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NUTRIENT LOADINGS AND PHYTOPLANKTON DYNAMICS WITHIN A POWER PLANT COOLING POND

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ABSTRACT

Cultural eutrophication within the Ottertail Power Plant cooling pond has led to frequent blooms of noxious algae, fish kills, and odor problems. The objectives of this project were to (1) estimate phosphorus and nitrogen loadings to the cooling pond and (2) evaluate seasonal phytoplankton dynamics and pond trophic state. Water chemistries and phytoplankton samples were collected monthly over the period January 1 to December 31, 1998 and 1999. Total nitrogen, total phosphorus, and phytoplankton counts were analyzed according to standard limnological methods. Sources of nutrient loading include Big Stone Lake water, fly ash pond return flows, domestic wastewater and overwintering waterfowl. Big Stone Lake water was found to contribute the greatest nitrogen load (4.8 g m^{-2} yr^{-1}) while waterfowl were estimated to contribute the greatest total phosphorus load (0.54 g m^{-2} yr^{-1}). An average volume of 3,532,766 m^3/yr is pumped from Big Stone Lake into the Ottertail Cooling pond and contributes on average 76% of total nitrogen and 39% of total phosphorus loads. Overwintering waterfowl (average number = 13,464) contribute 27% of total nitrogen and 91% of total phosphorus load, respectively. Nitrogen:phosphorus ratios (by mass) average 3.2:1 in the cooling pond versus 15.7:1 in Big Stone Lake. Total phytoplankton cell counts averaged 39,099 cells/ml and ranged from 11,776 to 66,423 cells/ml. Diatoms, green algae and euglenophytes were found in great abundance during winter months (range = 0 to 30,248 cells/ml) while cyanobacteria predominated during the warmer summer months (range = 0 to 28,709 cells/ml) at all sites. High nutrient concentrations and low nitrogen to phosphorus ratios suggest that nitrogen may be limiting to algal productivity relative to phosphorus, favoring Cyanobacteria capable of fixing nitrogen during summer months.

INTRODUCTION

The Ottertail Power Plant by Milbank, South Dakota began construction in May 1971 and entered commercial operations on May 1, 1975. The plant is a coal-fired steam electric generating facility located in Grant County, South Dakota. A cooling pond provides water to the boilers inside the plant. This pond was designed as a zero discharge facility. Thus, water moving through the plant can only evaporate from the pond, concentrating nutrients and minerals within the pond basin. In addition, heated water exiting the plant provides overwintering habitat for large numbers of waterfowl.

Plant personnel have witnessed excessive summer algal blooms, severe odor problems, summer fish kills and calcium carbonate precipitation on structures within the pond and inside the plant. This project was initiated to evaluate current conditions within the pond and target problem areas for management focus. The objectives of this project were to (1) estimate phosphorus and nitrogen loadings to the cooling pond and (2) evaluate seasonal phytoplankton dynamics and pond trophic state.

STUDY AREA

The Ottertail Power Plant is located 3.2 kilometers west of Big Stone City, SD (Grant County; 45° 18'N, 96° 30'W). Water is pumped from Big Stone Lake to an adjacent cooling pond. The pond basin is 161 kilometers long, averages 4.3 meters deep and 145 hectares in area.

METHODS

Five sampling stations were established at roughly equidistant locations around the pond (Fig. 1). Measurements and samples were collected from 0.5 m off the bottom, mid-depth and 0.5 m from the surface at each location. Sampling occurred monthly over the period 1 January, 1998 to 31 December, 1999.

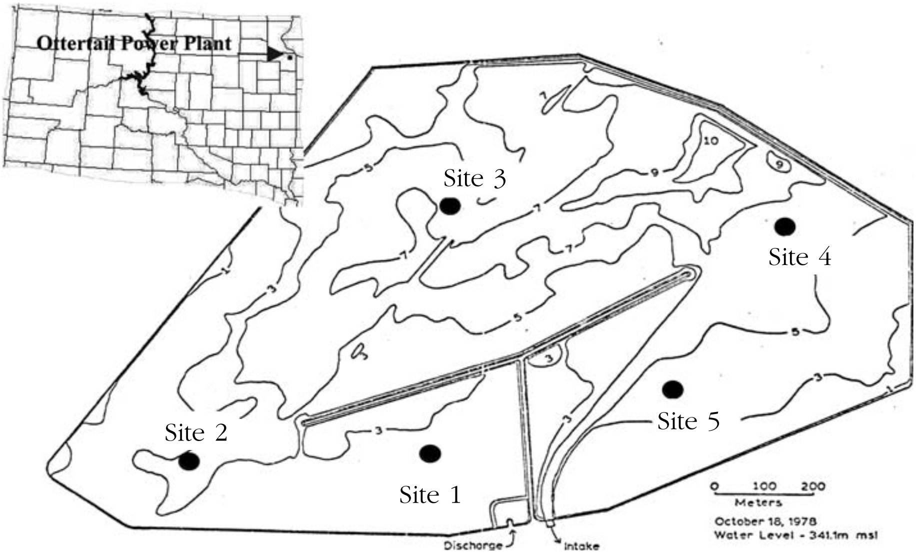

Figure 1. Sampling locations in the Ottertail cooling pond (Grant County, South Dakota)(modified from Wheeler 1979).

Total phosphorus, water transparency, chlorophyll a and total and relative abundance of phytoplankton were evaluated monthly from each site. Estimation of total phosphorus was preceded by acid persulfate digestion followed by a modified ascorbic acid treatment and spectrophotometric analysis (Hach Company, 1997).

Total Kjeldahl nitrogen (TKN) samples were collected on selected dates with other chemistry samples and processed by the South Dakota State University Water Quality Laboratory. Total nitrogen present in the cooling pond was determined by summing TKN and nitrate+nitrite.

Water transparency was determined using a Secchi disk from the shaded side of the boat at each site between 1000 hours and 1400 hours. Duplicate Secchi readings were taken from each site and date.

Chlorophyll samples were collected using a Van Dorn bottle. These samples were filtered onto glass fiber filters and frozen for later analysis. Frozen samples were extracted with 90% buffered acetone and corrected chlorophyll a determined spectrophotometrically following Eaton et al. (1995).

Waterfowl counts were provided by South Dakota Game, Fish and Parks and United States Fish and Wildlife Service. Pumping data for Big Stone Lake, bottom ash return and rural water use were obtained from Ottertail Power Plant personnel. Big Stone Lake total nitrogen and total phosphorus samples were taken three times during the two-year project (April, 1998 and March, April, 1999) and bottom ash return samples were taken during December, 1999. These samples were processed as outlined above.

Trophic State Index values were measured using Chlorophyll a, Secchi disk transparencies and total phosphorus (Carlson 1977). An overall site TSI value was obtained by averaging these values for each site and date.

Phytoplankton samples were collected with a Van Dorn bottle, transferred to darkened polypropylene bottles and preserved with Lugol's iodine (Lind 1979). Random subsamples were drawn from each sample and filtered onto membrane filter disks, cleared with immersion oil and counted following the membrane filter count method (Eaton et al. 1995).

DATA ANALYSIS

Loading estimates were generated using total nitrogen and total phosphorus chemistry data, monthly Big Stone Lake pumping volumes, average daily ash pond return volumes, average monthly rural water usage, average domestic wastewater total nitrogen and total phosphorus (Tchobanoglous and Schroeder 1985; Tchobanoglous et al. 1991), average winter waterfowl counts, and daily fecal output and fecal nutrient composition from Canada geese (Manny et al. 1974). Waterfowl loading estimates were calculated as weighted contributions by species relative to the average Canada goose *(Branta canadensis).* Waterfowl contributions were estimated for the period November through February, as these are the months during which high numbers were observed on the cooling pond. All loadings were estimated as annual contributions per square meter of pond surface.

Field data consist of separate monthly measurements for each parameter by depth, location and date over the period January 1998 to December 1999. Collected data were entered onto Excel spreadsheets and statistical summaries were estimated for each parameter by sampling location, season and depth.

RESULTS

Total nitrogen concentrations of the cooling pond ranged from 2.65 to 5.71 mg/L (mean=3.50 mg/L) while total phosphorus concentrations ranged from 0.32 to 4.40 mg/L (mean=1.10 mg/L). The total nitrogen:total phosphorus ratio ranged from 1.4 to 5.9 (mean=3.4).

Total nitrogen and phosphorus concentrations from all loading sources ranged from 1.9 to 2.63 and 0.09 to 0.77 mg/L, respectively (Table 1). Fly ash return flows contained the highest total nitrogen and phosphorus concentrations. However, greater volume contributions from Bigstone Lake and goose feces resulted in greater loadings of nitrogen and phosphorus from these sources. Bigstone Lake pumping contributed on average 4.8 g N/m^2/yr while goose feces contributed 1.7 g N/m^2/yr. In contrast, Bigstone Lake pumping contributed 0.23 g P/m^2/yr while goose feces contributed 0.54 g P/m^2/yr.

N:P ratios by mass within the cooling pond were similar to ratios observed from waterfowl and were much lower than those observed from water pumped from Big Stone Lake (Table 2).

Average Carlson Trophic State Index (TSI) values ranged from 64 to 104 and were lower from Secchi depth and chlorophyll a measurements than those calculated from total phosphorus concentrations (Table 3). TSI values gener-

Table 1. Average concentrations (mg/L) and estimated annual loadings (g/m^2/yr) of total nitrogen and total phosphorus from various sources to the Ottertail Power Plant cooling pond.

	Ave. Conc. (mg/L)		Estimated Annual Loadings (g/m^2/yr)	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Ash Pond Return	2.63	0.77	-0.25	-0.61
Rural Water Use	0.40	0.012	0.025	0.082
Big Stone Lake	1.9	0.09	4.8	0.23
Waterfowl	1.9	0.09	1.7	0.54

Table 2. Average nitrogen:phosphorus ratios in the Ottertail Cooling pond, Big Stone Lake source water and goose feces.

Source	N:P Ratio (by mass)
Cooling Pond	3.4:1
Big Stone Lake Water	15.7:1
Goose Feces*	3.2:1

*Source: Manny et al. (1974)

Table 3. Carlson Trophic State Index values for the Ottertail cooling pond. Index values generated using field data for total phosphorus, chlorophyll a and Secchi depth.

Source of Data	TSI Value	Carlson Trophic Class
Total Phosphorus	104	Hypereutrophic
Chlorophyll a	64	Eutrophic
Secchi Depth	66	Eutrophic
Overall Average	78.2	Hypereutrophic

ated from Secchi and chlorophyll data suggest that the cooling pond is a eutrophic basin while total phosphorus TSI's suggest that this same basin is hypereutrophic. Overall TSI values averaged 78.3 and within the hypereutrophic range.

Twenty-three algal genera were found in Ottertail cooling pond samples. These genera comprised four phyla (Cyanobacteria, Chlorophyta, Chrysophyta and Euglenophyta). Chlorophyta contributed 10 genera (*Franceia* sp., *Micractinium* sp, *Pandorina* sp., *Pediastrum* sp., *Scenesdesmus* sp., *Selenastrum* sp., *Tetraedron* sp., *Ulothrix* sp., *Volvox* sp., and green unicells) followed by Chrysophyta (*Chaetoceros* sp., *Cocconeis* sp., *Cyclotella* sp., *Gyrosigma* sp., *Melosira* sp., *Navicula* sp., *Nitzschia* sp., *Stephanodiscus* sp. and an unknown pennate diatom), Cyanobacteria (*Anabaena* sp., *Lyngbya* sp., *Microcystis* sp. and *Oscillatoria* sp.) and Euglenophyta *Euglena* sp. Total phytoplankton counts ranged from 11,776 to 66,423 cells/ml. Chlorophyta (Fig. 2), Chrysophyta (Fig. 3) and Euglenophyta (Fig. 4) were found in greater abundance during winter months

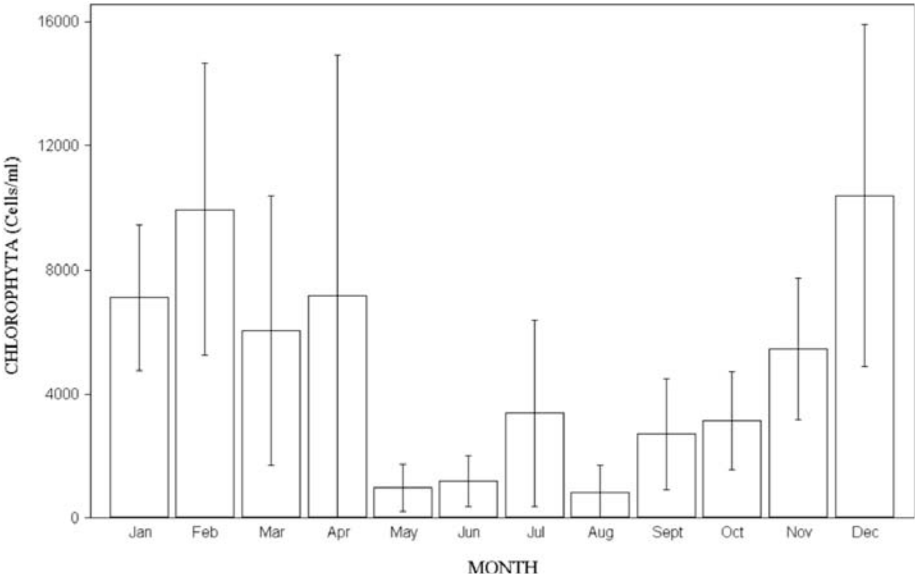

Figure 2. Mean (+/- 1 s.e.) abundance of Chlorophyta by month within the Ottertail Power Plant cooling pond.

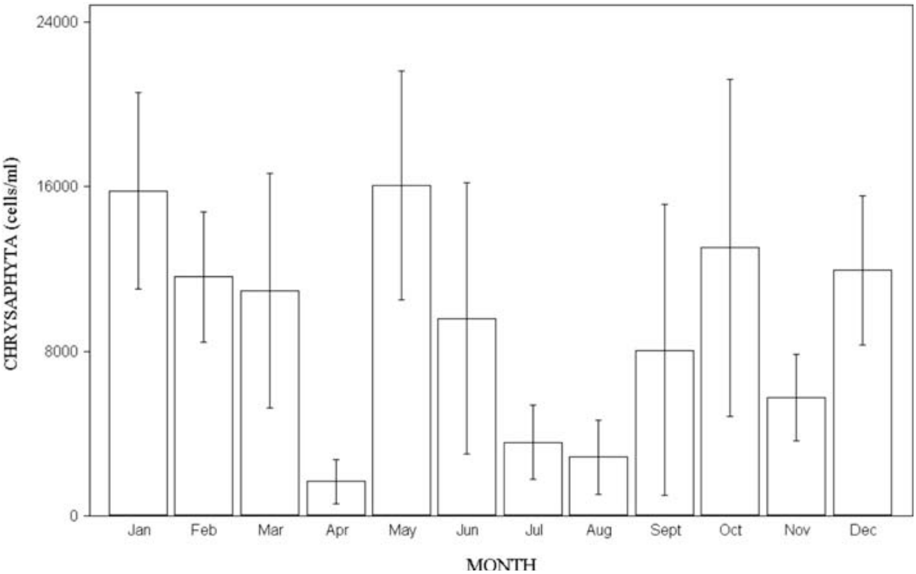

Figure 3. Mean (+/- 1 s.e.) abundance of Chrysophyta by month within the Ottertail Power Plant cooling pond.

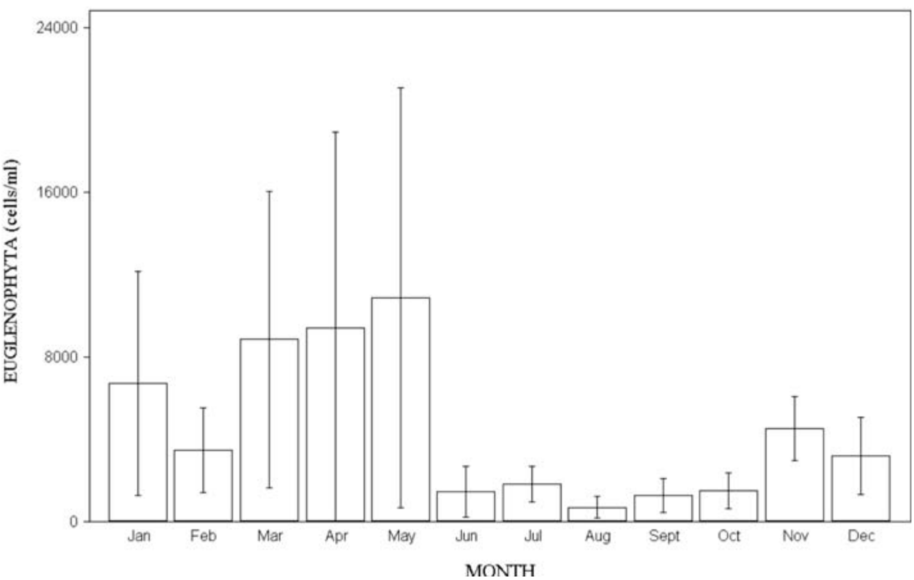

Figure 4. Mean (+/- 1 s.e.) abundance of Euglenophyta by month within the Ottertail Power Plant cooling pond.

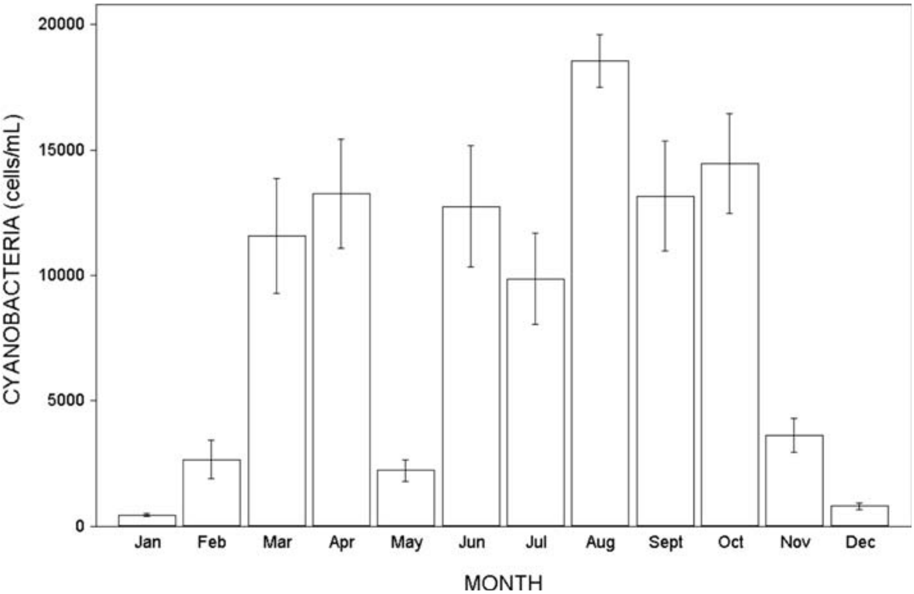

Figure 5. Mean (+/- 1 s.e.) abundance of Cyanobacteria by month within the Ottertail Power Plant cooling pond.

(range = 0 to 43,101 cells/ml) while Cyanobacteria dominated numerically during the summer months (range = 0 to 28,709 cells/ml) (Fig. 5) at all sites. No significant differences in algal unit counts were observed among sampling sites.

CONCLUSIONS

Lake basins, by definition, occupy lower elevations within a catchment. As a result, sedimentation, nutrient enrichment and changes in aquatic community structure are natural phenomenon throughout the life of a lake basin (Kalff 2001; Wetzel 2001). However, these processes are often accelerated following watershed development leading to rapid changes in physical, chemical and biological characteristics. Higher catchment erosion rates, basin sedimentation and nutrient enrichment enhance productivity and alter the composition of biotic communities within lake basins (Kallf 2002; Wetzel 2001). These changes may in-turn impair water quality for specific designated uses.

Cultural eutrophication has degraded water quality within the Big Stone cooling pond. Nutrient loading from Big Stone Lake and waterfowl have reduced nitrogen:phosphorus ratios, increased water column calcium concentrations, enhanced primary production, facilitated biogenic decalcification and altered algal community structure as compared to Big Stone Lake source water. In addition, high water temperatures throughout the year support high winter primary production and reduce oxygen solubility during summer months.

High water temperatures and decomposition during summer months result in oxygen deficit causing summer fish kills.

The Big Stone cooling pond functions as a hypereutrophic lake basin. However, this characterization is strongly influenced by high total phosphorus loadings. Algal biomass as measured by chlorophyll a and water transparency values suggest that this basin should be eutrophic. Sources of sediment and nutrients to the Big Stone cooling pond include the Bigstone Lake catchment, migrating waterfowl and impervious surfaces immediately surrounding the pond. Major sources of total nitrogen and phosphorus include water pumped from Big Stone Lake and waterfowl. Loading reductions from these sources may improve nitrogen:phosphorus ratios, lower critical algal nutrient levels and improve water quality for use by plant managers. In addition, it may be necessary to reduce cooling pond water temperatures and calcium loadings into the pond. High nutrient concentrations, low nitrogen:phosphorus ratios and high water temperatures all contribute to observed problems within the pond (algal blooms, summer fish kills, biogenic decalcification).

Water temperature, light, nutrients and herbivores may all exert some control over the composition and productivity of primary producers in lake basins (Kalff 2002; Wetzel 2001). However, phosphorus concentrations are often the most limiting resource to aquatic algae (Monson 1992; Schelske and Stoermer 1971). Most aquatic algae require a ratio of total nitrogen to total phosphorus approximately 7:1 (by mass) (Kalff 2002). Big Stone Lake, source of cooling pond water, demonstrated a ratio of 15.7:1 (by mass). Thus, phosphorus would be limiting relative to nitrogen in Big Stone Lake. However, nitrogen:phosphorus ratios within the cooling pond average 3.2:1 (by mass), very similar to the average reported in waterfowl feces (Manny et al. 1974). This low ratio suggests that algae within the cooling pond may be nitrogen limited.

Summer dominance of Cyanobacteria within the Ottertail cooling pond may reflect nitrogen limitation within the water column. Several species of Cyanobacteria are capable of fixing their own nitrogen (Smith 1983). This places them at a competitive advantage over other phytoplankton when N:P ratios are low (< 10:1) (Kalff 2002). In addition, Cyanobacteria are tolerant of warmer waters (Wetzel 2001) and low light conditions (Scheffer et al. 1997). Low nitrogen:phosphorus ratios, high water temperatures and greater biogenic shading were observed together in the cooling pond during the summer months. These conditions favor the establishment and maintenance of high Cyanobacteria production, a condition we observed in our phytoplankton data. High winter temperatures also favor greater winter production and enhance autochthonous loading of organic matter as compared to surrounding natural basins.

The cooling pond represents an important link in plant functionality. Protocols and strategies have been proposed to facilitate future monitoring of the pond and facilitate corrective actions to enhance pond integrity. Cold lime softening, microscreens, buffered alum, and controlled waterfowl hunting have all been proposed as possible management strategies. These strategies should be explored to address problems associated with nutrient enrichment and algal productivity. Short-term monitoring data would allow plant personnel to anticipate impending conflicts between pond water quality and plant operations. Limited monitoring should be conducted weekly and include measurements of water temperature, Secchi depth transparency, calcium concentrations and dissolved oxygen. Long-term monitoring data should be used to guide strategic management. Samples collected every 5 years might provide a baseline against which future management goals may be measured.

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