time just prior to the implementation of NPS controls (1974–76) and the completion of the installation of most of the practices. Annual phosphorus loading rates were highly variable, with the highest rate being 15 times greater than the lowest (Figure 2). This variability is not uncommon in watersheds of this size (Minns and Johnson 1979), especially in lakes with areas of watershed to lake ratios less than 10:1 (similar to White Clay Lake) (Baker 1988). In small watersheds, most loading typically occurs when bare soils and high rainfall intensities occur such as during spring runoff. In fact, in White Clay Lake, precipitation during the winter season corresponds well with annual loading rates (Figure 2). As can be seen in Figure 2, the amount and timing of precipitation varies annually resulting in a wide range of annual phosphorus loading. In the East Branch Subwatershed, the winter precipitation and resultant spring runoff is largely responsible for the annual phosphorus loadings.

The variation of annual phosphorus loading makes it difficult to directly assess the effectiveness of the efforts to reduce sediment and nutrients from the watershed. This problem has been noted in assessing the effectiveness of NPS controls in other studies (Meals 1993). Consequently, Persson et al. (1983) modelled expected loadings from the East Branch Subwatershed for sediment and phosphorus to estimate the effectiveness of the structural and management changes. Separate models were used for animal waste runoff and cropland runoff. Models are detailed in Persson et al. (1983).

The modelling exercise estimated that the mean annual phosphorus loading from the East Branch Subwatershed prior to NPS controls was 305 kg. The model predicted that the greatest reduction in phosphorus loading resulted from animal waste management practices where the reduction was 46 percent. The reduction of phosphorus loading from cropland runoff was estimated to be 19 percent. Although a greater percentage of phosphorus loading was reduced from animal waste runoff, the overall reduction in phosphorus loading was 28 percent since runoff from cropland contributed 76 percent of the total loading. However, the modelling effort was only performed in one subwatershed which in 1974 contributed about 65 percent of surface water phosphorus loading to the lake (Peterson and Madison 1979). Livestock waste controls and improved cropland management practices performed in this subwatershed were similar to those incorporated in the other subwatersheds. Therefore, it is expected that NPS control practices instituted in the White Clay Lake watershed should have reduced phosphorus from surface runoff by about 30 percent. Although the amount of phosphorus entering the lake is enough to classify the lake in the slightly eutrophic range, the intent of this project was to protect the lake from further degradation of its water quality.
During the period when NPS controls were installed in the watershed, the mean concentration of phosphorus at spring overturn was 30 μg L⁻¹ (Table 2). Spring phosphorus values are a good indicator of summer algal community size (Dillon and Rigler 1974). The level found in the late 1970's would classify the lake in the lower eutrophic range. In fact, during this time, water clarity during the summer was good and with a mean summer Secchi value of 2.7 m. The mean summer chlorophyll a value for 1977 through 1979 was 9.4 μg L⁻¹ (Figure 3). In a random survey of Wisconsin lakes, Lillie and Mason (1983) found that water quality conditions in White Clay Lake were typical of the majority of other lakes in the region. The algal community was diverse and there were few if any blue-green algal blooms (Garrison, unpubl. data).

Water quality conditions of White Clay Lake a decade following the implementation of NPS controls had degraded significantly. Although the purpose of installing these controls was to protect the lake's water quality (Peterson and Madison 1979), this did not happen. Summer chlorophyll values were greater on average than values observed during the implementation phase (Figure 3). In fact, during two of the last three years, mean summer chlorophyll a values were almost double the values in the late 1970's. Water clarity was also reduced with the mean summer Secchi depth declining from 2.7 to 2.1 m. The volume-weighted mean phosphorus concentrations were also elevated compared to the late 1970's (Figure 4). These elevated phosphorus levels are evident during spring turnover (Table 2) implicating spring runoff as the time period when much of the phosphorus enters the lake. In fact, the mean concentration of phosphorus at spring...
turnover from 1986-1991 was 73 g L\(^{-1}\). Using the model of Dillon and Rigler (1974), summer chlorophyll values should be in the hypertrophic range.

Table 2. Phosphorus concentrations (µg L\(^{-1}\)) at spring turnover

<table>
<thead>
<tr>
<th>Year</th>
<th>Concentration (µg L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>40</td>
</tr>
<tr>
<td>1975</td>
<td>20</td>
</tr>
<tr>
<td>1976</td>
<td>15</td>
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<td>1977</td>
<td>30</td>
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<td>1978</td>
<td>30</td>
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<td>1979</td>
<td>20</td>
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<tr>
<td>Mean</td>
<td>26</td>
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<tr>
<td>1986</td>
<td>90</td>
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<tr>
<td>1987</td>
<td>67</td>
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<td>1989</td>
<td>68</td>
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<tr>
<td>1990</td>
<td>124</td>
</tr>
<tr>
<td>1991</td>
<td>60</td>
</tr>
<tr>
<td>Mean</td>
<td>73</td>
</tr>
</tbody>
</table>

**WHITE CLAY LAKE**

**SUMMER MEAN**

Figure 3. Summer mean values of chlorophyll a and water clarity (Secchi depth) during implementation of NPS controls and 10 to 15 years later.
Figure 4. Volume weighted mean phosphorous concentrations during implementation of NPS controls and 10 to 15 years later. A mean value was only computed for the period 1988-1990 because there were not enough samples collected annually for other years.

DISCUSSION

Although direct measurements have not been made of surface runoff from the White Clay Lake watershed to assess the long-term effectiveness of the NPS control measurements, the watershed's receiving water body has been monitored. The water quality of the lake has degraded significantly since the work was completed in the watershed. There are four possible causes of this degradation. One possibility is that precipitation, especially during the winter, has increased in recent years. However, winter precipitation for each of the years 1988 through 1992 was less than that experienced in four of the six study years when phosphorus runoff was directly measured in the watershed (Figure 2). A second possible cause could be the elimination of the filtering capacity of the marsh surrounding the lake. The lake district in the late 1970s rezoned this wetland to prevent any development that would alter the marsh's character. Sloey et al. (1978) reviewed the effectiveness of wetlands to filter nutrients during the growing season. Although some of these retained nutrients are released at other times, the overall effect is nutrient retention. In a study of the wetland around White Clay Lake, Johnson (1982) found that the wetlands retain 2.6 gP m$^{-2}$ annually. This zoning remains in effect and there is no visible evidence that the marsh would not be able to attenuate both sediment and phosphorus delivery to the lake as it has done in the past. A third possibility is an additional phosphorus source that was not present when the NPS controls were installed. There is no evidence of another source and, in fact, the single resort on the lake upgraded its failed septic system in the late 1970s so that this potential source should contribute less phosphorus than it did previously.

The most likely possibility is that the NPS controls have not reduced phosphorus runoff as was expected. The modelling effort predicted that loading from surface runoff should be reduced by 30 percent. Even if this degree of reduction did not occur, the controls should at least have maintained the lake's water quality condition. Although contractual requirements ended in the mid-1980s, farmers continue to use the manure
storage facilities. Manure is still not spread on frozen ground but instead most of it is spread in the fall and incorporated during fall plowing. That which is not spread in the fall is put on the fields in the spring. Herd sizes have increased only slightly although the amount of manure being spread has increased somewhat. Likewise, the improvements to the feedlots were of a permanent nature and continue to be utilized.

The controls to reduce cropland runoff were not as permanent. Modelling efforts estimated that cropland runoff contributed 76 percent of the annual phosphorus loading to the lake from surface waters. Grassed waterways are not very efficient during spring runoff when there is little vegetative cover. Part of the management plan to reduce runoff involved changing crop rotation to emphasize less row crops, ie. corn, and more hay, ie. alfalfa. Wendt and Corey (1980) found that the runoff of bioavailable phosphorus is greater from alfalfa in the fall after the foliage has been killed by frost than from corn. The increased emphasis on alfalfa probably increased the phosphorus delivered to the lake. Recent soil tests have found that soil phosphorus concentrations in the watershed are extremely high. Soil phosphorus concentrations have increased statewide over the last two decades because of a general policy to increase soil phosphorus (Combs and Bullington 1992). Although best management practices (BMP) to reduce cropland runoff reduced P loading by an estimated 20 percent, the policy of "banking soil P" would be expected to offset any reductions in phosphorus runoff.

Phosphorus loading rates from the East Branch Subwatershed prior to NPS controls were considered excessive to the point that eutrophication would be accelerated (Dillon and Rigler 1974). Even with the reduction in loading as a result of NPS controls, the loading rate from the East Branch Subwatershed was still considered excessive, although at a lower level. If the loading from the rest of the watershed is included, then loading even after the installation of NPS controls is greater than the excessive level.

The water quality of White Clay Lake is better than that predicted by the Dillon and Rigler model. This is because of the nutrient attenuation of the marsh as well as the fact that the lake is a marl lake. Wetzel (1966) discusses that marl lakes, i.e. hard water lakes that are saturated with calcium carbonate, are less productive than would be expected from phosphorus levels because CaCO₃ adsorbs phosphate molecules as well as the unavailability of several essential micronutrients.

It seems from this study that the NPS controls installed in this watershed were not effective in protecting the lake's water quality. Although a large number of farmers (76%) installed animal waste management controls, the water quality of the lake degraded in the last fifteen years. The participation in BMP's for cropland runoff was not as effective yet most of the phosphorus in surface runoff came from this source. Changes in crop rotation to emphasize cover crops can be an effective means to reduce runoff during much of the year, but following fall frosts, much P may runoff into the lake. Also, grassed waterways are less effective during spring runoff. These practices need to be reevaluated to determine if better designs can be developed. Meals (1993) reported that in the LaPlatte River watershed in Vermont, P reductions did not occur until 80-90 percent of the animal units were under BMP. It may be that not enough animal units participated in the program at the White Clay Lake watershed. Also, and perhaps more importantly, one of the farms that did not participate is on the lake shore and animals have been observed in the lake. Also the barnyard closest to the East Branch stream did not have any NPS controls.

Other studies also found that implementation of NPS controls did not improve the water quality of the receiving water body (Johengen et al. 1989, McCoy and Summers 1992, Schlagel 1992). Although NPS controls were not successful in protecting the water quality of White Clay Lake, they were still beneficial in retarding the rate of eutrophication. Without these controls, it is expected that the lake would have degraded at a faster rate. There are also other potential benefits of these controls. This lake is heavily used for recreation. Although bacterial levels were not measured in the lake, Meals (1989) reported reduced fecal streptococci levels in a Vermont watershed since implementation of agricultural best management practices. The improvements in animal waste management in the White Clay Lake Watershed should have been especially effective in reducing bacteria in the lake.
ACKNOWLEDGEMENT

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REFERENCES


