Eutrophication Of Small Reservoirs In Eastern Nebraska

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ABSTRACT: Numerous small reservoirs constructed in Nebraska are used for recreation and many more are being planned. While these impoundments seemingly alleviate the long standing need for recreational waters, many existing impoundments exhibit symptoms of accelerated eutrophication after only a few years of existence. It is natural that such lakes, impounding nutrient-rich water, should be productive and generate nuisances that interfere with projected recreational uses. Unfortunately, neither this fact nor the lack of feasible methods for nutrient control were perceived prior to providing recreational facilities at the reservoir sites.

Rates of eutrophication, nutrient sources, and eutrophication control have been examined in a study of five eastern Nebraska reservoirs. The following conclusions have been established by the research studies: Runoff waters impounded in the Salt Valley reservoirs have sufficient nutrient salts to support abundant growths of aquatic plants; reservoirs that are light-limited by soil turbidity support neither abundant growths of aquatic plants nor dense blue-green algal blooms; 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; and in clear water reservoirs the rate of eutrophication is very rapid and appears to be directly related to age. Projections based upon existing data indicate that the useful life of these reservoirs for body-contact recreation is only a few years.

DEFINITION OF EUTROPHICATION

Eutrophication is the process whereby lakes become enriched with nutrients resulting in water quality characteristics which are undesirable for man's use of the water, both for water supply and for recreation.

Limnologists categorize lakes according to their biological productivity. Oligotrophic lakes are nutrient poor. Typical examples are a cold water, mountain lake and a sand-bottomed, spring-fed lake characterized by transparent water, very limited plant growth, and low fish production. A slight increase in fertility results in a mesotrophic lake with some aquatic plant growth, greenish water, and moderate production of game fish. Eutrophic lakes are nutrient rich. Plant growth, in the forms of microscopic algae and rooted aquatic weeds, produces a water quality undesirable for body-contact recreation.

The process of eutrophication is directly related to the aquatic food chain, Fig. 1. Algae use carbon dioxide, inorganic nitrogen, orthophosphate, and trace nutrients for growth and reproduction. These plants serve as food for microscopic animals (zooplankton). Small fish feed on zooplankton, and large fish consume small fish. Productivity of the aquatic food chain is keyed to the availability of nitrogen and phosphorus, often in short supply in

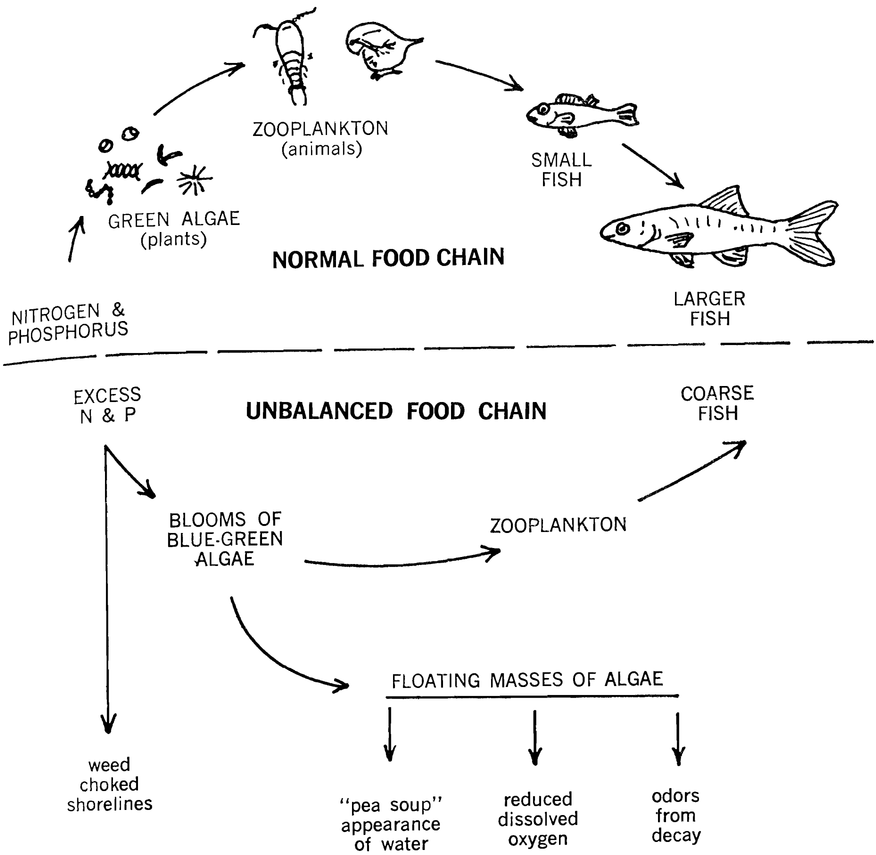

Fig. 1. Normal and unbalanced food chains.

natural waters. The amount of plant growth and normal balance of the food chain are controlled by the limitation of plant nutrients.

The food chain becomes unbalanced (shifts from one succession to another) if excessive amounts of plant nutrients are present. Abundant nutrients promote blooms of blue-green algae that are not easily utilized as food by zooplankton. Thus, the water becomes turbid and under extreme conditions takes on the appearance of "pea soup." Floating masses of algae are windblown to the shore where they decompose producing malodors. Decaying algae also settle to the bottom reducing dissolved oxygen.

Shorelines and shallow bays become weed-choked with the prolific growth of rooted aquatics. Preferred food-fishes cannot survive in these unfavorable conditions and, as eutrophication intensifies, are replaced by a succession of increasingly tolerant fishes. Trout are succeeded by warm-water fishes such as perch, walleye, and bass and these in turn by coarse fishes like bullheads and carp (Fig. 1).

The most common natural sources of nitrogen and phosphorus are land runoff, animal excreta, and decaying vegetation. However, the majority of plant nutrients entering surface waters originate from man-generated wastes and runoff from agricultural land. Approximately 60 percent of the phosphorus in domestic waste water is from phosphate builders used in synthetic detergents. Secondary waste-water treatment processes (current practice) remove only about 30 percent of the phosphorus while reducing the waste organics 90 percent. Plant nutrient contributions from agricultural land drainage depend upon land use, fertilizer additives, hydrology and topography.

In a simple agrarian economy the amounts of nitrogen and phosphorus transported by surface runoff from cultivated farmland are normally limited. In a complex urban economy, such as the United States, phosphate rock is mined and processed into fertilizers, detergents, animal feeds, and other chemicals. A significant amount of this phosphate ultimately reaches surface waters. Thus, our high standard of living has resulted in the use and disposal of large quantities of phosphorus which had previously been underground. Phosphorus is considered by most authorities to be the most common limiting factor

A few of the many lakes effected by accelerated eutrophication are: Zurichsee, Lake Zoar, Lake Washington, Lake Erie, the Madison, Wisconsin lakes, the Salt Valley reservoirs and hundreds of other lakes and reservoirs throughout the United States and the world. Perhaps the most devastating aspect of eutrophication is that the process appears to be difficult to retard, except in unusual cases. Once a lake has become eutrophic it remains so, at any rate for a very long time, even if the source of extra nutrients is eliminated.

SALT VALLEY RESERVOIRS

Numerous small reservoirs used for recreation have been constructed in eastern Nebraska and many more are being planned. While these lakes seemingly alleviate the long standing need for recreational waters, many existing impoundments exhibit symptoms of accelerated eutrophication after only a few years of existence.

During the 1960's, several reservoirs were built within a 20 mile radius of Lincoln, Nebraska for flood control and soil conservation. Recreation as a secondary benefit was developed by providing paved access roads and facilities. Since very little was known about the eutrophication of small reservoirs, the authors initiated limnological studies of several impoundments in 1968. The research studies were to determine the present level of eutrophy (nutrient concentrations, biological productivity, and water quality) and the rate of reservoir deterioration due to eutrophication. The reservoirs studied are listed in Table I.

Table 1. **SALT VALLEY RESERVOIRS INCLUDED IN EUTROPHICATION STUDY**

Name and Date of Completion	Permanent Pool Area Acres	Mean Depth Meters	Water-based Recreation			
			Swimming	Water Skiing	Boating	Fishing
Holmes, 1962	112	1.9			x	x
Stagecoach, 1964	195	3.0			x	x
Wagon Train, 1962	315	2.6	x		x	x
Pawnee, 1965	740	3.7	x	x	x	x
Brached Oak, 1967	1,800	4.4	x	x	x	x

The reservoirs generally store sufficient water for recreation within 3 to 5 years after construction; however, at permanent pool elevation the retention time of the impounded water is closer to 8 years due to the high evaporation loss. Discharge is intermittent and generally occurs only during heavy spring rains in combination with melting of accumulated snow. The reservoirs are wind mixed through their entire depth, except under ice cover. Transient stratification may occur occasionally for a few days during hot, windless periods in the summer.

The impounded water is relatively high in dissolved salts, i.e., calcium bicarbonate and magnesium sulfate, and inorganic nutrients – ammonia, nitrate and phosphate. The water temperature is influenced directly by ambient air temperature and ranges from 65 to 80°F during the summer months. The pH remains in the range of 7.5 to 8.5, and soil turbidity varies with size of reservoir and degree of wind mixing. Table II lists the summer means of selected physical-chemical parameters in study reservoirs.

Table II. SUMMER MEANS (JUNE, JULY, AUGUST) OF SELECTED PHYSICAL-CHEMICAL PARAMETERS IN THE STUDY RESERVOIRS

Name	Secchi Depth Inches	Alkalinity mg/1 as $CaCO_3$	Ortho Phosphate mg/l as PO_4	Total Phosphate mg/l as PO_4	NH_3 Nitrogen mg/l as N	NO_3 Nitrogen mg/l as N	Dissolved Solids mg/l	pH
Holmes								
1968	9	99	0.22	0.49	0.36	0.44	185	8.0
1969	10	102	0.27	0.35	0.44	0.99	181	8.1
Wagon Train								
1968	23	174	0.18	0.56	0.32	0.22	244	8.1
1969	11	129	0.14	0.25	0.33	1.49	221	7.9
1970	20	178	0.04	0.13	0.28	0.10	269	8.2
1971	20	144	0.05	0.12	0.38	0.11	225	8.3
Pawnee								
1968	80	164	0.16	0.47	0.35	0.21	210	8.3
1969	72	139	0.05	0.29	0.45	0.30	198	8.4
1970	24	156	0.04	0.12	0.35	0.09	220	8.2
1971	30	137	0.05	0.13	0.48	0.12	192	8.4
Branched Oak								
1968	93	235	0.20	0.51	0.37	0.28	325	8.2
1969	68	200	0.22	0.36	0.40	0.48	325	8.2
1970	44	186	0.05	0.13	0.47	0.11	280	8.4
1971	52	158	0.04	0.11	0.28	0.11	222	8.3
Stagecoach								
1969	41	130	0.06	0.22	0.69	0.25	231	8.3
1970	27	135	0.04	0.12	0.49	0.08	243	8.7
1971	32	127	0.08	0.15	0.63	0.12	229	8.2

Runoff waters entering the lakes are principally from cultivated farmland. The watersheds contain very few point waste sources, such as, domestic waste effluents or waste water from large feedlots. The land drainage contains high concentrations of nitrogen, 0.7 to 1.3 mg/1 inorganic N, and soluble phosphorus, 0.4 to 1.6 mg/1 PO^4 (Engberg, 1971) which result in average concentrations of 1.0 mg-N/1 of inorganic nitrogen, NH^3 + NO^3, and 0.2 mg-PO^4/1 orthophosphate in the reservoir waters in the spring. These levels of nutrients are sufficient to create excessive development of floating algae and rooted aquatic plants, producing eutrophic conditions. (The generally accepted upper limits for plant nutrients in lakes free of aquatic nuisances are 0.3 mg-N/1 of inorganic nitrogen and 0.1 mg-PO^4/1 of inorganic phosphorus – Lueschow, Helm, Winter and Karl, 1970.)

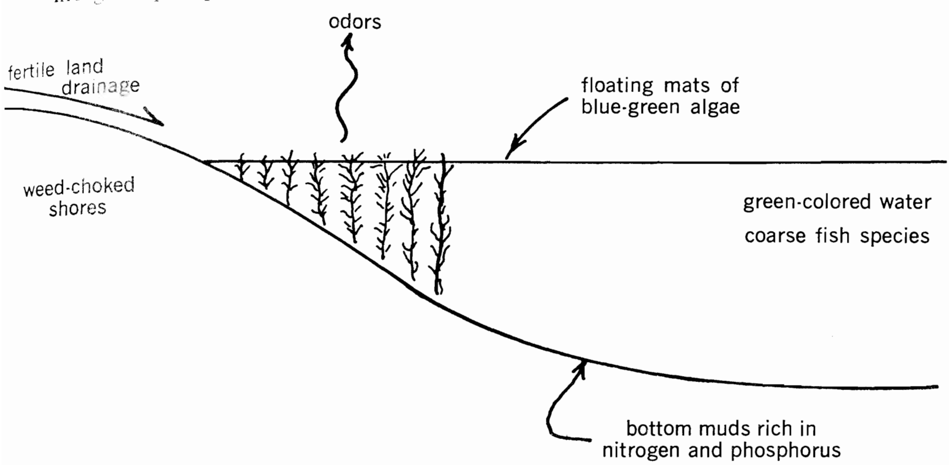

Figure 2. Reservoirs with Low Soil Turbidity (clear water)

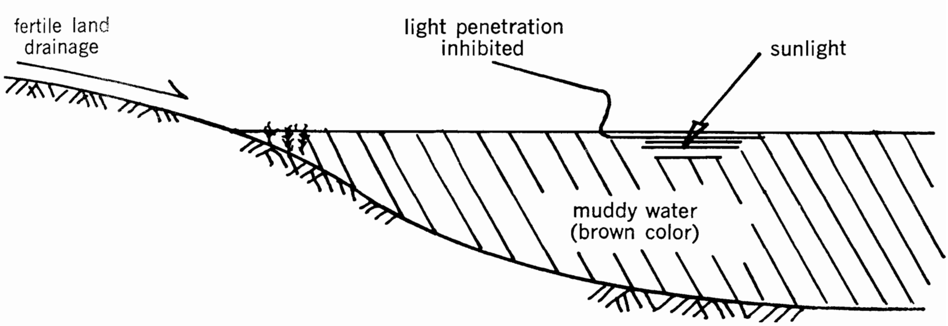

Figure 3. Reservoirs with High Soil Turbidity (light inhibiting)

Storm runoff from intense rains is turbid with suspended silt and clay. In larger reservoirs, the soil grains settle out of suspension quickly even though the water mass is stirred by wind action. However, in shallow reservoirs with long reaches in the direction of prevailing winds, the water remains turbid resulting in reduced sunlight penetration. Even though inorganic plant nutrients are in abundant supply, the light-inhibited reservoirs do not support extensive plant growth since photosynthesis is impeded.

Holmes and Wagon Train are typical turbid reservoirs exhibiting the characteristics shown schematically in Fig. 2. Holmes with muddy water throughout the growing season, has an average Secchi Disc depth of 9 inches. It supports neither noticeable weed growth nor significant algal populations. (A Secchi Disc is a 20-centimeter diameter, white disc with a rope line attached to the center. Secchi depth is the submergence at which the disc disappears from view and is an indicator of water clarity.) The Secchi depth of Wagon Train ranges between 1 and 2 feet. The water remains muddy during the spring and retains considerable soil turbidity throughout the summer. The inhibition of light penetration prevents extensive algal blooms and limits aquatic plants to shallow areas close to the shore.

Waters impounded in Stagecoach, Pawnee, and Branched Oak reservoirs contain very little soil turbidity during the plant growing season. Suspended soil from spring runoff generally settles out quickly allowing sunlight penetration. As a result, the transparency of the water in late spring permits light penetration sufficient to stimulate rooted weed growth from water depths up to 15 feet. All three of these clear-water reservoirs have frequent, dense, blooms of blue-green algae that reduce the transparency to a Secchi Disc depth of less than 2 feet. The features of fertile reservoirs with low soil turbidities are illustrated in Fig. 3.

The clear-water reservoirs are undergoing accelerated eutrophication with dramatic water quality deterioration with age. Figure 4 shows plots of chlorophyll "a" concentrations for Branched Oak and Stagecoach during the summer months. (The amount of chlorophyll extracted from the algae per unit volume of water is a common method of quantifying the magnitude of algal growth.) Chlorophyll concentrations less than 15 mg/cu meter usually indicate low algal populations and water transparencies greater than 6 feet. Chlorophyll greater than 40 mg/cu meter are related to blue-green algal blooms with water transparency less than 2 feet in the study reservoirs. At about 140 mg/cu meter the water has the appearance of pea soup with a Secchi depth of 1 foot or less.

The first year after construction of Branched Oak (1968) the impounded water had low algal populations and an average transparency of 8 feet. The second year a pronounced blue-green algal bloom occurred in mid-June. The water cleared briefly and then became increasingly green as summer progressed. The average Secchi Disc depth was 5 feet, with a low reading of 2.5 feet during a bloom in early August. During 1970, the third year of aging, Branched Oak was in continuous bloom throughout July and August with an average transparency of 2.5 feet. Dense blue-green algae blooms in early August coincided with a major fish kill, reported as consisting of 5,000 to 10,000 fish.

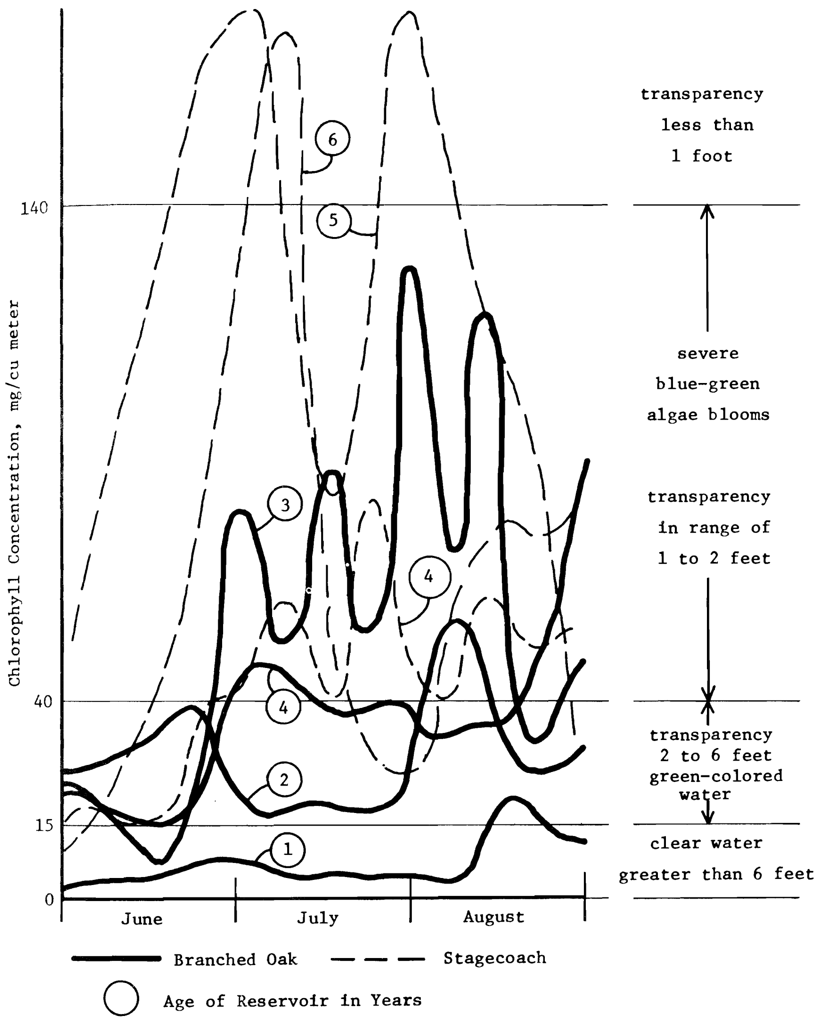

Fig. 4. Chlorophyll concentrations in Stagecoach and Branched Oak Reservoirs (Lancaster County) during summer months.

From closing of the dam in 1967, Branched Oak had filled to slightly over one-half its normal water volume and about 80 percent of the operating pool area by 1970. Heavy spring rains in 1971 raised the water level 5 feet, to within 1 foot of permanent pool elevation. This increased the impounded quantity of water from 16,000 acre-feet to 27,000 acre-feet and the water surface to near 1700 acres, 1800 being permanent pool area. The chlorophyll amounts during the summer of 1971 do not differ appreciably from those of 1970.

Chlorophyll concentrations for the fourth, fifth and sixth years after storing water in Stagecoach show the effects of rapid enrichment (Fig. 4). In 1969 serious blue-green algae blooms occurred in July and August, and in 1970-71, after only 5-6 years, the reservoir supported extremely dense blue-green blooms from the beginning of June through August. The Secchi depth was less than 2 feet 50 percent of the time, and during the bloom peaks the transparency dropped to less than 1 foot. Floating mats of decaying algae collected in the weeds along the shore and emitted foul odors.

The data in Fig. 4 indicate that those Salt Valley reservoirs with low soil turbidity have a useful life span for water-contact recreation of only a few years. Water quality in Branched Oak, the largest of the Salt Reservoirs, has deteriorated sharply within four years after construction, and if the rate of enrichment continues, this reservoir will probably be unsuitable for body-contact water recreation from mid-June through August within the next few years.

The following conclusions are based on research data collected since June 1968:

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 heavy aquatic plant growth nor dense algal blooms.
3. Clear-water reservoirs, those with low soil turbidity, are very eutrophic. Weed-choked shorelines, dense blue-green algal blooms, 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 (swimming and water skiing) is only a few years. The useful life for fishing i.e., the number of years until fish kills become frequent and most of the desired game fish species find the environment intolerable, cannot be determined from the data currently available.

EUTROPHICATION PREVENTION AND CONTROL

The rate of eutrophication of a lake can be retarded by reducing nutrient input. The chief method used to limit nutrient concentrations has been diversion of nutrient-rich waste waters. Construction of a pipeline to divert the treated waste water from the city of Madison, Wisconsin around a chain of lakes was completed in 1959. Although these lakes still receive nutrients from other uncontrolled sources, the rate of eutrophication has been slowed with no further deterioration since the diversion. All waste flows were diverted from Lake Washington to Puget Sound between 1963 and 1967. Significant improvement in water quality has already occurred due to the flushing action of the nutrient-poor river water entering the lake.

Advanced waste treatment can be used to remove nutrients from waste water in cases where diversion is not possible. Operating treatment plants have been successful in removing phosphates, but nitrogen compounds are more difficult to eliminate and methods for nitrogen removal are still in the developmental stage. Processing wastes for nutrient removal nearly doubles the cost of waste-water treatment; this is a significant deterrent to the application of tertiary treatment.

The Salt Valley watersheds contain very few point waste sources, such as, waste-water effluents or runoff from feedlots, that can be controlled by diversion or advanced waste treatment. The vast majority of the nitrogen and phosphorus entering the reservoirs is from storm water draining from cropland. Unfortunately, there is no ready solution for removal of nutrients from land runoff, whether this be from untilled land or cultivated fields. Land management to control soil erosion, feedlot drainage and loss of fertilizers may reduce the concentrations of water-borne nutrients, but in eastern Nebraska where the surface soils are rich in nitrogen and phosphorus, it is doubtful that soil and water conservation practices can reduce the nutrient levels in runoff water to prevent eutrophication in a receiving body of water. Furthermore, the rainfall-runoff patterns of thunderstorm weather typical in Nebraska makes nutrient control in drainage water impractical.

Algal blooms in water supply reservoirs are commonly controlled by periodic dosing with the algicide copper sulfate. However, the use of copper sulfate has generally been abandoned in recreational lakes for several reasons: copper accumulates in bottom muds and is toxic to most forms of aquatic life, regular applications to large bodies of water are very expensive, and in the case of very eutrophic waters, the frequency with which the chemical must be applied becomes excessive. Several herbicides can be used to control submerged and emergent aquatic weeds. These chemicals must be used with caution to prevent unwanted biological damage. Limited applications of herbicides are commonly used to control weed growth near boat docks, swimming beaches, and fishing points.

Harvesting of plant growth has been suggested as a possible means of removing nutrients from eutrophic lakes. However, in most situations this process can remove only small quantities of nutrients. For example, in the Salt Valley reservoirs, approximately 4 tons per surface acre (wet weight) of aquatic plants would have to be removed to offset the estimated input of phosphorus in one year. Microstrainers would also be required for harvesting and removal of algae, a procedure that exists only in theory.

Other miscellaneous concepts include mixing for artificial destratification (the Salt Valley reservoirs are naturally mixed and unstratified), dredging of bottom deposits, harvesting of fish, flushing with pure water, and biological control, e.g., viruses or other diseases of blue-green algae. None of these appear to be applicable for control in the Salt Valley reservoirs.

A novel approach to controlling weed and algae growth in reservoirs is currently being evaluated (Eicher, 1947). The idea is to control the rate of photosynthesis by inhibiting sunlight penetration through the application of chemicals into the water or on the surface. (Light-limited, nonproductive waters exist in nature, for example, bog lakes and reservoirs with high soil turbidity.) The first substances being tested are commercially available dyes. Effectiveness of dyeing water is under laboratory and field investigation using cultures of blue-green algae that commonly bloom in the Salt Valley reservoirs.

ACKNOWLEDGEMENT

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