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Project Summary

Agricultural Runoff and Reservoir Drawdown Effects on a 2760-Hectare Reservoir

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The 2760-hectare Big Eau Pleine Reservoir in Marathon County, Wisconsin has experienced frequent winter fish kills and summer algae blooms since its construction in 1937. From 1974 to 1979 a study of the reservoir and its 945-km^2 watershed was conducted in an attempt to identify and quantify the sources of water quality problems and recommend management practices to reduce these problems.

Land use and nutrient loading studies in the watershed identified agricultural runoff, especially animal waste, as the major source of nutrient loading. Total phosphorus loss from the watershed averaged 0.59 kg/ha/yr for the 4-year period with approximately 60 percent occurring during the spring snowmelt and runoff season. Hydrologic and soil erosion modeling indicated that the greatest runoff and soil erosion occurred during spring snowmelt and that much of the erosion and runoff originates on the lower slopes and alluvial soils.

Reservoir studies identified *Aphanizomenon flos-aquae* as the major bloom-producing alga. Chlorophyll *a* values for the four summers averaged 105 μg/l, ranging from 65 in 1978 to 120 in 1976. Yearly variations in chlorophyll *a* did not correlate with differences in yearly or seasonal total phosphorus loading from external sources. Internal phosphorus loading appeared to be more important in determining summer algae blooms; much of the internal loading is believed to be from drawdown-related resuspension of sediments. Total phosphorus levels in the reservoir begin to increase at about the same time as summer drawdown begins.

Winter oxygen problems in the reservoir were related closely to reservoir drawdown. Sediment oxygen demand, long-term BOD studies, and reservoir monitoring showed that while considerable oxygen was lost over winter due to biological reactions, the reservoir would not go anaerobic. Winter drawdown was found to result in scouring of sediments high in BOD as the reservoir was gradually drawn down to the old river channel. This scouring resulted in rapid loss of the remaining oxygen as drawdown moved progressively down the reservoir.

Recommendations include controlling animal-waste spreading during winter and increased use of conservation practices, especially on lower slope portions of the watershed, including fencing streams at least 30 feet from the stream channel. Recommended reservoir management changes include delaying summer drawdown to minimize internal phosphorus loading, delaying winter drawdown to at least mid-January, and increasing minimum pool volume by 25 percent.

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

The 2700-hectare Big Eau Pleine Reservoir in Marathon County, Wisconsin, has a history of excessive algal growth and winter fish kills. Several major kills in the early and mid-1970s resulted in demands by the public for corrective action. Other studies have labeled the reservoir very eutrophic and identified agricultural runoff as the major source of nutrients.

The present study, initiated in 1974, was an attempt to identify the relationship of nutrient sources and reservoir management to the trophic conditions and the winter oxygen problem and to make recommendations for alleviating these problems. Computer models were used to characterize the watershed hydrology, soil erosion and nutrient runoff characteristics. Another computer model was used to quantify the limnological processes occurring in the reservoir.

The 945-km^2 watershed is characterized by rolling topography; its silt loam surface soils are underlain by fairly impermeable dense glacial till or residuum. This creates ideal conditions for surface runoff during snowmelt or heavy rains. The reservoir, built in 1937 to augment the flow of the Wisconsin River, has an annual water level fluctuation of about 9 meters, amounting to over 95% of its total volume.

Results

There were three major components of the project:

1. A land use survey covering 3 percent of the total watershed area, with use of the universal soil loss equation to determine conservation needs on each field in the sample.
2. A modeling project to relate hydrologic characteristics in seven sub-basins of the Hanann Creek sub-watershed to nutrient loss and land use.
3. A soil erosion modeling project to relate sediment and associated nutrient loss to land use and watershed characteristics.

The soil erosion modeling project showed that 60 to 70 percent of erosion occurred during spring snowmelt and runoff. This finding required the calculation of a new rainfall factor for the watershed to use in the soil loss equation, e.g., a factor of 184 compared to 125-150 based on the Soil Conservation Service annual erosion index. This finding is consistent with data on nutrient loading which is also highest in early spring.

Results from both the soil erosion and the hydrologic models indicate that the largest overland flow and soil erosion occur on the lower slope portions nearest the stream. Soil transport to the stream was lowest where there was a permanent vegetation strip between cultivated fields and the stream channel, supporting the concept of vegetated buffer strips to reduce sediment and nutrient transport to streams. Winter manure spreading on these lower slope areas should be avoided.

The land use survey revealed the following percentages of total land use: corn, 13.8; oats, 14.4; hay, 29.5; pasture, 22.3; forest, 14.0; idle land, 2.1; other, 4.2.

Results of the soil erosion project indicated that the average soil loss for the watershed was 4.82 metric tons per hectare compared to the "allowable soil loss" established by the Soil Conservation Service of 6.72 metric tons/ha. Twenty-four percent of the total land area exceeded the allowable soil loss.

Cost estimates for erosion control are presented in Table 1. These costs are based on 13 soil conservation plans for erosion control in the Big Eau Pleine Watershed and on 1978 cost estimates. Major practices recommended were diversions and grass waterways with lesser amounts of contour strips and terraces. The additional expense of controlling nutrient loss from barnyards and manure storage facilities would increase this cost greatly.

Reservoir Studies

Nutrient loading

Nutrient and BOD inflow and outflow to the reservoir were determined using daily values collected with an autometer sampler on the Big Eau Pleine River and bi-weekly samples from other tributaries and at the dam. Table 2 shows the annual summary of these data for the four years of the study. Daily, monthly and yearly data vary considerably because of annual differences in rainfall. Total phosphorus loading alone ranged between 26.4 to 83.3 metric tons per year; greatest loading occurred in the early spring, except in 1978, when heavy July rain created large summer runoff events. Nitrogen and BOD loading followed the trend observed for phosphorus.

Reservoir discharge and retention of nutrients was almost as variable as loading because of rainfall and runoff variability and the effect of reservoir management on nutrient retention.

Phytoplankton response to nutrient loading was determined by chlorophyll analysis, supplemented by ^{14}C primary production studies and plankton counts during 1975 and 1976. Primary production for 1975 and 1976 was 340 and 685 gC/m^2, respectively; mean summer chlorophyll values were 52.2 and 103 mg/l. These data support previous studies indicating that the reservoir is hypereutrophic with summer phytoplankton dominated by *Aphanizomenon flos-aquae.*

Total phosphorus loading and chlorophyll *a* data presented in Figure 1 and Table 3 indicate that the annual phosphorus loading does not correlate closely enough to chlorophyll *a* levels to use simple phosphorus loading models for the Big Eau Pleine Reservoir. Seasonal phosphorus loading as represented in Figure 1 also shows poor correlation to chlorophyll *a*.

In this reservoir, the major processes affecting annual primary production are seasonal phosphorus loading from agricultural runoff, internal phosphorus loading, solar radiation, and retention

Table 1. *Estimates of Cost to Implement Various Soil Conservation Practices for Erosion Control in the Big Eau Pleine Watershed*

Area to be Treated	*Cost per Ha*	*Total Cost Estimate (Rounded)*	*Basis for Treatment*
14,928 ha	*$155.14*	*$2,300,000*	*Areas exceeding 6.7 tons/ha soil loss using rainfall factor 125-150*
23,587 ha	*$155.14*	*$3,700,000*	*Areas exceeding 6.7 tons/ha soil loss using rainfall factor 184*
55,315 ha	*$155.14*	*$8,500,000*	*All cropland*

Table 2. *Yearly Inflow and Outflow of Nitrogen, Phosphorus, and BOD, and Water Volumes for the Big Eau Pleine Reservoir 1975-1978 (Metric Tons)*

	1975		1976		1977		1978		Total	
	In	Out	In	Out	In	Out	In	Out	In	Out
Total Phosphorus	63.4	16.2	50.5	56.4	26.4	4.8	83.3	50.9	223.6	128.3
Reactive Phosphorus	41.7	8.4	27.0	23.5	19.0	2.3	53.7	20.9	141.4	55.1
Kjeldahl Nitrogen	312.2	241.4	451.6	523.7	168.4	66.3	530.1	647.1	1462.3	1478.5
NO_3 & NO_2 Nitrogen	168.9	34.2	195.8	114.1	77.4	15.9	224.3	106.1	666.4	270.2
BOD_5	650.1	504.0	402.6	896.6	148.4	107.6	565.7	1697.8	1803.2	3206.0
Water (Hectometers)	204.5	179.7	222.2	328.2	132.6	63.6	369.2	454.4	928.5	1025.9

Table 3. *Yearly and Seasonal Total Phosphorus Loading, Summer Drawdown, and Average Chlorophyll* a *Values for the Big Eau Pleine Reservoir*

	Total P Inflow (Metric Tons)			Summer Drawdown Meters	Average Chlorophyll a (mg/l)
	Yearly	Jan. 1-July 1	June 1-Sept. 1	June 1-Sept. 1	July-August
1975	63.4	44.2	5.3	1.31	104
1976	50.4	48.9	1.4	2.53	126
1977	26.4	9.0	1.5	0.61	105
1978	83.3	36.6	33.1	0.0	65

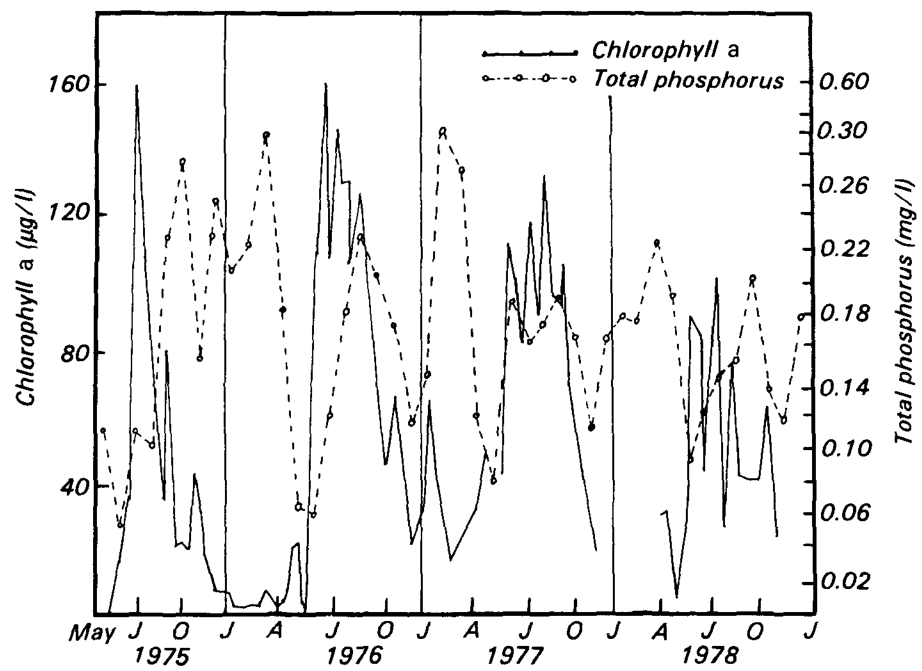

Figure 1. *Chlorophyll* a *and total phosphorus for the Big Eau Pleine Reservoir 1975-1978.*

time. While all are important, the data generated during this project indicate that internal loading from sediment disturbance during reservoir drawdown is a major factor affecting phosphorus levels and primary production. Figure 2 shows the relationship between reservoir volume and total phosphorus concentrations. Phosphorus levels are high following spring runoff, decline rapidly, increase again when summer drawdown is initiated and then remain high throughout the summer. The exception was during 1978, when heavy rains kept water levels near capacity for the entire summer, resulting in a more rapid water exchange, little sediment disturbance, more turbid water and consequently lower chlorophyll levels (Figure 2).

Reservoir Oxygen Relationship

Studies of oxygen demand by runoff water, phytoplankton and sediments showed that large increases of both BOD_5 and sediment oxygen demand result from summer phytoplankton populations. It was, however, found that

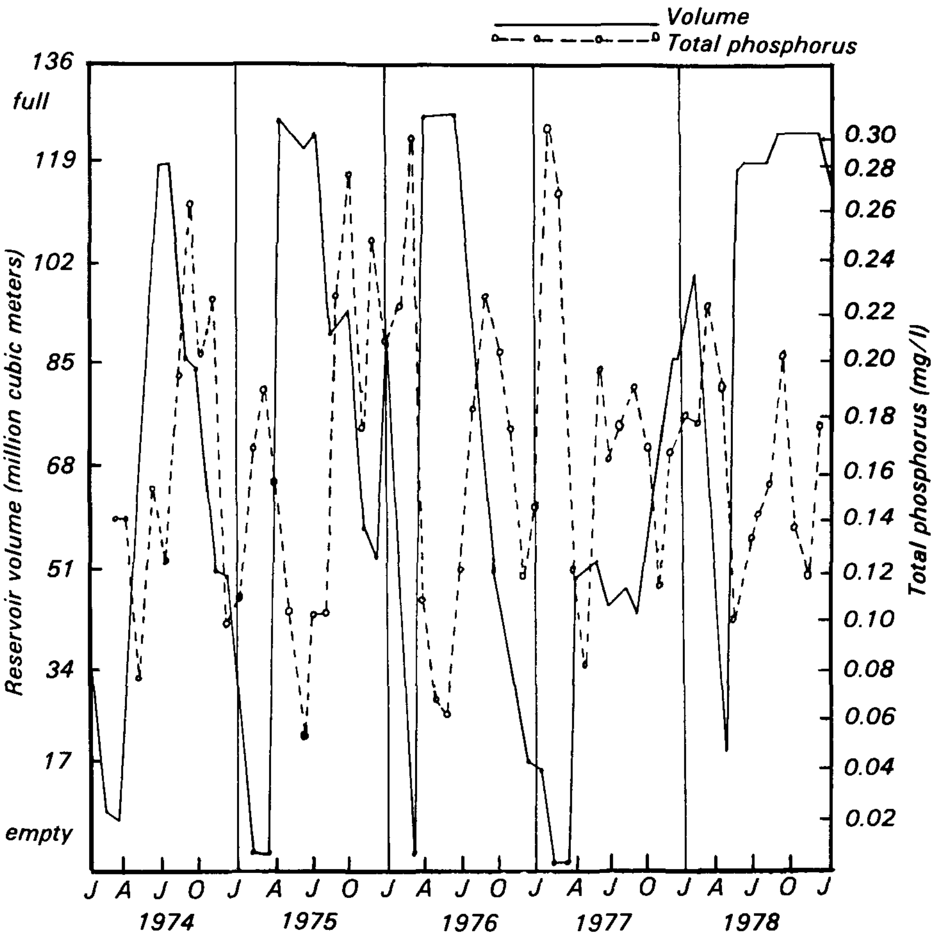

Figure 2. Reservoir volume and total phosphorus concentrations for the Big Eau Pleine Reservoir 1974-1978.

these oxygen demands alone are unlikely to result in the complete oxygen depletion that occurs in the reservoir during the winter. Winter oxygen depletion was found to occur from the bottom upward and gradually throughout the water column, as is typical of eutrophic lakes. However, as winter drawdown progresses, often there is a complete loss of oxygen beginning at the upper end of the reservoir and moving gradually downstream. This process is believed to be caused by scouring and resuspension of sediments high in settled organic matter, and therefore oxygen demand, as the reservoir is drawn down to its old river channel. This often occurs when the reservoir volume is reduced to about 40 percent of its capacity (Figure 3).

Conclusions

The problems in the Big Eau Pleine Reservoir are due both to land-use activities in the watershed and to reservoir management.

The main cause of high nutrient loading to the reservoir is agriculture and related activities in a watershed where surface runoff is seasonally high. Family-owned dairy farms account for over 90 percent of the land-use in the watershed; winter spreading of manure and cattle grazing up to and often through the stream channel are very common. These sources of animal wastes, coupled with fertile soils that have slow infiltration rates, result in high nutrient losses to the drainage.

The heaviest nutrient loss from the watershed occurs during snowmelt and spring rains which coincide with the period when the reservoir is being refilled after winter drawdown. Approximately 60 to 70 percent of the annual total phosphorus load enters the reservoir during March and April.

The spring runoff results in initially high total phosphorus concentrations in the reservoir (0.2 mg/l), which stimulate an early bloom of diatoms and green algae. However, the phosphorus concentration decreases rapidly due to sedimentation and algal uptake and only begins to increase again when water levels are lowered. Phosphorus is released by wind agitation of sediments exposed during drawdown and, to a lesser extent, from anaerobic sediment release. This process increases total phosphorus concentrations throughout the drawdown period which, in turn, support exceptionally large blooms of *Aphanizomenon flos-aquae.*

Winter oxygen depletion in the reservoir and subsequent fish kills are, however, the major water quality concern. Oxygen depletion proceeds from the bottom upward as is common in eutrophic lakes. But this process alone would not result in anaerobic conditions throughout the entire reservoir. As drawdown proceeds, the upstream portions of the reservoir are converted to a river condition, resulting in resuspension of sediments that have accumulated in the deeper water during spring runoff events and summer algae production. Because these sediments are anaerobic and high in organic matter, reduced iron and sulfur, they extract any remaining oxygen in the water they contact. Thus, the condition moves downstream, gradually removing remaining oxygen in the lower reaches of the reservoir as drawdown and sediment resuspension continue. During winters with high tributary flows and delayed drawdowns, less severe oxygen depletion occurs.

The computer models used in this project were generally helpful in quantifying environmental processes and in identifying major factors to be considered in solving the watershed and reservoir problems. However, all of the models used need further refinement; ideally they should be linked to make modeling a more useful management and research tool.

Recommendations

Solutions to the water quality problems in the Big Eau Pleine Reservoir are expensive and complex. Recommended actions fall into two categories—land use and reservoir management.

A. Land Use

1. Overwinter manure storage should be provided on each farm; manure applied to the land should be incorporated into the soil without delay.
2. Stream channels should be fenced to exclude livestock, except at

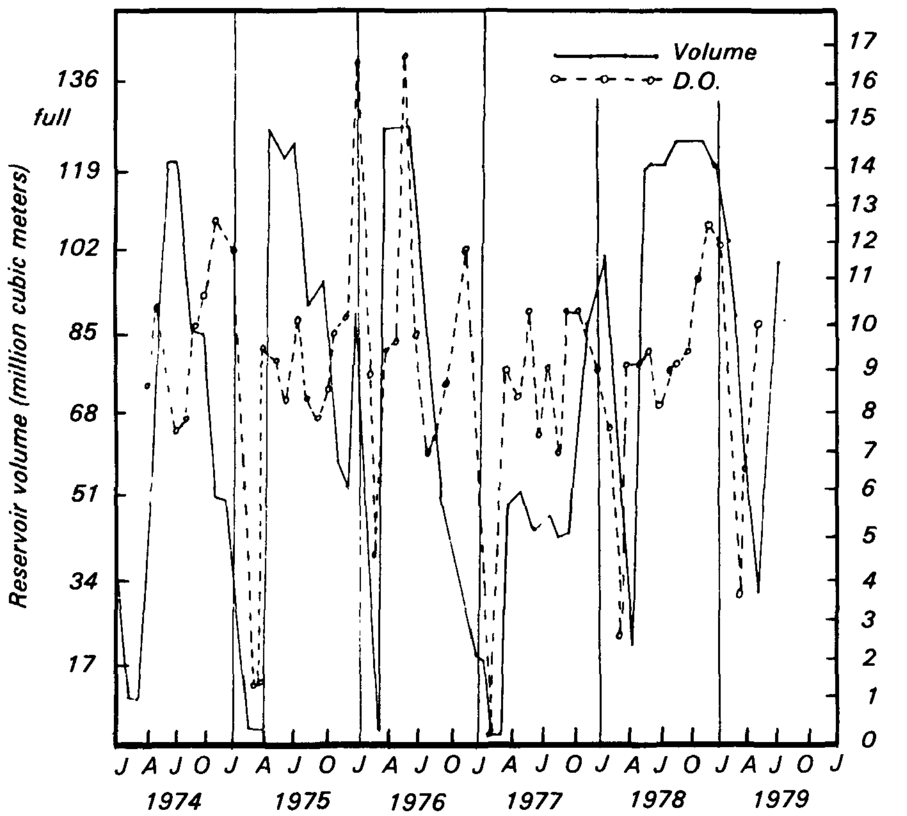

Figure 3. Reservoir volume and dissolved oxygen for surface samples 1974-1979.

well-chosen watering sites. Buffer strips should be a minimum of nine meters on each side of the stream.

3. Soil conservation plans should be prepared and implemented on each farm to reduce soil erosion and associated nutrient loss.
4. Small runoff-retention ponds should be constructed to act as sediment and nutrient traps and thus result in higher base flow levels in the river by increasing ground-water recharge.
5. Land disposal of cheese factory wastes should follow the same procedures as for animal wastes. However, caution must be used to avoid overloading soils, since these wastes are very high in nitrogen and phosphorus. Lagoon storage and summer spreading would prevent much of the present nutrient loss.

B. Reservoir Management

Even if all of the proposed land-use recommendations were followed, there probably would still be serious water quality problems in the Big Eau Pleine Reservoir. The following guidelines would be helpful in managing the reservoir to overcome existing problems and those that will persist even after land-use practices have improved.

1. Summer nutrient levels and resulting algae blooms could be reduced:
   a. If early spring runoff, which has the highest phosphorus levels, could be allowed to flow through the reservoir before refilling is started. This would reduce the amount of phosphorus retained in the reservoir for use by algae later in the year. However, this procedure could only be followed during years in which a large snow pack exists.
   b. Since resuspension of sediment phosphorus has been shown to be a significant source for summer algae blooms, it would be desirable to hold the reservoir at as constant a level as possible, using short periods of rapid drawdown instead of constant slow drawdown.
2. Winter oxygen problems could be minimized by:
   a. Allowing the reservoir to fill as much as possible during the fall prior to freeze-up.
   b. Delaying any winter drawdown until at least mid-January.
   c. Stopping drawdown when the reservoir volume is reduced to 25 percent of the full volume.

If these recommendations are not feasible for economic or political reasons, it may be possible to minimize winter fish kills using mechanical aeration; however, even with aeration, a modified drawdown may be necessary.

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The complete report, entitled "Agricultural Runoff and Reservoir Drawdown Effects on a 2760-Hectare Reservoir," (Order No. PB 82-186 529; Cost: $9.00, subject to change) will be available only from:
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