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Project Summary

Lake Restoration: A Five-Year Evaluation of the Mirror and Shadow Lakes Project Waupaca, Wisconsin

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The objectives for the Mirror and Shadow Lakes study were to determine: (1) the response of both lakes to storm sewer diversion; (2) the effectiveness of an aluminum hydroxide layer in preventing phosphorus migration from the sediments; (3) if the nutrient control measures would effectively reduce the pelagial productivity and standing crop; (4) the response of the pelagial zooplankton and benthic invertebrate communities to the restorative measures.

Important physical, chemical, and biological data were collected before, during, and after the various restorative procedures. The data collection began October 1976 and continued until September 1981. The first restorative technique was storm sewer diversion. The diversion, which was completed in December 1976, reduced the watershed size by 60 percent for Mirror Lake and 26 percent for Shadow Lake. External phosphorus loading rates were reduced by 58 to 65 percent. In May 1978, both lakes were treated with aluminum sulfate, reducing inlake P concentrations from 0.09 mg/l in Mirror Lake and 0.055 mg/l in Shadow Lake to between 0.02-0.03 mg/l. These lower concentrations were still present at the end of the study. Artificial circulation of Mirror Lake in the fall prevented fish winter kill by increasing oxygen concentrations, while spring circulation increased the period of oxidation above the sediments.

Following restorative measures, algal primary productivity was reduced 40 percent in Mirror Lake and consequently sedimentation rates of C, P, and N also declined. The vernal phytoplankton standing crop was reduced in Mirror Lake and the community composition changed from one dominated by blue-green algae to a more diverse assemblage. In response to a decrease in the trophic status of Mirror Lake, the zooplankton community declined. In response to the spring and fall artificial circulation periods in Mirror Lake, the size of the benthic invertebrate community greatly increased.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In the last century, cultural eutrophication of some lakes has become a problem. With an increasing population, greater impact has been placed on our waters. With increasing nutrient loads due to perturbation of the watershed, the lakes have become less desirable, owing to large standing crops of algae and macrophytes. With the increase in population and leisure time activities has come greater awareness of lake water quality conditions and a desire to promote improvements.

The strategies and schemes for corrective action include both those which control the problem sources and measures which treat only the symptoms. Perhaps one of the most frequently applied solutions is diverting the major source of incoming nutrients away from a lake. The results of such diversion can be very spectacular as in the case of Lake Washington (Edmondson, 1977), or very disappointing as in the case of Lake Norrviken (Ahlgren, 1977). In cases where nutrient diversion is not successful, the problem can be traced to continued nutrient input from the sediments.

The restoration plan for Mirror and Shadow Lakes included elimination of the major external nutrient source by diversion of the storm sewers, reduction of internal phosphorus loading by adding aluminum sulfate after the storm sewers were diverted, and artificial circulation in Mirror Lake to prevent winter fish kills. Storm sewer diversion was completed by December 1976, the aluminum sulfate was applied in May 1978, and mixing began in November 1977.

Study Area

The study lakes (Figure 1) are kettle lakes that were formed during the last glaciation period about 12,000-13,000 years ago in the pitted margin of the Cary outwash plain. The lakes are located in central Wisconsin in the City of Waupaca. The current watershed of Mirror Lake consists of 13.1 ha of residential lawns and rooftops. The present watershed of Shadow Lake, 56.7 ha, is more diverse containing residential areas, undeveloped lowlands, and some paved streets Mirror Lake has a maximum depth of 13.1 m, mean depth of 7.8 m and a surface area of 5.1 ha. The maximum depth of Shadow Lake is 11.6 m while the mean depth is 5.3 m and the surface area is 17.1 ha.

Results

By the late 1960s, residents surrounding Mirror Lake complained of winter fish kills and offensive algal odors. Subsequent studies indicated that storm sewers were adversely impacting Mirror and Shadow Lakes. A paleolimnological study confirmed that in Mirror Lake following the introduction of storm sewers in the 1930s, the eutrophication process was accelerated as demonstrated by an increased sedimentation rate, occurrence of diatoms that indicate eutrophic conditions, increased organic matter and pigment degradation products including the blue-green algal pigment oscillaxanthin.

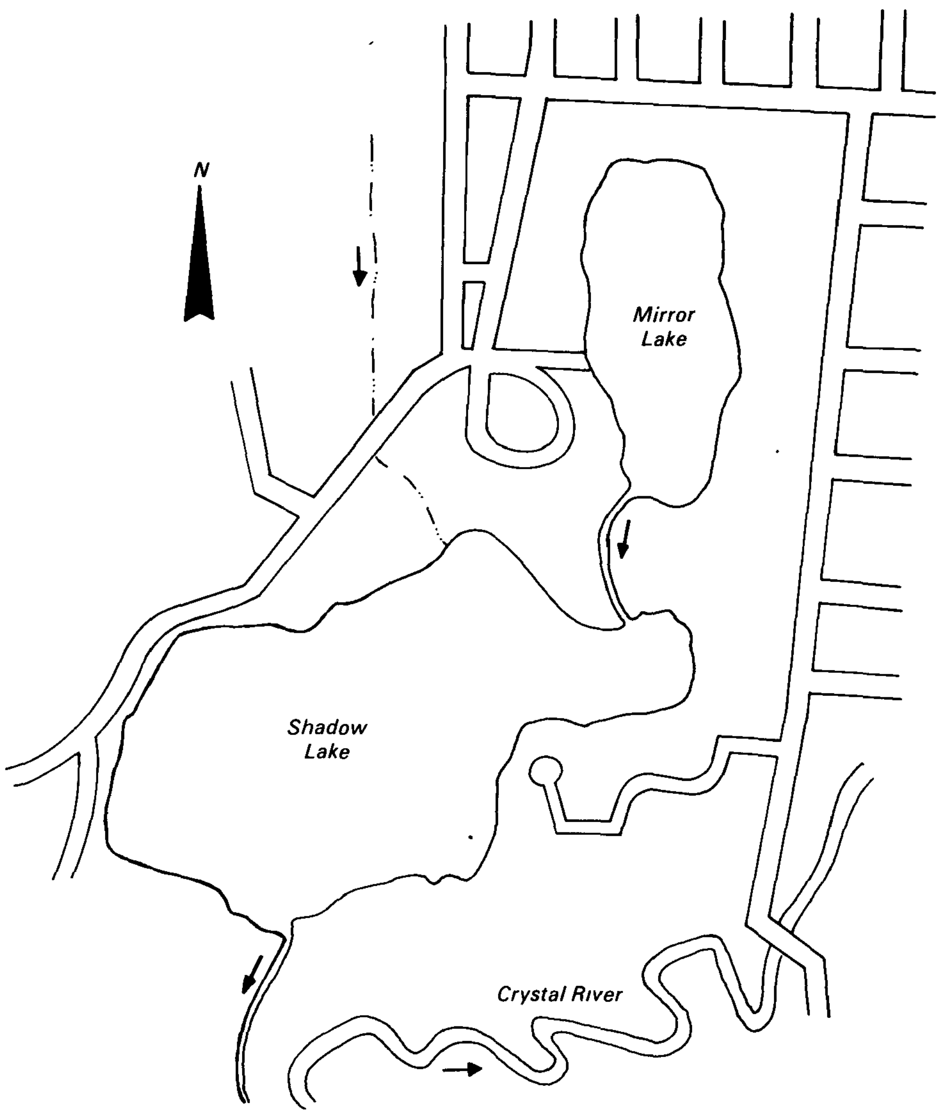

Figure 1. *Mirror and Shadow Lakes study area in the city of Waupaca, Wisconsin.*

Nutrient Diversion

The diversion of the storm sewers was completed in December 1976. This reduced the Mirror Lake watershed size from 32.2 ha to 13.1 ha and Shadow Lake's from 76.9 ha to 56.7 ha. More importantly, the phosphorus loading rate was greatly reduced from 0.341/g/m^2/yr to 0.120 g/m^2/yr for Mirror Lake. The phosphorus loading rate to Shadow Lake was reduced from 0.236 g/m^2/yr to 0.099 g/m^2/yr. In Mirror Lake, epilimnetic concentrations of P and N were reduced 50 percent and 34 percent respectively the first summer following storm sewer diversion. Unlike years prior to storm sewer diversion (Knauer 1975), algal biomass and primary productivity were unresponsive to occasions of majc rainfall events.

Artificial Circulation

Mirror Lake usually did not complete| mix in the spring or fall prior to th installation of the aeration unit. Becaus of the relatively large accumulated oxyge deficit in the bottom 1 meter and failure t mix in the fall, winter fish kills occasior ally were experienced. Much of the bo tom sediments were constantly overlai with anaerobic waters so the benth invertebrate community in the deep wat area was nonexistent.

The Mirror Lake implementation plε requires the lake to be artificially mixε for two to three weeks in November ar immediately following ice out. As a result of artificial circulation, dissolved oxygen concentrations have been maintained at adequate levels during ice cover even during the winter of 1978-1979 when many potential winter kill lakes in the area were severely stressed with a prolonged period of low dissolved oxygen. Spring mixing has resulted in higher water temperatures during summer stratification of 2-4°C. The mixing regime greatly increased benthic invertebrate population (*Chaoborus punctipennis*) to a high of 2200 organisms/m^2.

Alum Treatment

Although storm sewer diversion greatly reduced external phosphorus loadings, the inlake phosphorus concentrations at spring mixing remained almost unchanged. The high phosphorus concentrations were maintained because of internal loading via phosphorus migration from the hypolimnetic sediments. In order to reduce the internal loading, aluminum sulfate was applied below the epilimnion in both lakes in May 1978. As shown in Figures 2 and 3, total phosphorus concentrations were greatly reduced in both lakes In previous years, dissolved reactive phosphorus (DRP) concentrations exceeded 0.40 mg/l in the hypolimnion as P migrated from the bottom sediments. Following the alum treatment, DRP levels were generally less than 0.004 mg/l throughout the lake and never exceeded 0.060 mg/l in the bottom waters. *In-situ* measurements of internal loadings from the lake sediments were measured using nutrient regeneration chambers before and after the alum treatment. While ammonium-N release rates were unaffected, P rates were greatly reduced. Prior to the alum treatment, the release rate in both lakes was 1.30 mg P/m^2/day Release rates following the treatment were 0.07 mg P/m^2/day in Mirror Lake and 0 12 mg P/m^2/day in Shadow Lake. The relatively low summer epilimnetic nutrient concentrations in Mirror Lake were unchanged following alum treatment The main reason was the development of a large population of the blue-green alga *Oscillatoria agardhii* The population dynamics of this alga involved an early spring bloom which incorporated most of the inlake dissolved phosphorus into an organic form. Since *O. agardhii* prefers cool water temperatures it concentrates into the lower metalimnion during the summer, thus displacing most of the nutrients from the upper waters. With the reduction of internal P loading,

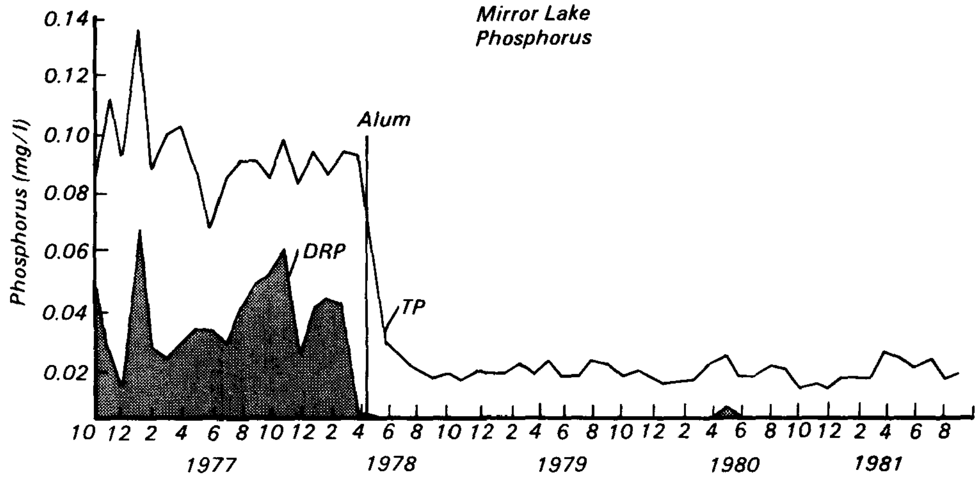

Figure 2. *Weighted mean phosphorus concentration for Mirror Lake*

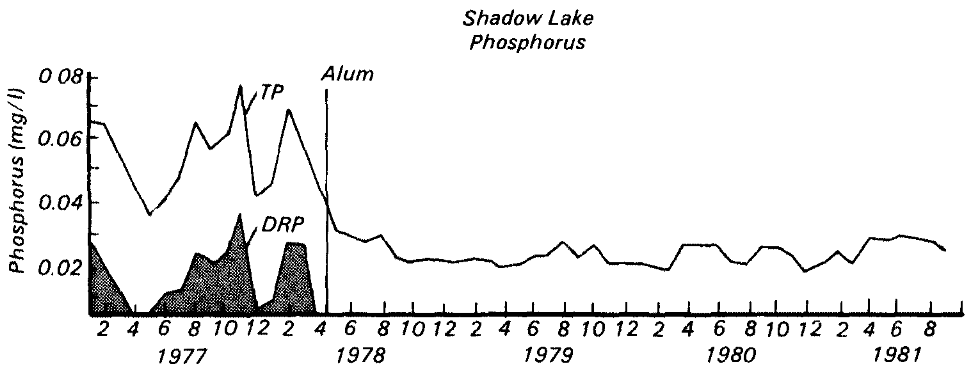

Figure 3. *Weighted mean phosphorus concentration for Shadow Lake*

the biomass of the vernal algal community was greatly reduced. In Mirror Lake, the spring chlorophyll *a* concentrations in 1977 and 1978 were greater than 50 mg/m^3. In the spring of 1979, 1980, and 1981, the chlorophyll *a* concentrations were reduced to 5-10 mg/m^3. In Mirror Lake the spring phytoplankton community also exhibited a steady decline in dominance by *O. agardhii* from 78% in 1977 to 13% in 1981. The *O. agardhii* population was replaced by a diverse algal assemblage.

The annual primary producton in Mirror Lake was reduced from 210 gC/m^2 in 1978 to 130 gC/m^2 in 1981. While productivity was lower the summers following storm sewer diversion and the alum treatment, the greatest reduction occurred during spring mixing. With a reduction in primary productivity, the sedimentation rates of carbon, nitrogen, and phosphorus were reduced. Carbon and nitrogen sedimentation rates declined 27 percent while phosphorus declined 56 percent. This indicates that competition for phosphorus increased as the inlake phosphorus concentration decreased. Since 80-85 percent of the phosphorus produced in the euphotic zone is mineralized before it is buried in the sediments, it is very important to reduce major external nutrient sources.

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The complete report, entitled "Lake Restoration: A Five-Year Evaluation of the Mirror and Shadow Lakes Project Waupaca, Wisconsin," (Order No. PB 83-176 578; Cost: $13.00, subject to change) will be available only from:

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