Eutrophication of Small Reservoirs in the Great Plains

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The Great Plains region does not have a large number of natural lakes. However, many reservoirs have been constructed in recent years by the Soil Conservation Service, the Bureau of Reclamation, and the U.S. Army Corps of Engineers for flood control and soil conservation. Many of these impoundments have facilities such as boat ramps, bathhouses, sand beaches, and campsites to provide a measure of water-based recreation for residents of the area. Yet, the demand for additional recreational waters by the general public continues unabated. More and more of the costs for new dam construction are being charged to recreational benefits, both because it is recognized that reservoirs constructed to provide water recreation constitute justifiable expenditures of public funds and also because the total benefits that can accrue from additional land treatment are declining as an increasing percent of the land area receives modern soil conservation and flood control practices.

Unfortunately, as laudable as efforts to secure additional recreational waters in the Great Plains may be, it appears that many of the small reservoirs, present and future, will be troubled by excessive and rapid eutrophication, resulting in deterioration of their recreational uses after a few years of existence. The naturally fertile soils of the region, the widespread application of fertilizers to agricultural lands, and the development of the livestock-feeding industry can all contribute to high nutrient loads in runoff water. It is natural that reservoirs impounding nutrient-rich water should be productive and have the potential to generate nuisances, which interfere with projected recreational uses.

The Salt Valley watershed district in eastern Nebraska contains 10 sizable reservoirs constructed by the U.S. Army Corps of Engineers for flood control with recreational facilities developed by the state of Nebraska. Hunting, fishing, swimming, boating, hiking, picnicking, and camping are all popular activities provided by these facilities. The reservoirs are located within a 32-km radius of Lincoln, Nebraska, and range in age from 3 to 8 years. Several of them are already exceedingly eutrophic and exhibit many of the symptoms of advanced eutrophication.

In the summer of 1968 limnological studies of five of these reservoirs were initiated with these specific objectives: (1) to determine the existing trophic conditions, (2) to estimate the rate of eutrophication, if it was possible, by measuring changes in several parameters [*Fruh et al.*, 1966], (3) to identify sources of nutrient inputs, and (4) to evaluate preventive and remedial measures. The preliminary results reported herein are extracted from work still in progress; more detailed information will be provided in subsequent publications.

METHODS

During June, July, and August, each of the study reservoirs (Holmes, Wagon Train, Pawnee, Stagecoach, and Branched Oak) is sampled at weekly intervals. Weekly sampling continues on Pawnee throughout the year except during ice cover, when the reservoir is sampled at less frequent intervals. Vertical profiles of dissolved oxygen and temperature are determined with a dissolved oxygen–temperature monitor at each of three permanent stations on each reservoir except Stagecoach, which has only two permanent stations. Underwater light intensity is measured with a submersible photometer, and transparency is determined by using a Secchi disk. Water samples are collected at each meter of depth with a Van Dorn bottle, and a sample representing each station is composited. Oblique tows from bottom to surface are made with a Clarke-Bumpus sampler, and bottom samples are obtained with an Ekman dredge along transects crossing the reservoirs at each station. The water samples are analyzed in the laboratory for alkalinity, *p*H, hardness, total dissolved and suspended solids, iron, chemical oxygen demand, orthophosphate and total phosphate, ammonia, nitrate and organic nitrogen, chloride, sulfate, and turbidity. All analyses are performed by the standard methods published by the *American Public Health Association* [1965] except those for sulfate, iron, and turbidity, which are measured with a Hach Drel (direct reading engineer's laboratory) kit. Orthophosphate and total phosphate are determined on the filtrate of filtered samples, but all nitrogen analyses are performed on unfiltered water. Chlorophyll is determined according to the method outlined in *Golterman and Clymo* [1969]. The genera of algae present are identified in fresh whole mounts; numbers are determined according to the method of *McNabb* [1960] and converted to volume by appropriate formulas.

Carbon[14] primary production is studied at frequent intervals in situ at the deepest station of each reservoir. A 4-hour incubation period with solar noon as the midpoint has proved to be adequate. Aerial flights over the reservoirs are made during the summer to record on Aero-Infrared and Ektachrome films the relative development of algae and rooted aquatics. Although striking pictures are obtained, they provide only a relative index of the spread and development of aquatic plants.

RESULTS

Of the several parameters being studied, temperature, nutrient content, Secchi transparency chlorophyll, and primary production will be emphasized here to illustrate the eutrophication trends in these reservoirs. Pertinent physical features of the study reservoirs are given in Table 1. All the reservoirs are relatively shallow and are exposed to the constant winds characteristic of the Great Plains region. Consequently, permanent thermal stratification does not develop during the summer. Weak stratification may develop following several days of calm, but it is easily destroyed with the return of windy weather. The reservoirs warm rapidly in the spring and cool quickly in the fall. The rapid warming can promote the predominance of blue green algae in early summer in some of the reservoirs. The vertical variation of temperature seldom exceeds 2°C, but the mean temperature of the entire water column fluctuates widely with changes in air temperature. It is not uncommon for the water mass to change by 7°–9°C in the course of 1 week in the spring and fall. Figure 1 shows the annual temperature cycles for Pawnee Reservoir commencing June 1968 and continuing through September 1970. This magnitude of temperature variation is also typical of the other four reservoirs. The duration of ice cover depends on the ambient air temperatures.

The reservoirs can be conveniently divided into two groups based on the nature of their water turbidities. Pawnee, Stagecoach, and Branched Oak are relatively clear water reservoirs whose turbidities result mainly in the summer from algal populations. Wagon Train and Holmes are exceedingly turbid from colloidal dispersions of clay and silt maintained in suspension by prevailing winds. Soil turbidity is the most important parameter regulating production in these two reservoirs. Because they are light limited, troublesome blooms of blue green algae do not occur, even though substantial quantities of nutrients are present (Table 2). Rooted aquatic

TABLE 1. Physical Features of the Study Reservoirs

Name	Date of Completion	Surface Area, hectares	Maximum Depth, meters	Mean Depth, meters	Watershed Area, hectares
Holmes	1962	45.3	4 to 5	1.9	1,386.2
Stagecoach	1964	78.9	5	3.0	2,513.4
Wagon Train	1962	127.5	7	2.6	4,042.1
Pawnee	1965	299.6	8	3.7	9,224.3
Branched Oak	1967	728.7	8	4.4	22,983.0

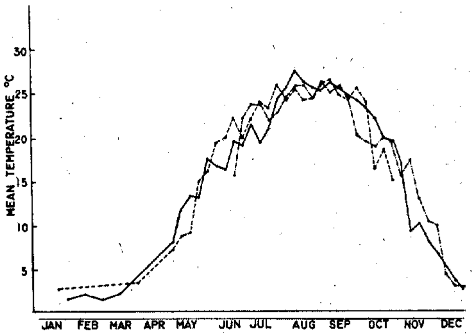

Fig. 1. Annual temperature cycles for Pawnee Reservoir commencing June 1968 and continuing through September 1970. The magnitude of variation shown is characteristic of the other four study reservoirs. The dash dot line represents 1968, the solid line represents 1969, and the dashed line represents 1970.

plants, principally *Polygonum* and *Sagittaria*, are confined to the shoreline. The average Secchi disk transparency for Holmes is usually <0.3 meter, and that for Wagon Train is <0.6 meter (Table 2). These turbid waters have occasionally begun to clear after a few days of calm, and algae, responding quickly to the improved lighting, have rapidly established substantial populations. Inevitably, wind-induced mixing resuspends the soil particles, and population growth declines. In Wagon Train Reservoir, normally less turbid than Holmes, carbon fixation rates per unit of chlorophyll with improved light conditions approximate the values obtained in the clear reservoirs (Table 3). However, under usual conditions, carbon fixation appears to be limited by insufficient light.

The dominant phytoplankton in the turbid reservoirs (Holmes and Wagon Train) are completely different from those in the clear reservoirs. Diatoms, mainly *Cyclotella, Melosira,* and *Stephanodiscus,* and flagellates, mostly *Trachelomonas* and *Euglena*, are the dominant forms. Various species of green algae are present but usually in small numbers. Blue greens also occur but never become very abundant. The chlorophyll content of these reservoirs is less than that of the clear water reservoirs; furthermore, there has been no consistent trend observed in the average content of chlorophyll during the three summers (Table 4). Neither have there been progressive changes in quantities of macronutrients except for a consistent decrease in the total phosphorus. In 1969, nitrate levels reached very high values, probably a reflection of the higher than average spring runoff (Table 2).

The situation in the clear water reservoirs (Pawnee, Branched Oak, and Stagecoach) is quite different from the conditions found in the turbid impoundments. During the summer these reservoirs contain extensive beds of rooted aquatics, primarily *Potamogeton pectinatus, P. americanus,* and *Polygonum* with some *Najas*. Weed growths hamper swimming, water skiing, boating, and fishing. Obnoxious blooms of blue green algae

TABLE 2. Summer Means (June to August) of Selected Physical and Chemical Parameters in the Study Reservoirs

Date	Secchi Depth, inches	Alkalinity, mg/l $CaCO_3$	Orthophosphate, mg/l PO_4	Total Phosphate, mg/l PO_4	NH_3 Nitrogen, mg/l N	NO_3 Nitrogen, mg/l N	Total Dissolved Solids, mg/l	pH
				Holmes				
1968	9 (23)	99	0.22	0.49	0.36	0.44	185	8.0
1969	10 (25)	102	0.27	0.35	0.44	0.99	181	8.1
				Wagon Train				
1968	23 (58)	174	0.18	0.56	0.32	0.22	244	8.1
1969	11 (28)	129	0.14	0.25	0.33	1.49	221	7.9
1970	20 (51)	178	0.04	0.13	0.28	0.10	269	8.2
				Pawnee				
1968	80 (203)	164	0.16	0.47	0.35	0.21	210	8.3
1969	72 (183)	139	0.05	0.29	0.45	0.30	198	8.4
1970	24 (61)	156	0.04	0.12	0.35	0.09	220	8.2
				Branched Oak				
1968	93 (236)	235	0.20	0.51	0.37	0.28	325	8.2
1969	68 (173)	200	0.22	0.36	0.40	0.48	335	8.2
1970	44 (112)	186	0.05	0.13	0.47	0.11	280	8.4
				Stagecoach				
1969	41 (104)	130	0.06	0.22	0.69	0.25	231	8.3
1970	27 (69)	135	0.04	0.12	0.49	0.08	243	8.7

Values in parentheses are given in centimeters.

TABLE 3. Representative ^{14}C-Chlorophyll Relationships in the Study Reservoirs

Date	Secchi Depth, inches	Carbon Assimilation, mg C/m²/hr	Chlorophyll Content, mg/m³	mg C/m² / mg chlorophyll/m³
		Holmes		
7/11/69	10 (25)	16.85	15.98	1.05
9/8/69	8 (20)	26.61	15.70	1.69
		Wagon Train		
8/6/68	24 (61)	119.35	14.89	8.02
7/23/69	6 (15)	13.44	41.85	0.32
9/3/69	13 (33)	30.12	26.15	1.15
8/24/70	20 (51)	209.05	20.95	9.98
		Pawnee		
8/7/68	74 (188)	247.53	12.04	20.56
9/24/68	68 (173)	313.43	27.52	11.40
7/25/69	78 (198)	159.06	20.34	7.82
6/16/70	22 (56)	296.22	63.20	4.69
7/3/70	24 (61)	241.52	30.06	8.03
7/21/70	21 (53)	188.15	66.85	2.81
		Stagecoach		
7/1/69	53 (135)	117.98	30.90	3.82
8/27/69	33 (84)	164.78	56.85	2.90
7/9/70	20 (51)	190.06	157.86	1.20
7/31/70	16 (41)	633.26	225.28	2.81
8/27/70	56 (142)	298.31	20.67	14.43
		Branched Oak		
8/22/68	73 (185)	64.34	25.63	2.51
6/19/69	27 (69)	906.09	67.83	13.36
8/28/69	36 (91)	273.78	25.12	10.90
7/8/70	32 (81)	774.09	58.05	13.33
7/17/70	22 (56)	254.71	87.64	2.91

Values in parentheses are given in centimeters.

from three genera, *Aphanizomenon, Anabaena,* and *Microcystis* are common. Moreover, the frequency of bloom formation and the intensity of individual blooms have been increasing as the reservoirs age. Other algae are present and sometimes can become abundant. In the summer, however, blue green algae dominate.

Problems are associated with the use of chlorophyll as an index of standing crop; however, as long as these limitations are kept in mind, chlorophyll can be used as a parameter to measure eutrophication [*Vollenweider*, 1968]. Figure 2 shows the trend of increasing concentrations of chlorophyll in Pawnee Reservoir during the past 3 years. The monthly means of chlorophyll given in Table 4 show similar trends in Branched Oak and Stagecoach. As the reservoirs age, higher standing crops are produced earlier in the season, and tremendous increases have occurred in successive years in each of the three reservoirs, the oldest reservoir having the largest standing crop. Pawnee had 1.7 times more chlorophyll in 1969 than in 1968 and 2.0 times more in 1970 than in 1969. Branched Oak had 4.0 times more chlorophyll in 1969 than in 1968 and 1.9 times more in 1970 than in 1969. A significant fish kill occurred in Branched Oak in August 1970 at the height of an *Aphanizomenon* bloom. There was 2.6 times more chlorophyll in Stagecoach Reservoir in 1970 than there was in 1969. (No data are available for 1968.) It suffices to say that during much of the recreational season these three reservoirs have a pea soup appearance. In Pawnee, high chlorophyll concentrations can persist until late October. The highest concentration recorded in 1969 was 107 mg/m³ and occurred on October 15 during an *Aphanizomenon* bloom.

Nutrient concentrations in the waters of both clear water and turbid impoundments are similar (Table 2). The only consistent change during the 3 years has been an apparent decline in total

TABLE 4. Monthly and Summer Means of Chlorophyll per Milligram per Cubic Meter in the Study Reservoirs

Date	June	July	August	Summer
		Holmes		
1968	8.64	19.78	11.84	13.42
1969	10.50	20.06	22.97	17.85
		Wagon Train		
1968	18.75	27.99	27.27	24.67
1969	16.51	22.07	19.10	19.23
1970	24.05	31.10	23.46	26.20
		Pawnee		
1968	4.23	9.92	30.00	14.72
1969	19.92	18.95	36.43	25.10
1970	38.25	52.86	62.86	51.32
		Branched Oak		
1968	6.03	4.32	10.10	6.82
1969	26.53	16.84	38.05	27.14
1970	14.87	79.64	64.23	52.91
		Stagecoach		
1969	22.53	50.46	59.27	44.09
1970	99.02	144.98	95.19	89.74

phosphorus. High nitrate values in 1969 are attributed to heavy spring runoff. No nutrient appears to be in short supply, although nitrate N and orthophosphate values sometimes decline to barely detectable amounts coincident with intense algal blooms. Ammonia concentrations during these times remain at fairly high levels, a not unusual situation [*Vollenweider*, 1968].

A decreasing Secchi depth has been cited by *Fruh et al.* [1966] and others as indicating the progressive eutrophy of a lake. In Figure 3 the average Secchi depth for Branched Oak Reservoir for each of the three summers is shown. Clearly, the average Secchi depth has declined as the numbers of algae in the water increased. The same trend was observed in Pawnee and Stagecoach reservoirs.

The ^{14}C production rates, as would be expected, are higher in the clear water reservoirs. The highest production rates were associated with low standing crops, as others have noted [*Wright*, 1959; *Findenegg*, 1965], and, as crops increased, production per unit of plant material decreased (Table 3). *Fruh et al.* [1966] have suggested that changes in primary production over a period of time can be used as a measure of eutrophication. Although the average rate of carbon fixed per square meter per hour appears to be increasing as the clear reservoirs age, our data are not complete enough to allow us to make a definitive statement.

NUTRIENT SOURCES

The runoff waters entering the Salt Valley reservoirs are principally from cultivated farmland. The watersheds contain very few or no point waste sources, such as domestic sewage effluents or drainage from large feedlots. All the reservoir watersheds contain agricultural lands in current production. Fertilizers plus nutrients in the naturally fertile soils are carried into the reservoirs mainly during spring runoff periods. Because the reservoirs discharge very infrequently, most of the nutrients that enter are retained. For example, Pawnee Reservoir has had only one major discharge since it was filled in 1965; this occurred with a greater than normal runoff in the spring of 1969. Consequently, the total concentration of nutrients in the reservoirs is increasing, although it is not known to what extent nutrients are lost to the bottom sediments and become unavailable for plant growth.

DISCUSSION

If the observed trend between reservoir age and chlorophyll increase continues for reservoirs with low soil turbidity, it can be predicted that in a few years Branched Oak Reservoir (the newest,

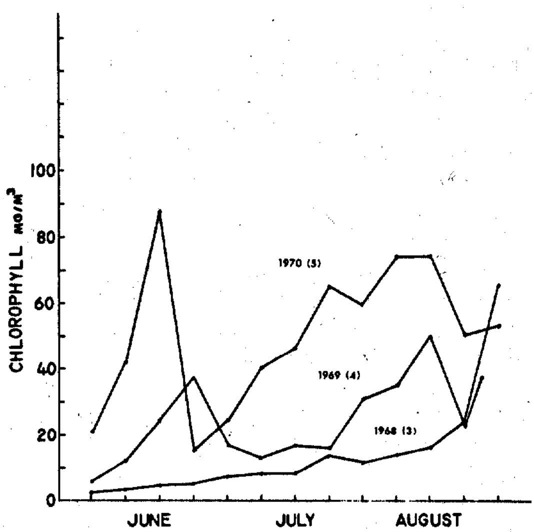

Fig. 2. Trend of chlorophyll concentration in Pawnee Reservoir in 1968, 1969, and 1970. Similar trends were observed in Branched Oak and Stagecoach reservoirs. The numbers in parentheses are the reservoir ages.

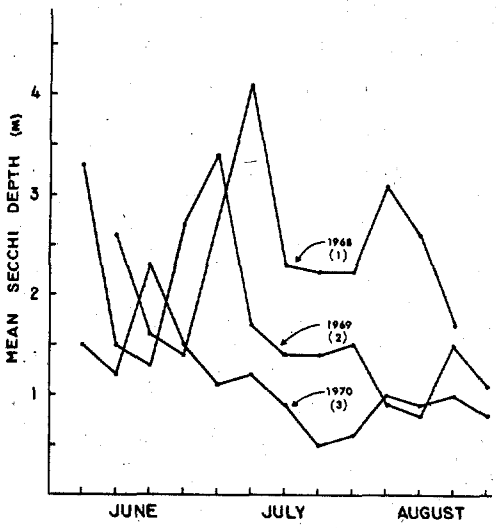

Fig. 3. Average Secchi depth for Branched Oak Reservoir for each summer of the study. Similar trends were observed in Pawnee and Stagecoach reservoirs and are a result of increasing numbers of algae. The numbers in parentheses are the reservoir ages.

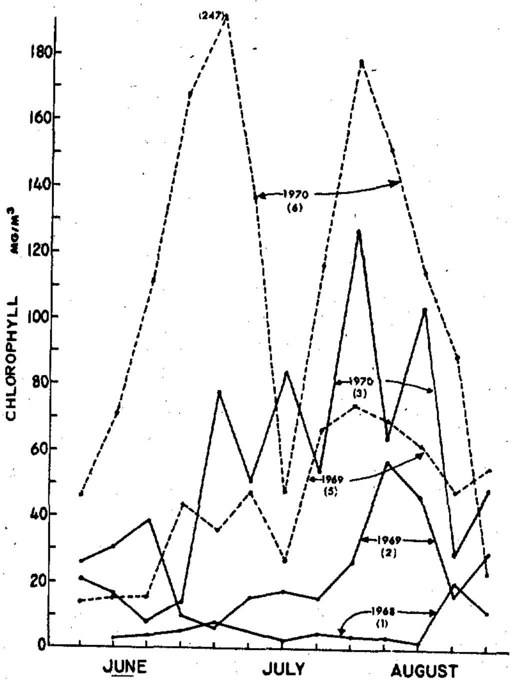

Fig. 4. Relationship between reservoir age (in parentheses) and chlorophyll content exemplified by Stagecoach (solid line) and Branched Oak (dashed line) reservoirs.

largest, and most desirable for recreation because of its size) will be in the advanced stage of hypereutrophication currently exhibited by Stagecoach Reservoir. The relationship between age and chlorophyll for these two reservoirs is shown in Figure 4. When Branched Oak reaches that state of eutrophy now present in Stagecoach, most forms of water recreation will suffer seriously, except perhaps fishing.

Considerable funds have gone into the development of recreational facilities at these reservoirs. If eutrophication cannot be effectively controlled, the wisdom of spending funds to construct paved access roads, beaches, bathhouses, boat docks, picnic areas, and other facilities is open to question. Of more profound importance is the problem of how future recreational reservoirs can be justified in the Great Plains if their fates are to be similar to those of the Salt Valley reservoirs. That the potential for eutrophication problems exists in Great Plains reservoirs must be recognized by those planning future construction. This potential may dictate changes in reservoir design, siting, watershed management, and water level regulation.

Since the source of water for reservoir impoundment is surface runoff, nutrient reduction or removal is impractical. Rather, it would be appropriate to approach the eutrophication problem from another aspect, that is, the control of photosynthesis by the regulation of light penetration into reservoirs. Examples of natural light-limited systems are Holmes and Wagon Train reservoirs. Unfortunately, water contact sports are no more popular in muddy waters than in pea soup green ones. The efficacy of adding substances that do not offend the esthetic senses either to the water or to the water surface to prevent sunlight penetration would appear to be a fruitful avenue of research. Although such a solution may only be applicable to the small shallow reservoirs in the Great Plains, it could vastly affect the future development of surface waters in the region.

CONCLUSIONS

1. Runoff waters impounded in the Salt Valley reservoirs contain sufficient nutrient salts to support abundant growths of aquatic plants.
2. Reservoirs that are light limited by soil turbidity support neither abundant growths of aquatic plants nor dense blue green algal blooms.
3. Clear water reservoirs are very eutrophic.

Shorelines choked with rooted aquatics, dense blooms of blue green algae, odorous emissions, and occasional fish kills are typical characteristics of these impoundments.

4. In clear water reservoirs the rate of eutrophication is very rapid and appears to be directly related to age. Projections based on existing data indicate that the useful life of these reservoirs for body contact recreation is only a few years.

5. Because there is no ready solution for the removal of nutrients from land runoff, methods of controlling reservoir eutrophication in the presence of abundant nutrients must be evaluated. One concept that should be investigated is the control of photosynthesis through the inhibition of sunlight penetration by the addition of various substances to the reservoir directly or to the water surface.

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