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# Phosphorus removal by sedimentation in some Iowa reservoirs[1]

JOHN R. JONES and ROGER W. BACHMANN

With 2 figures and 2 tables in the text

Data from natural lakes have been used to develop relationships between the annual inputs of nutrients to lakes and limnological measures of their trophic states (VOLLENWEIDER 1969, 1976; DILLON & RIGLER 1974; LARSEN & MERCIER 1975; JONES & BACHMANN 1976; CHAPRA & TARAPCHAK 1976). With reasonable success, these models relate annual phosphorus loading, hydrology, and morphology to the concentrations of total phosphorus (TP) and chlorophyll *a* in natural water bodies covering a wide trophic range. We have found, however, that these models cannot be used directly to predict P concentrations in artificial reservoirs (JONES & BACHMANN 1976). This study was designed to examie the P input-output relationships in several central-Iowa impoundments.

## Methods and materials

Morphometric and watershed data for the reservoirs studied, Big Creek, Don Williams, Hickory Grove, and McFarland, are summarized in Table 1. Inflowing streams to each reservoir were monitored every 10—15 days from January 1974 through June 1975 to estimate the annual inputs of TP. Areas monitored represent approximately 94 % of the Big Creek and Don Williams watersheds and 70 % of the Hickory Grove and McFarland watersheds. Inputs from areas where runoff was not monitored were based on an areal proportion of the monitored region of each watershed. This sum represents the terrestial input to the respective reservoirs. The contribution of rainfall was small compared with terrestial inputs and was not considered.

Sampling of limnological parameters within the reservoirs began in July 1973 and continued through August 1975. Additional sampling was done during the spring and summer of 1974 and summer of 1975 in 17 natural lakes and Beeds and Pine reservoirs. P loading rates for these reservoirs were estimated from watershed areas by using an average annual output of 0.35 kg/ha of P, which is typical for nothern Iowa (JONES, BOROFKA & BACHMANN 1976).

All TP analyses (MURPHY & RILEY 1962) were made after a persulfate oxidation (MENZEL & CORWIN 1965). Samples for total dissolved P were filtered through a 0.45-$\mu$m membrane filter and treated as TP. Chlorophyll *a* was extracted by use of the methods of YENTSCH & MENZEL (1963) and calculated according to the equations of PARSONS & STRICKLAND (1963).

## Results

Values for P loading and average July—August TP concentrations for the four reservoirs are given in Table 1. On the average, the watersheds lost 1.08 kg/

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Table 1. Morphometric characteristics, hydraulic flushing coefficient, estimated TP loading, mean total phosphorus concentration, summer total phosphorus values (1973, 1974 and 1975), and range of calculated P values based upon published models for Big Creek, Don Williams, Hickory Grove, and McFarland reservoirs.

| Parameter | Big Creek | Don Williams | Hickory Grove | McFarland |
|---|---|---|---|---|
| Area (ha) | 358 | 65 | 40 | 2.7 |
| Volume ($1 \times 10^6 \times m^3$) | 19.2 | 3.3 | 2.0 | 0.07 |
| Mean Depth (m) | 5.4 | 5.1 | 4.9 | 2.5 |
| Flushing coefficient ($yr^{-1}$) | 3.4 | 8.3 | 3.3 | 9.0 |
| Drainage area (ha) | 19,095 | 7930 | 1854 | 172 |
| TP loading ($gm/m^2$) | 7.20 | 6.39 | 6.20 | 7.11 |
| Mean TP concentration ($mg/m^3$) of the inflow | 389 | 151 | 386 | 315 |
| Open-water TP ($mg/m^3$) (July—August) | | | | |
| 1973 | 22 | 40 | 27 | 63 |
| 1974 | 34 | 24 | 28 | 50 |
| 1975 | 22 | 31 | 41 | 84 |
| Mean value | 26 | 32 | 32 | 66 |
| Range of calculated P values | 234—329 | 93—122 | 193—320 | 169—295 |

ha of TP, with 66 % being in fractions retained by a 0.45-$\mu$m filter. We used various published P models to predict the concentration in the reservoirs (VOLLENWEIDER 1969, 1976; DILLON & RIGLER 1974; LARSEN & MERCIER 1975; JONES & BACHMANN 1976; CHAPRA & TARAPCHAK 1976) and found that these models overestimate summer P values in the reservoirs by approximately 3 to 10 times (Table 1). Artificial lakes in Iowa, therefore, have much lower TP levels than would be expected on the basis of relationships worked out in natural lakes.

It is proposed that this overestimation results from greater P sedimentation rates in the artificial than in natural lakes. We had previously found that a sedimentation coefficient of 0.65 in the VOLLENWEIDER (1969) model worked quite well for predicting P levels in natural lakes covering a wide range of trophic states (JONES & BACHMANN 1976). For the reservoirs studied, we know the value of all variables in the VOLLENWEIDER model except sedimentation (Table 1). When sedimentation coefficients for these reservoirs are estimated by rearranging the VOLLENWEIDER equation, the values range from 31 to 48. The mean value of 37 is two orders of magnitude greater than the coefficient used for natural lakes, but likely is a reasonable estimate of P sedimentation in these reservoirs. Substituting this value into the VOLLENWEIDER equation with data from Beeds and Pine reservoirs located in north-central Iowa, we find good agreement between observed and predicted P concentrations (Table 2).

In support of this idea of enhanced P sedimentation is the finding that, unlike the natural lakes, the open-water TP concentrations in the reservoirs decline sharply from spring to summer. In 1974, TP measurements were made during the growing season in 17 natural lakes in addition to the 6 artificial reservoirs. P levels in the natural lakes did not change from spring to summer,

Table 2. Phosphorus loading, morphometric data, and observed and predicted P concentrations in Beeds and Pine reservoirs.

| Lake | Phosphorus loading gm/m² | Flushing rate yr⁻¹ | Mean depth (m) | Observed TP (mg/m³)[a] | Predicted TP (mg/m³) |
|---|---|---|---|---|---|
| Beeds | 6.67 | 9.0 | 2.9 | 48 | 50 |
| Pine | 5.51 | 9.1 | 2.8 | 44 | 43 |

[a] Mean of July—August 1974 and 1975 values.

with late-summer values averaging 97 % of spring concentrations. In the reservoirs, however, there were sharp drops in the P concentrations during this period, with late-summer values averaging only 37 % of spring concentrations (Fig. 1). This difference between the seasonal P dynamics in natural and artificial lakes occurs in other water bodies and is not just an Iowa phenomenon (Shiomi & Chawla 1970; Emery, Moon & Welch 1973; Shapiro & Pfannkuch 1973; Stewart & Markello 1974; Goodwyn 1975).

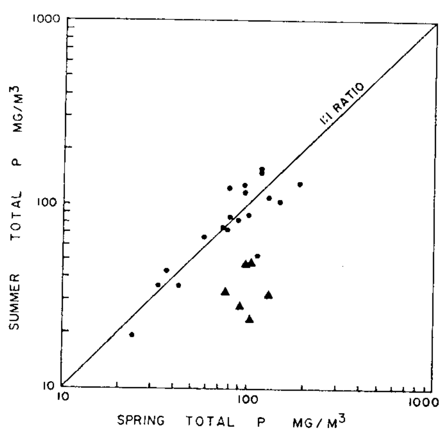


Fig. 1. Relationship between TP concentrations measured in the spring and late summer for lakes and reservoirs in Iowa. The triangles represent artificial lakes, and the circles natural lakes.

Differences in the sedimentation characteristics between the natural and artificial lakes could be related to differences in the inputs of inorganic particulate materials in these two classes of lakes. The natural lakes in Iowa lie in glaciated depressional topography and generally do not have well-defined tributary streams. The artificial reservoirs, however, are built in the valleys of erosional topography and have one or two major tributary streams. Although we are lacking sufficient data on inputs of suspended solids to test this idea, it is worth noting that the natural lake basins have persisted for the past 11,000 years since the last glaciation and that the artificial reservoirs generally have projected useful lives on the order of 100 years, indicating greater physical sedimentation.

These reservoirs receive the largest inputs of P associated with silt during the spring runoff. This is the period of minimum transparencies and maximum P concentrations in these waters because of the suspended silt (Jones & Bach-

MANN unpubl). As the silt settles from the water column during the summer, transparency improves, and P concentrations decrease. Late-summer transparencies are determined by algal populations. In contrast, transparencies decrease as the summer progresses in natural lakes, corresponding to the increased algal populations during the growth season with relatively little change in P concentration. By late-summer, algal populations in these artificial lakes bear the same relationship to measured TP concentrations as has been found in natural lakes (Fig. 2). Algal populations, therefore, are responsive to P concentrations among reservoirs and within individual reservoirs as has been observed in natural lakes (JONES & BACHMANN 1976; DILLON & RIGLER 1974).

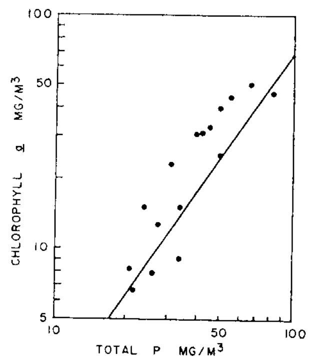


Fig. 2. Relationship between average July—August chlorophyll *a* concentrations and TP concentrations for the following artificial lakes: Beeds (1974 and 1975), Big Creek (1973, 1974 and 1975), Don Williams (1973, 1974 and 1975), Hickory Grove (1973, 1974 and 1975), McFarland (1973, 1974 and 1975), and Pine (1974 and 1975). The line represents the regression calculated for these variables in 143 lakes covering a broad range of trophic states (JONES & BACHMANN 1976).

## Discussion

The limnology of these central-Iowa reservoirs is dominated by the spring to summer decline of open-water P concentrations, which is a function of the high P sedimentation rate. Because of high P sedimentation, open-water P concentrations are less than would be expected from P loading models developed by using data from natural lakes. For this reason, Iowa reservoirs are less eutrophic than natural lakes at a given P load.

This study indicates that caution is necessary in applying existing P loading models to artificial reservoirs. In our case, sedimentation coefficients two orders of magnitude greater than those used for natural lakes were necessary to calculate the summer P levels. More work will be needed on other reservoirs before a generalized model can be proposed.

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Authors' addresses:

Dr. J. R. JONES, School of Forestry, Fisheries and Wildlife, University of Missouri, Columbia, Missouri 65201, U. S. A.

Dr. R. W. BACHMANN, Department of Animal Ecology, Iowa State University, Ames, Iowa 50011, U. S. A.