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Project Summary

Response of Skinner Lake (Indiana) to Agricultural Drainage

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Agricultural runoff has been shown to be relatively rich in plant nutrients that promote high densities in algae populations in lakes. Decomposition of these algae stresses the oxygen system, which in very productive lakes results in release of water quality degrading substances from sediments, and causes shifts in animal and plant populations toward less desirable species. Turbidity in the water is increased in the process. For lakes in the north central States, phosphorus is most commonly the key nutrient responsible for development of excessive algae densities. Various agricultural land management practices are known to promote conservation of this and other nutrients on the land.

From measurements over an annual cycle in 1978-79, a phosphorus runoff-algae density model was developed for a lake at the bottom of an agricultural watershed in northern Indiana. Like other models in the literature, this model stated that mean total phosphorus and chlorophyll *a* concentrations in the epilimnion of the lake in the ice-free period of the year were predictable from mean total phosphorus in inflowing streams and residence time of water in the lake (t_w). For this particular system, $[\overline{TP}]_{epi}$ and $[\overline{chl\ a}]_{epi}$ were predictable from $[\overline{TP}]_{streams}$ and t_w measured during spring and summer, rather than over a longer interval of the year. Measurement of the last two variables during the period of spring runoff just prior to thermal stratification of the lake when the flushing coefficient (ρ) equaled 1, and continued through the duration of stratification, was sufficient.

Land management practices were implemented on erosion-sensitive portions of the watershed between 1978 and 1981. These included conservation tillage, terraces, livestock exclusion, grassed waterways, diversions, group tile mains, settling basins, and stabilizing stream banks with vegetation. The model was tested in 1982 on the assumption that this work would change $[\overline{TP}]_{streams}$, and alter total phosphorus and chlorophyll *a* concentrations in the lake. It proved to be a reasonable predictor of $[\overline{TP}]_{epi}$ and $[\overline{chl\ a}]_{epi}$ for the ice-free period of the year. In the absence of unusual rain events and by design of the model, t_w in 1979 and 1982 were nearly the same; 0.60 and 0.65 respectively. $[\overline{TP}]_{streams}$ was 127 mg m^{-3} in 1979 and 100 mg m^{-3} in 1982. Total phosphorus and chlorophyll *a* concentrations in the lake were reduced between years from 63 to 54 mg m^{-3} and 15 to 10 mg m^{-3} respectively. The model predicted 55 mg m^{-3} $[\overline{TP}]_{epi}$ and 13 mg m^{-3} $[\overline{chl\ a}]_{epi}$ for 1982.

When a lake model can be calibrated to fit specific characteristics of a watershed, it becomes a powerful management tool. It focuses attention of planners on management alternatives most likely to achieve intended goals. This study showed that proper management of an agricultural watershed can improve water quality of a receiving lake. Maintenance of established land-use practices and implementation of others at key sites on the watershed will likely result in continued improvement of this lake.

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

During 1978-1981, various land management practices were put in place on the agricultural watershed of Skinner Lake in Noble County, Indiana. The objective was to reverse the process of eutrophication in the lake. Studies reported here were conducted to evaluate the effectiveness of the program.

Skinner Lake had an average depth of 4.4 m, a maximum depth of 10 m and surface area of 49.4 ha. One hundred twenty-five permanent residences line the shore of the lake. Lake level was controlled by a concrete sill dam that was constructed in 1962. The lake discharged to the Croft Drain that entered the South Branch of the Elkhart River some 8.3 km downstream.

Stable thermal stratification during summer was characteristic of Skinner Lake. It existed from mid-May through mid-October. Figure 1 shows a typical temperature regime for the ice-free season. The hypolimnion approached anaerobic conditions rapidly as stratification became established (Figure 2). Relative areal oxygen deficits in the hypolimnion calculated for the interval 1 May through 15 May in 1978 and 1979 were in the range of 700-900 mg m^{-2} day^{-1}. Lakes with areal oxygen deficits greater than 550 mg m^{-2} day^{-1} have been considered highly fertile or eutrophic. Other expressions of eutrophy for Skinner Lake included extensive growth of aquatic macrophytes such as *Nymphaea odorata, Ceratophyllum demersum,* and *Myriophyllum spicatum,* and blooms of blue-green algae (*Aphanizomenon sp.*). The dominant fish in Skinner Lake included small sunfish (*Lepomis spp.*) and crappies (*Pomoxis spp.*), and a large rough fish population composed of the white sucker (*Catastomus commersoni*) and the golden shiner (*Notemigonus crysoleucas*). The lake's turbidity, algal blooms, macrophytes and low oxygen conditions were blamed for a general decline in fishing quality over the last two decades.

The Watershed

The area of Skinner Lake watershed was 3649 hectares, 68% of which was used for agriculture. The remaining 32% was in woodlands and wetlands. The Rimmell inlet was the most important continuously discharging surface flow to Skinner Lake (Figure 3). Eighty-two percent of the watershed (3091 ha) was within the Rimmell drainage system. Land there was put to varied crop and livestock use. Sub-

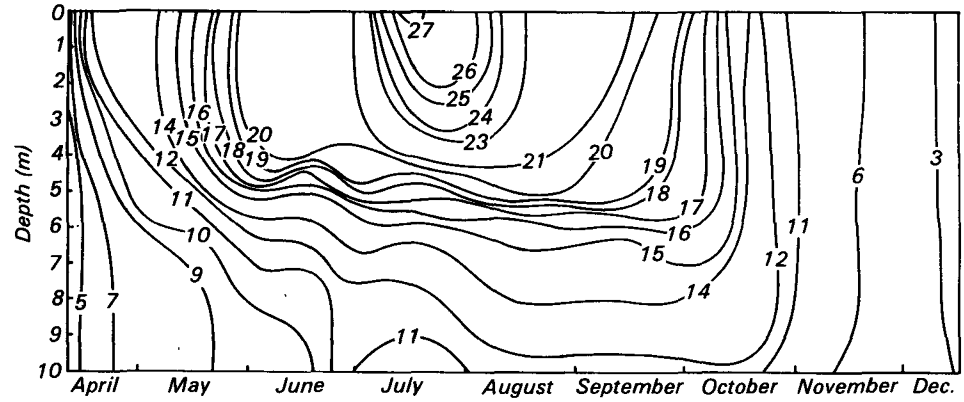


Figure 1. *Temperature isopleths (°C) for Skinner Lake during the ice-free season of 1979.*

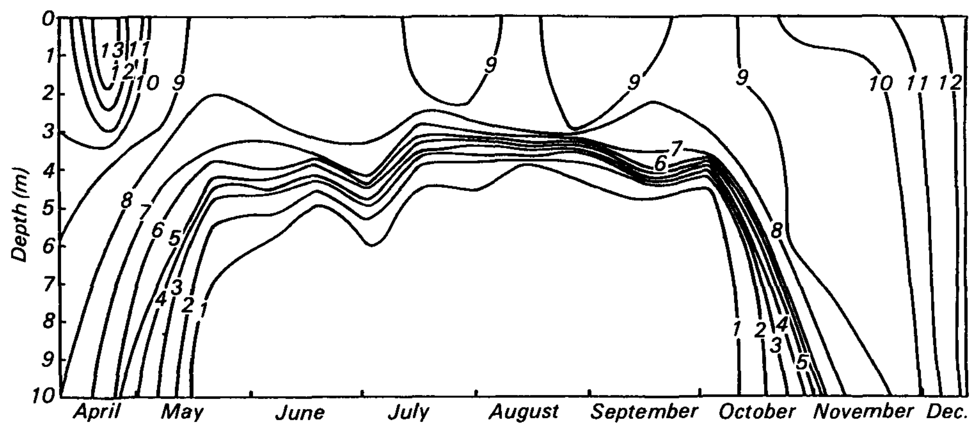


Figure 2. *Dissolved oxygen isopleths (mg l⁻¹) for Skinner Lake during the ice-free season of 1979.*

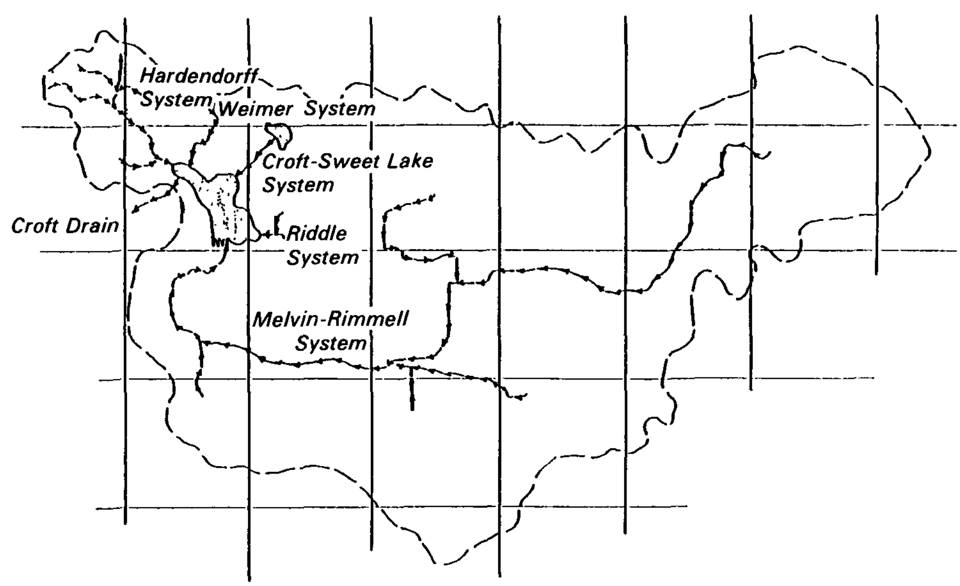


Figure 3. *The Skinner Lake watershed in Noble County, Indiana. Section boundaries form the grid shown.*

surface tiles were widely employed for drainage. Three smaller streams carrying tile and surface runoff entered the lake from agricultural land: the Hardendorff system drained 180 ha, the Riddle stream 107 ha, and the Weimer stream 42 ha of the watershed. The overflow from nearby Sweet Lake ran along a 0.8 km channel through a woodland to Skinner Lake. The Croft-Sweet system drained 229 ha of watershed.

The particular land treatment practices implemented on the watershed of Skinner Lake from 1978 to 1981 were chosen from the data and experience generated by the nonpoint-source pollution study of Black Creek in nearby Allen County, Indiana. These included settling basins, conservation tillage, group tile mains, terraces, livestock exclusion, diversions, grassed waterways, and planting vegetation on critical erosion sites. The work accomplished is shown in Figure 4.

Phosphorus - Algae Model

The product of the evaluation studies was a model which described the quantitative relationship between phosphorus concentration in inputs to the lake and algal biomass in the lake in the ice-free period of the year. This model was based on eutrophication models that were developed in the literature over the past several decades. More specifically, it resulted from a modification of a model developed by Vollenweider and Kerekes from data of 200 lakes in 50 countries participating in the Organization for Economic Cooperation and Development (OECD) Cooperative Program on Lake Eutrophication. Skinner Lake was considered phosphorus limited, rather than nitrogen limited, on the strength of high ratios of [TN]/[TP]. These ranged from 19 to 220 in Skinner Lake during 1979.

Modifications were made to the Vollenweider and Kerekes model by considering (1) major sources contributing to [TP] in loading to Skinner Lake, (2) seasonal differences in $[\overline{TP}]$ in input and water residence time of the lake (t_w), and (3) differences in epilimnetic and hypolimnetic $[\overline{TP}]$ during summer, and their relation to $[\overline{chl\ a}]$.

Atmospheric bulk loading to Skinner Lake over a 12-month interval in 1978-1979 amounted to 0.04 g TP m^{-2}. While this measurement fell within the range predicted for the geographical region, it constituted only 1.4% of the annual loading. Septic tank loading was estimated using a constant, 0.08 kg TP $caput^{-1}$ yr^{-1}. There were 125 cottages and approximately 375 people served by septic tanks around Skinner Lake. By this constant, they contributed 30 kg TP yr^{-1}. This septic tank loading comprised 2% of the 1978-79 annual TP load.

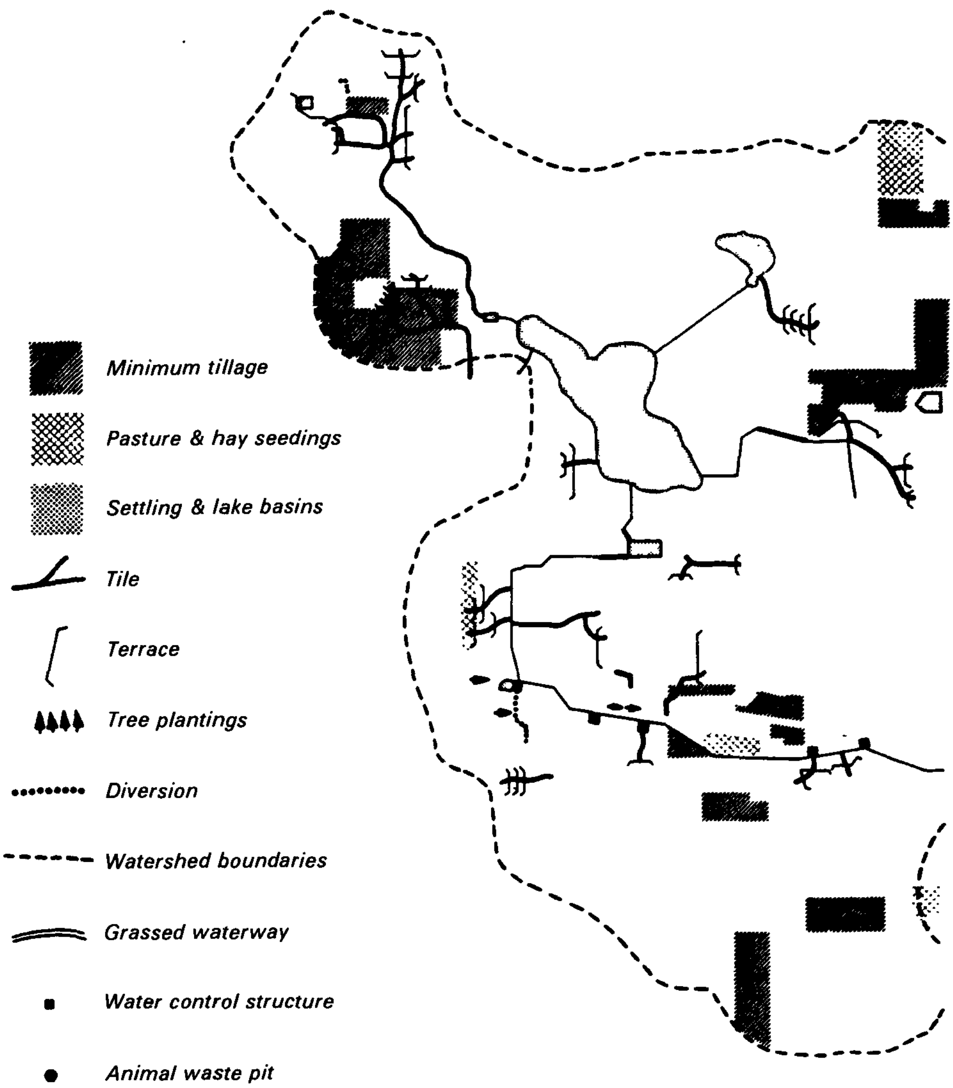


Figure 4 (a). *Land management practices applied to the west portion of the Skinner Lake watershed during 1979-1981.*

Estimates of internal phosphorus loading were calculated for intervals of the ice-free period of 1979 from the following:

$$TP_{Internal} = \Delta \text{ lake storage - } (TP_{in} - TP_{out})$$

where $TP_{Internal}$ was mass of TP internally loaded to Skinner Lake during an interval, TP_{in} was the mass of TP entering in stream flow, TP_{out} was the mass of TP exiting the lake, and Δ lake storage was the difference in mass the lake contained between the beginning and end of an interval. $TP_{Internal}$ was negative for intervals of measurement after ice-out until mid-July. By these calculations, a net loss of phosphorus occurred to sediments during that time. For the interval July 16 - October 3, internal loading to the water column was calculated to be 120 kg TP. This comprised 8% of the annual TP load to the lake in 1978-79. Of the sources of phosphorus, stream loading comprised 90% of the annual TP input to the lake.

Many lake models calculate $[\overline{TP}]$ in inflowing streams and mean lake [TP] by averaging data over an annual cycle. However, in the Skinner Lake system there was great seasonal variation in both [TP] in

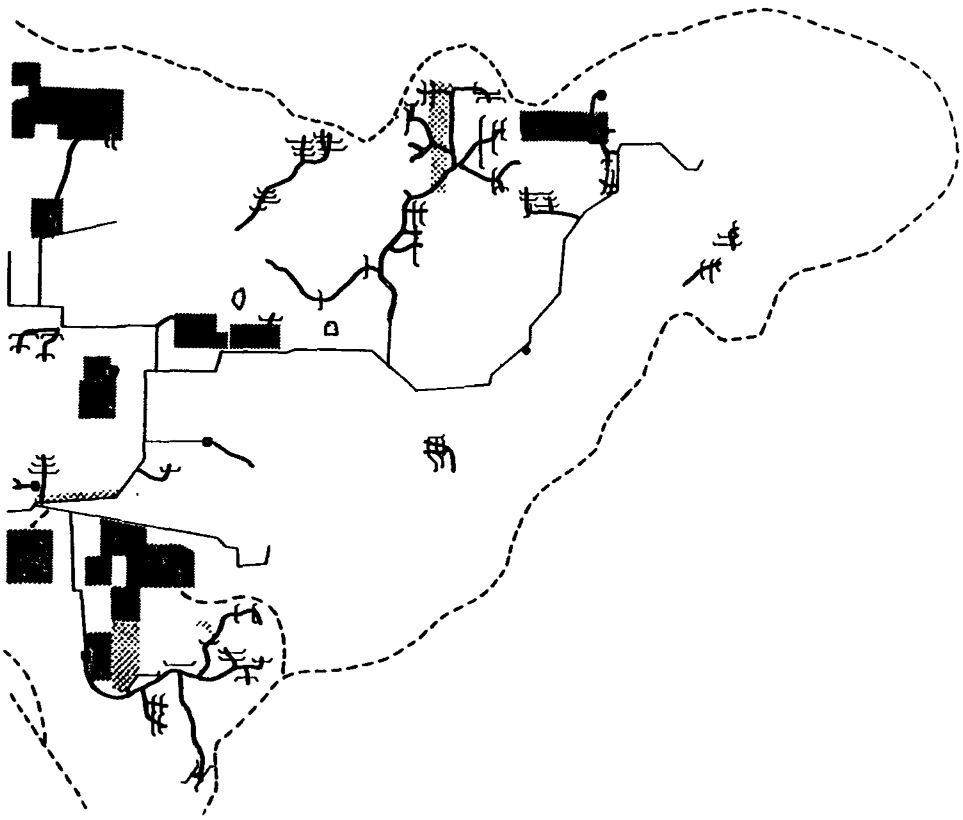


Figure 4 (b). *Land management practices applied to the east portion of the Skinner Lake watershed during 1979-1981.*

streams and t_w. These are illustrated in Table 1 and in Figure 5 for the principal stream discharging to Skinner Lake. Because of the high flushing rate during the spring overturn period (Table 1), TP inputs from streams during the preceding winter and period of spring snow-melt had little influence on $[\overline{TP}]$ in the lake during spring overturn and the following summer.

Table 1. *Flushing Coefficients (ρ = Volume Outflow/Volume Lake) of Skinner Lake during Periods of 1978-1979*

Period	*(ρ)*
Fall Overturn and Winter 9/6/78 - 2/6/79	0.02
Snow Melt 2/6 - 3/20/79	1.30
Spring Overturn 3/20 - 5/22/79	1.06
Summer Stratification 5/22 - 9/6/79	0.17
Whole Year 9/6/78 - 9/6/79	2.55

The following model fit the 1978-1979 data for Skinner Lake:

$$(1)\ [\overline{TP}_{epi}]_{ss} = \frac{[\overline{TP}_{stream}]_{ss}}{1 + t_{w_{ss}}^{1/2}}$$

In the model, ss is the period of spring overturn and summer stratification where the length of the spring period is defined as the interval prior to the onset of stratification during which the flushing coefficient (ρ) of the lake's epilimnion over the ss period is 1.0, $[\overline{TP}_{stream}]_{ss}$ is mean total phosphorus concentration in water delivered to the lake by inlet streams over the interval, and $t_{w_{ss}}$ is the residence time of water in the lake over the interval (reciprocal of ρ).

A major goal of this study was to predict $[\overline{chl\ a}]$ in the ice-free period from $[\overline{TP}]$ in Skinner Lake. The following relationship was generated from the data of 1979:

$$(2)\ \log\,[\overline{chl\ a}]_{ss} = 0.99\ \log\,[\overline{TP}_{epi}]_{ss} - 0.60$$

Model Tested and Results

Measurements were made in 1982 to test the predictability of the Skinner Lake model, and to put the effects of agricultural land treatment into perspective. The model proved to be a reasonable predictor of $[\overline{TP}_{epi}]_{ss}$ and $[\overline{chl\ a}]_{ss}$. In 1982, $[\overline{TP}_{stream}]_{ss}$ was 100 mg m^{-3} as compared to 127 mg m^{-3} in 1979. Concomitant decreases in $[\overline{TP}_{epi}]_{ss}$ and $[\overline{chl\ a}]_{ss}$ were expected as predicted by equations (1) and (2). Predicted $[\overline{TP}_{epi}]_{ss}$ was 55 mg m^{-3}; observed was 54 mg m^{-3}. Predicted $[\overline{chl\ a}]_{ss}$ was 13 mg m^{-3}; observed was 10 mg m^{-3}.

Figure 6 is a graphical representation of the Skinner Lake model, modified from the work of Vollenweider and Kerekes. This figure illustrates that given $[\overline{TP}_{stream}]_{ss}$ and t_w, $[\overline{TP}_{epi}]_{ss}$ is predicted. Curves across the figure give expected $[\overline{chl\ a}]_{ss}$. The figure also shows boundaries of trophic categories (ultraoligotrophic to hypertrophic) as presented by Vollenweider and Kerekes. These represent the synthesis of opinions of OECD investigators as to the trophic classification of lakes they studied.

Figure 6 shows an improvement in the condition of Skinner Lake between 1979 and 1982. Reduction in $[\overline{TP}_{stream}]_{ss}$, $[\overline{TP}_{epi}]_{ss}$ and $[\overline{chl\ a}]_{ss}$ occurred. This improvement was due to land management practices implemented on the watershed during 1978-1981, and/or to ordinary between-

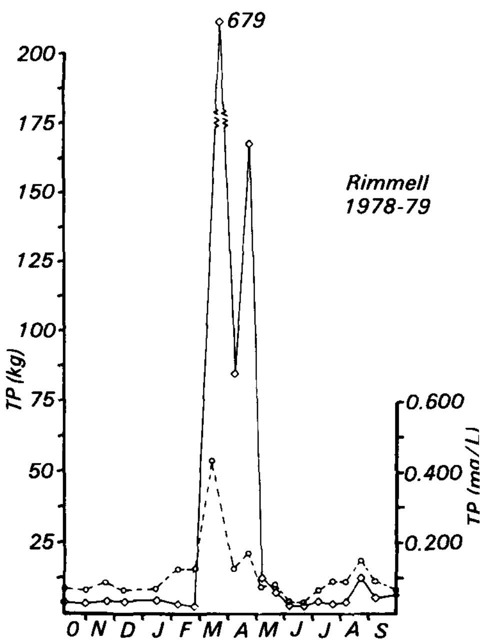
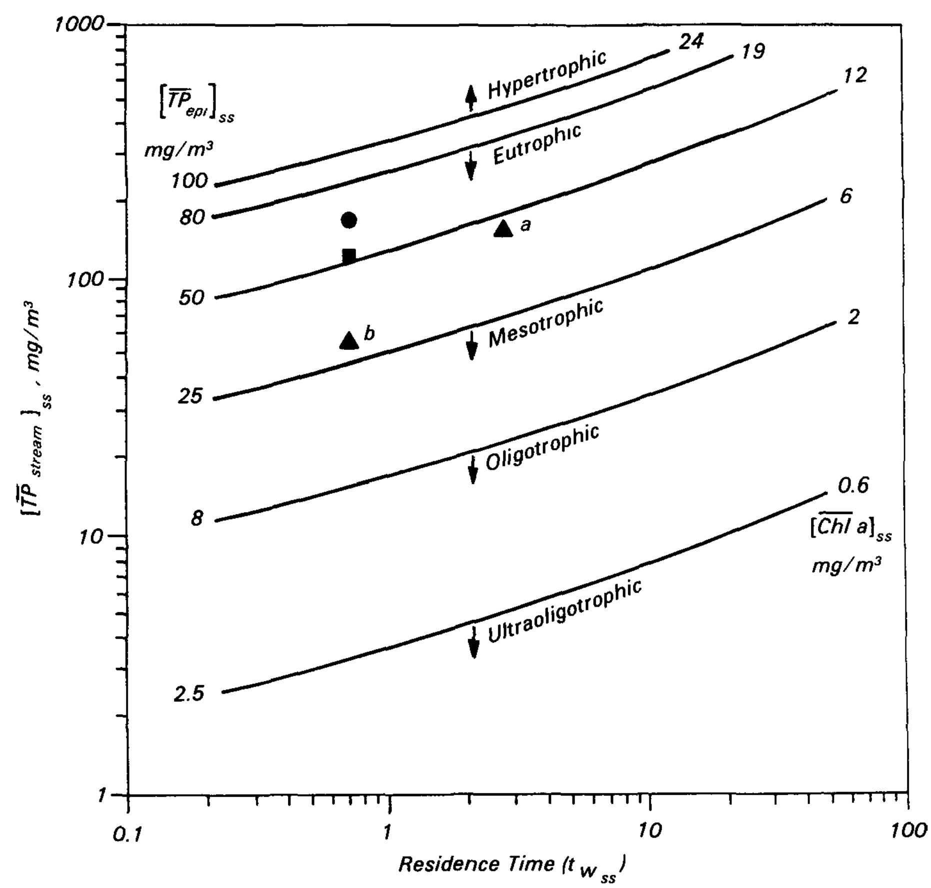


Figure 5. *Concentration (mg l^{-1}) and mass (kg) of total phosphorus (TP) delivered to Skinner Lake by the Rimmell inlet during 1978-1979.*



● represents plot of Skinner Lake coordinates of 1979.
■ represents plot of Skinner Lake coordinates of 1982.
▲a probable case for Skinner Lake with diversion of Rimmell stream around lake to outlet stream;
▲b probable case for Skinner Lake if settling basin on Rimmell stream removed 100% TP in stream discharge.

Figure 6. *Diagramatic representation of the Skinner Lake model.*

year variability in the systems. It should be noted that by definition of variables in the Skinner Lake model, comparable portions of the water-year in 1979 and 1982 were used in this study. Between-year differences in rain events on the watershed, for example, differences in the intensity of individual events and associated differences in erosional runoff, were minimized by the model. The time interval over which $t_{w_{ss}}$ was calculated was nearly the same for both years, as was the value to $t_{w_{ss}}$ (0.63 in 1979 and 0.65 in 1982). Unusually intense storms did not occur in those intervals in either year. It is probable that land management was the primary cause for the improvement observed in Skinner Lake during this study. However, ordinary between-year variability was not measured in the system during years prior to land treatment, and only a continuing trend of improvement with maintenance of existing practices and implementation of others on the watershed in the years ahead will confirm this.

Applications

A calibrated model fit to a specific lake's characteristics becomes a useful management tool. One treatment considered by planners of the Skinner Lake project was diversion of the Rimmell stream directly to the lake's outlet. Contours of the existing landscape favored such an approach. Compensation for disrupting intervening land use would have been costly. The Skinner Lake model could predict the effect of this strategy if, for example, it had been implemented in 1979. Figure 6 shows that diversion of the Rimmell would not have lowered $[\overline{TP}_{stream}]_{ss}$ appreciably. Other inlets were important in determining total $[\overline{TP}_{stream}]_{ss}$. Because the Rimmell provided a large percentage of inflow water to Skinner Lake, diverting the stream would have increased $t_{w_{ss}}$ from 0.63 to 2.35. The net effect of diverting the Rimmell would have been to reduce the $[\overline{TP}_{epi}]_{ss}$ from 63 mg m^{-3} to 45 mg m^{-3}, and $[\overline{chl\ a}]_{ss}$ from 15 mg m^{-3} to 11 mg m^{-3}. Another alternative for reducing the effect of runoff and nutrients on the lake was a settling basin on the Rimmell stream just above its inlet to Skinner Lake. On the basis of 1979 data, if the basin removed 100% of particulate phosphorus from the water, $[\overline{TP}_{stream}]_{ss}$ would have been reduced from 127 mg m^{-3} to 52 mg m^{-3}, $[\overline{TP}_{epi}]_{ss}$ from 63 mg m^{-3} to 20 mg m^{-3}, and $[\text{chl}\ a]_{ss}$ from 15 mg m^{-3} to 7.5 mg m^{-3}. As shown in Figure 6, this would represent a considerable improvement in water quality at Skinner Lake.

Expectations in these examples provide a focus for considering costs and benefits of various strategies for land management and lake improvement. Results of this study call attention to the need for site-specific information on which to base cost-benefit judgements.

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***Spencer A. Peterson** is the EPA Project Officer (see below).*
The complete report, entitled "Response of Skinner Lake (Indiana) to Agricultural Drainage," (Order No. PB 83-233 676; Cost: $10.00, subject to change) will be available only from:
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