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The complexities and contradictions associated with trophic classification criteria are discussed in this report. Many criteria are based on the process of nutrient enrichment (i.e., eutrophication) while others are based on the manifestations of eutrophication. Numerous chemical, physical, and biological criteria are compared within a tabular format. As presently used, trophic classification of lakes and reservoirs becomes a function of the criteria used and is frequently inconsistent among classification criteria. A more practical →
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approach to lake classification would place paramount consideration upon the potential beneficial uses of a lake and the water quality characteristics required to meet those uses.

Preface

This report was prepared by the Environmental Protection Agency (EPA), Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, for the U. S. Army Engineer Waterways Experiment Station (WES) under Interagency Agreement EPA-78-R-X0393 dated 23 August 1978. The effort is part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Task IB.1, Improved Description of Reservoir Ecological and Water Quality Processes. The EWQOS is sponsored by the Office, Chief of Engineers, U. S. Army, and is assigned to the WES Environmental Laboratory (EL).

The research was conducted by Mr. W. D. Taylor, Dr. L. R. Williams, and Mr. S. C. Hern under the general supervision and direction of Mr. V. W. Lambou, Environmental Monitoring and Systems Laboratory, EPA. The purpose of the study was to review concepts for estimating the relative trophic state of lakes and reservoirs.

The study was conducted under the direct WES supervision of Dr. K. W. Thornton and Mr. J. L. Norton; and under the general supervision of Mr. D. L. Robey, Water Quality Modeling Group, Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division, and Dr. J. Harrison, Chief, EL. Dr. J. L. Mahloch was the EWQOS Program Manager.

The Directors of WES during the conduct of this study were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

Contents

TROPHIC STATE OF LAKES AND RESERVOIRS

Introduction

1. Because of national interest in environmental quality and the realization that lakes and reservoirs are a valuable resource, increased emphasis has been placed on the development of classification schemes to describe their condition in terms of overall environmental quality. This overall quality has been expressed most frequently as the degree of nutrient enrichment or trophic state. Considerable confusion exists as to the appropriateness of various schemes that have been developed for classifying natural lakes and their general applicability to reservoirs. Three factors contribute to this confusion: (1) use of data which are either limited geographically to one part of the country or limited specifically to lakes; (2) use of a single parameter to characterize the complex ecological processes of lakes and reservoirs; and (3) the inherent differences between lakes and reservoirs which are mainly a function of morphometry and hydrodynamics. For example, a reservoir may receive a similar total nutrient load as a natural lake, but much of this load may be short-circuited through the reservoir due to project operation and essentially be unavailable to the reservoir's biological community. Also, light limitation, because of suspended sediment loads, frequently is more significant in reservoirs than in natural lakes. The purpose of this report is to provide a summary document describing the more commonly used classification schemes. It is not an exhaustive literature review, but an attempt to address the subject in a general fashion. This information will be used as a basis for subsequent studies to evaluate the appropriateness of various techniques for application to Corps of Engineers (CE) reservoirs. It also may be used as interim guidance on important considerations in selecting and applying trophic state classification schemes.

2. The term eutrophication has been widely used, often with different meanings, depending on the respective interests of its users.

As a consequence, the literature is somewhat confusing and inconsistent regarding the definition of the term. Naumann's (1919) concept of eutrophication, probably the first applied to lakes, was based on an increase in the nutrient content of water (Stewart and Rohlich 1967). A later statement by Naumann (1931) was more restrictive and defined eutrophication as the increase of nutritive substances, especially phosphorus and nitrogen, in a lake (Boland 1976). Hasler's (1947) definition, "enrichment of water, be it intentional or unintentional," has been broadly interpreted to include all nutritive substances. Others have modified the definition to address rates of nutrient input (Lee and Fruh 1966) and aging (Hasler and Ingersoll 1968).

3. Another class of definitions describes the manifestations or consequences of increased nutrients. Examples include "enrichment in nutrients and increases of plant production" (Ohle 1965), "the change in biological productivity which all lakes and reservoirs undergo during their life history" (Sawyer 1966), and a definition by Vollenweider (1968) which summarized the eutrophication of waters as meaning "... their enrichment in nutrients and the ensuing progressive deterioration of their quality, especially lakes, due to the luxuriant growth of plants with its repercussions on the overall metabolism of the waters affected...." Perhaps the most comprehensive definition of eutrophication is the one adopted by the Organization of Economic Cooperation and Development (Bartsch 1972):

> Eutrophication is the nutrient enrichment of waters which results in stimulation of an array of symptomatic changes among which increased production of algae and macrophytes, deterioration of fisheries, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses.

4. The current complexity of the definitions for eutrophication reflects man's increasing concern with problems associated with enrichment processes. To avoid additional confusion, the simple definition used in the review by Stewart and Rohlich (1967) will be used (i.e., the process of enrichment with nutrients).

5. As defined here, eutrophication does not necessarily result in the degradation of water quality. Whether or not the process adversely impacts water quality depends on the beneficial use for which a lake is being managed and the degree of nutrient enrichment. Reservoirs which are utilized mainly for warm water fisheries can tolerate a much greater degree of eutrophication than reservoirs which are being managed for coldwater fisheries or their aesthetic beauty.

6. For additional discussion on eutrophication, see Hutchinson (1967, 1969, and 1973), Rodhe (1969), Kalff and Knoechel (1978), and Lund (1978).

Lake Classification by Trophic State

7. Traditionally, most lakes have been placed in one of three trophic categories (i.e., oligotrophic, mesotrophic, or eutrophic). Oligotrophic lakes are poor in nutrients; eutrophic lakes are rich in nutrients; and mesotrophic lakes fall somewhere in between. The boundaries between the three categories are somewhat arbitrary; therefore, lake classification is more or less subjective. Welch (1952) compiled a summary which included some of the more important characterizations of these trophic groups which were and are still employed in a general fashion (Table 1). Brezonik (1969) developed a list of the more common trophic indicator parameters and indicated their response to increased eutrophication (Table 2). Numerous physical, chemical, and biological parameters are associated with the process of nutrient enrichment. Attempts have been made to establish trophic classification criteria for most of the parameters presented above. Some commonly used criteria are given in Table 3. Of particular interest in the table are the many different criteria for phosphorus, Secchi disk depth, and chlorophyll.

8. Phosphorus has been recognized as the probable controlling factor of productivity in most water bodies and, along with nitrogen, was considered by Naumann (1931) to be the most important nutrient associated with eutrophication. Chlorophyll has been shown to be highly

correlated with phosphorus, particularly in phosphorus-limited water bodies (Dillon and Rigler 1974, Jones and Bachmann 1976) and can be considered one of the major manifestations of eutrophication. Chlorophyll is closely related to algal biomass and is responsible for coloration of the water during phytoplankton blooms. Secchi disk measurements are commonly used in determining trophic state. These measurements are inexpensive and easy to make and can be correlated with total phosphorus in most water bodies (Dillon and Rigler 1974, Carlson 1977, Lambou et al. 1976, Taylor et al. 1979b). While some workers have reported strong correlations between Secchi disk values and chlorophyll (Bachmann and Jones 1974, Carlson 1977), others have not (Taylor et al. 1979b, Hern et al. in press). It seems that in lakes with high mineral turbidity, light may be limiting and does not allow the algae to utilize the available phosphorus (Hern et al. in press). In spite of this, most phosphorus-based classification criteria do not include consideration of light limitation.

9. The range of critical values used in trophic classifications is indicative of the problems inherent in defining eutrophication. According to Sawyer, Lackey, and Lenz (1945), the critical level of inorganic phosphorus that will support the development of algal blooms is 15 μg/ℓ. Sawyer (1947) later changed the critical level of inorganic phosphorus to 10 μg/ℓ after spring turnover. Sawyer (1947) considered algae blooms as characteristic of mesotrophic and eutrophic lakes. The U. S. Environmental Protection Agency (EPA) (1976) suggested 25 μg/ℓ total phophorus as the critical point in lakes and reservoirs above which biological nuisances can be expected. Identical criteria of 10 μg/ℓ have been established for both total phophorus (Allum, Glessner, and Gakstatter 1977) and inorganic phosphorus (Sawyer 1947). Although many algal blooms do not create nuisances, the 25 μg/ℓ suggested by U. S. EPA (1976) is well within the eutrophic ranges suggested by others where problem blooms may indeed occur. Results from data gathered by EPA (Williams et al. 1977) showed that only 2 of 194 lakes and reservoirs with reported blooms had annual mean total phosphorus values less than 19 μg/ℓ.

10. Phytoplankton have been studied more intensively and longer than any other group of organisms relative to trophic classifications. Many years ago, Naumann (1917) (cited in Hutchinson 1967) recognized algal related differences. He presented oligotrophic and eutrophic phytoplankton communities as early as 1919 and a number of years later established "final component members" (Table 3) (Naumann 1931, cited in Hutchinson 1967). In a review of phytoplankton associations, Hutchinson (1967, pp. 384-389) summarized the information into a series of 12 provisional classifications of phytoplankton types.

11. Numerous workers (Rawson 1956; Weber unpublished; Coesel, Kwakkestein, and Verschoor 1978) developed lists of algal species arranged in rank order of association with oligotrophic to eutrophic waters (Table 3). Although these lists have some merit, particularly at the extremes, most forms have been shown to grow well over wide ranges of environmental conditions (Coesel, Kwakkestein, and Verschoor 1978; Taylor et al. 1979a), making it impractical to use the species as definitive indicators of trophic state.

12. From the recognition of algal associations with various levels of nutrient enrichment came a series of trophic state indices based on phytoplankton assemblages. Thunmark (1945) began with a ratio of the number of species of Chlorococcales to the number of species of desmids as a measure of the position of any plankton association in a series running from those characteristic of extremely unproductive soft transparent waters to extremely productive hard waters turbid with plankton (Hutchinson 1967). Nygaard (1949) developed four similar indices of which the compound index is given in Table 3. More recently, Stockner (1971) proposed the A/C ratio based on the number of Araphidineae (A) diatom species to the number of Centrate (C) diatom species (Table 3).

13. These indices assume a degree of uniformity within various taxonomic groups that extensive phytoplankton analyses at U. S. EPA, Las Vegas, have not substantiated (Hern et al. 1979, Lambou et al. 1979, Morris et al. 1979, Taylor et al. 1979a, Williams et al. 1979). Nygaard's indices, in particular, correlate poorly against total phosphorus and chlorophyll criteria (Taylor et al. 1979b). The A/C ratio

was not tested.

14. A more current trend in lake classification is the employment of multiple parameter indices to quantitatively rank water bodies along a continuum of trophic state. Approaches vary from the six parameter relative trophic index developed at the Corvallis Environmental Research Laboratory (U. S. EPA 1974b) to phytoplankton community-based trophic state indices that combine algal taxa, related chemical and physical associations, and community structure to produce a relative ranking of water bodies (Taylor et al. 1979b).

15. Principal components analysis has been used to further refine the selection of parameters indicative of trophic state and to reduce the dimensionality of a multivariate system to a single numerical expression (Blackwell and Boland 1979; Boland 1976; Shannon 1970; Wezernak, Tannis, and Bajaz 1975). Once calculated, regardless of the technique, most of the numerical ranking indices are compared to traditional estimates of trophic state in order to judge their effectiveness.

16. Recently, 38 indices and measurements of trophic state were compared to evaluate their relative abilities to trophically rank a test set of 44 eastern and southeastern U. S. lakes and reservoirs (Taylor et al. 1979b). Included in the group of indices and measurements tested were many of the parameters and approaches discussed here. Some of the other approaches included diversity and evenness components of diversity indices, loading models, N/P ratio, and single parameter indicators such as total Kjeldahl nitrogen and conductivity. Lake rankings based upon total phosphorus and chlorophyll levels served as criteria for evaluation of the indices by Spearman Rank Correlation (Steel and Torrie 1960).

17. Phosphorus was used as a criterion because it is generally considered to be the most important nutrient associated with eutrophication of fresh waters, while chlorophyll is considered a primary parameter for measuring the manifestations of nutrient enrichment. Results from calculation of the various indices and measurements showed important differences relative to the two criteria. With the exception of total Kjeldahl nitrogen, which had agreement with both criteria,

indices that correlated well with the phosphorus criterion showed poor rank correlation with the chlorophyll criterion. The converse was also true, i.e., those that correlated well with chlorophyll did poorly with total phosphorus.

18. Phosphorus loading models were quite successful in ranking lakes relative to the phosphorus criterion rankings but were unsuccessful when compared to the chlorophyll rankings, i.e., they did not predict the primary manifestation of eutrophication. Secchi disk depth measurements closely approximated the rank orders of the loading models. High mineral turbidity, which binds phosphorus in a form unavailable to the algae and reduces the light reaching them, constitutes the primary reason for the poor correlation of loading models and Secchi measurements with the chlorophyll criterion.

19. Such widely used biological indices as Palmer's Organic Pollution Index (Palmer 1969), Nygaard's Trophic State Indices (Nygaard 1949), Shannon-Wiener's Phytoplankton Diversity Index (Shannon and Weaver 1963), and Pielou's Evenness Component of Phytoplankton Diversity (Pielou 1966) were generally ineffective for lake trophic state assessment. However, several phytoplankton community-based trophic indices introduced in the study were shown to be more effective in trophically ranking lakes, relative to the chlorophyll _a_ criterion, than most of the widely used trophic indices or measurements tested.

Conclusions and Recommendations

20. This report has illustrated the complexities and contradictions associated with attempts to label water bodies as oligotrophic, mesotrophic, or eutrophic. While eutrophication is the process of nutrient enrichment, the manifestations of nutrient enrichment present tangible problems to man. However, high nutrient loads to lakes and reservoirs (characterized as eutrophic by any of the phosphorus criteria presented here) often do not result in either massive algal blooms or excessive submerged aquatic weed growths. This is attributed to light limitation

due to mineral turbidity or other limiting factors (Hern et al. in press). In reservoirs, a portion of the nutrient load may be short-circuited through the lower depths of the reservoir by project operations and be essentially unavailable for influencing reservoir water quality and biological productivity. The process of nutrient enrichment does not always result in the degradation of water quality. Whether or not the process adversely impacts water quality depends on the beneficial use for which a lake or reservoir is being managed and the degree of nutrient enrichment. Trophic classification of a lake or reservoir becomes a function of the criteria used and is frequently inconsistent among existing classification criteria.

21. Trophic classification should be placed in proper perspective and the need for appropriate application of classification techniques should be recognized. Consistent application of a specific trophic classification technique to a single lake or group of lakes can reveal useful information concerning relative changes over time (trophic trend analyses). However, the limitations inherent in forcing lakes into categories with ill-defined limits--particularly when the limits are based upon single parameters--must be recognized and discretion used in application of such techniques. A more practical approach to reservoir classification would place paramount consideration upon the potential beneficial uses of the lake and, possibly, the regional water quality characteristics required to meet those uses. From such analyses, it would be readily apparent whether a reservoir can support such uses or whether it can be managed to bring important water quality parameters within acceptable ranges.

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Table 1

Characterizations of Oligotrophic and Eutrophic Waters*

Oligotrophic Waters	Eutrophic Waters
Very deep; thermocline high; volume of hypolimnion large; water of hypolimnion cold.	Relatively shallow; deep, coldwater minimal or absent.
Organic materials on bottom and in suspension very low.	Organic materials on bottom and in suspension abundant.
Electrolytes low, or variable; calcium, phosphorus, and nitrogen relatively poor; humic materials very low or absent.	Electrolytes variable, often high; calcium, phosphorus, and nitrogen abundant; humic materials slight.
Dissolved oxygen content high at all depths and throughout year.	Dissolved oxygen, in deeper stratified lakes of this type, minimal or absent in hypolimnion.
Larger aquatic plants scanty.	Larger aquatic plants abundant.
Plankton quantitatively restricted; species many; water blooms rare; Chlorophyceae dominant.	Plankton quantitatively abundant; number of species variable; water blooms common; Myxophyceae and diatoms predominant.
Profundal fauna relatively rich in species and quantity; _Tanytarsus_ type present; _Corethra_ usually absent.	Profundal fauna, in deeper stratified lakes of this type, poor in species and quantity in hypolimnion; _Chironomus_ type present; _Corethra_ present.
Deep-dwelling, coldwater fishes (salmon, cisco, trout) common to abundant.	Deep-dwelling coldwater fishes usually absent; suitable for perch, pike, bass, and other warmwater fishes.
Succession into eutrophic type.	Succession into pond, swamp, or marsh.

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* Adapted from Welch (1952).

Table 2

Trophic Indicators and Their Response to Increased Eutrophication*

Physical	Chemical	Biological
Transparency (d) (Secchi disk depth)	Nutrient concentrations (i) (e.g., at spring maximum)	Algal bloom frequency (i)
		Algal species diversity (d)
Depth	Chlorophyll a (i)	Littoral vegetation (i)
Suspended solids (i)	Conductivity (i)	Zooplankton (i)
	Dissolved solids (i)	Fish (i)
	Hypolimnetic oxygen deficit (i)	Bottom fauna (i)
	Epilimnetic oxygen supersaturation (i)	Bottom fauna diversity (d)
		Primary production (i)
		Phytoplankton biomass (i)

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*An (i) after an indicator signifies the value increases with eutrophication; a (d) signifies the value decreases with eutrophication. The biological indicators all have associated qualitative changes (i.e., species changes occur as well as quantitative (biomass) changes as eutrophication proceeds). Adapted from Brezonik (1969).

Table 3

Commonly Used Trophic Classification Criteria

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
CHEMICAL					
Nutrients	Waters with low concentrations of nutrients	Waters of intermediate concentrations of nutrients	Waters rich in nutrients, well nourished	Glossary definitions.	Stewart and Rohlich (1967)
Ambient total phosphorus, µg/ℓ	<14	14 - 30	>30	For P-limited lakes.	National Academy of Science (1972)
Ambient total phosphorus, µg/ℓ	<10	10 - 20	>20	For P-limited lakes.	Vollenweider (1968), U.S. EPA (1974a), Dillon (1975), Larsen and Mercier (1976)
Ambient total phosphorus, µg/ℓ	<10	10 - 20	>20-25	For P-limited lakes.	Allum, Glessner, and Gakstatter (1977)
Inorganic phosphorus, µg/ℓ				Based on 17 Wisconsin lakes. Critical level for the development of algal blooms was set at 15 µg/ℓ. Algal blooms are generally considered characteristic of mesotrophic and eutrophic water bodies.	Saywer, Lackey, and Lenz (1945)

(Continued)

(Sheet 1 of 9)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
<u>CHEMICAL (Continued)</u>					
Inorganic phosphorus, μg/ℓ				Critical level for the development of algal blooms was set at 10 μg/ℓ at spring turnover.	Sawyer (1947)
Total phosphorus, μg/ℓ				To prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates should not exceed 100 μg/ℓ in streams, 50 μg/ℓ in streams at the point where they enter lakes or reservoirs, or 25 μg/ℓ within the lake or reservoir.	U.S. EPA (1976)
Annual total phosphorus loading $g/m^2/yr$	Oligotrophic or Permissable Loading $g/m^2/yr$		Eutrophic or Critical Loading $g/m^2/yr$	Mean Depth/Hydraulic Detention Time m/yr	Vollenweider (1973) cited in U. S. EPA (1976)
	0.07		0.14	0.5	
	0.10		0.20	1.0	
	0.16		0.32	2.5	
	0.22		0.45	5.0	
	0.27		0.55	7.5	
	0.32		0.63	10.0	
	0.50		1.00	25.0	
	0.71		1.41	50.0	
	0.87		1.73	75.0	
	1.00		2.00	100.0	

(Continued)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
CHEMICAL (Continued)					
Inorganic nitrogen, $\mu g/\ell$				Critical level for the development of algal blooms was set at 300 $\mu g/\ell$ after the spring turnover. Algal blooms are generally considered characteristic of mesotrophic and eutrophic water bodies.	Sawyer, Lackey, and Lenz (1945) Sawyer (1947)
Hypolimnetic dissolved oxygen. % saturation	>80	10-80	<10		Allum, Glessner, and Gakstatter (1977)
Loss rate of hypolimnetic oxygen, mg/cm^2/day	0.004 to 0.033	>0.033 to 0.05	0.05 to 0.14		Hutchinson (1957)
Suggested limits of oxygen loss in hypolimnion, mg/cm^2/day	Upper Limit is 0.025	--	Lower Limit is 0.055		Mortimer, date unknown, cited in Hutchinson (1957)
pH	Usually <7.0	—	Usually >7.0		Hutchinson (1967)
Calcium, g/ℓ	<10	—	>10		Hutchinson (1967)
PHYSICAL					
Secchi disk depth, m	3.7	2.0-3.7	2.0	Based emperically on data from 98 phosphorus-*limited lakes* sampled by National Eutrophication Survey during 1972.	U.S. EPA (1974b)

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(Sheet 3 of 9)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
PHYSICAL (Continued)					
Secchi disk depth, m	>3.7	--	--	Based on data from 12 Wisconsin lakes.	Lueschow et al. (1970)
Secchi disk depth, m	>4.6	2.0-4.6	< 2.0		Michigan (1977), cited in Rogers (1977)
Secchi disk depth, m	>6.1	3.0-6.1	<3.0		Dobson, Gilbertson, and Sly (1974)
Secchi disk depth, m	>5.0	3.0-5.0	<3.0		Ministry (1973), cited in Rogers (1977)
Mean depth, m	≥20	—	≤10		Rawson (1955)
BIOLOGICAL					
Chlorophyll a, μg/ℓ	<2.3	2.3-6.4	>6.4		Hern et al. (In Press)
Chlorophyll a, μg/ℓ	0.3-2.5	1.0-15.0	5.0-140.0	Nonmacrophyte dominated lakes.	Sakamoto (1966)
Chlorophyll a, μg/ℓ	0.0-4.0	4.0-10.0	>10.0	Nonmacrophyte dominated lakes.	National Academy of Science (1972), Allum, Glessner, and Gakstatter (1977), cited in Rogers (1977)

(Continued)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
BIOLOGICAL (Continued)					
Chlorophyll a, µg/ℓ	0.0-4.5	4.3-8.8	>8.8	Nonmacrophyte dominated lakes.	Dobson, Gilbertson, and Sly (1974)
Chlorophyll a, µg/ℓ	< 7.0	7.0-12.0	>12.0	Based emperically on data from 98 phosphorus-limited lakes sampled by WES* during 1972.	U.S. EPA (1974b)
Chlorophyll a, µg/ℓ	0.0-3.0	3.0-5.0	>5.0		Ministry (1973), cited in Rogers (1977)
Chlorophyll a. µg/ℓ	0.0-3.0	3.0-20.0	>20.0		Weber (unpublished)
Algal assay control yield, mg/ℓ dry wt	0.00-0.10	0.10-0.80	0.81-20.00		Miller et al. (1974)
Primary productivity. $g/m^2/day$	0.0-0.2	0.2-0.75	> 0.75		Weber (unpublished)
Phytoplankton concentration, number/mℓ	<1000 with no filamentous blue-green algae	1000-5000 blue-green algae not dominant	1000 when blue-green algae are dominant, >5000 when blue-green algae are not dominant		Allum, Glessner, and Gakstatter (1977)
Phytoplankton concentration, number/mℓ	0-2000	2,000-15,000	>15,000		Weber (unpublished)

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* WES = U. S. Army Engineer Waterways Experiment Station.

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
BIOLOGICAL (Continued)					
Oligotrophic formation	Desmid or Caledonian Chlorophycean *Botryococcus* *Sphaerocystis* Chrysophycean *Dinobryon* *Mallomonas* Peridinian *Ceratium* *Peridinium willet* Diatom *Tabellaria* *Cyclotella*				Naumann (1931), cited in Hutchinson (1967)
Eutrophic formation			Peridinian *Ceratium* *Peridinium* spp. Diatom *Melosira* *Stephanodiscus* Chlorophycean *Pediastrum* Myxophycean		Naumann (1931), cited in Hutchinson (1967)

(Continued)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
BIOLOGICAL (Continued)					
Algal bloom	Rare	--	Frequent		Fruh et al. (1966)
Algal indicator species (all species of *Cyclotella*)	*C. glomerata* *C. ocellata* *C. kutzingiana* *C. operculata* *C. michiganiana* *C. stelligera*	*C. comta* *C. memeghiana* *C. pseudostelligera* *C. atomus* *C. striata*	*C. nana*	Approximate trophic ranking from least to most eutrophic.	Weber (unpublished)
Algal species variety	Many	--	Variable to few		Fruh et al. (1966)
Characteristics algal group	—	--	Blue-green *Anabaena* *Aphanizomenon* *Microcystis* *Oscillatoria rubescens*		Fruh et al. (1966)
Algal indicator	*Asterionella formosa* *Melosira islandica* *Tabellaria fenestrata* *T. flocculosa* *Dinobryon divergens* *Fragilaria capucina* *Stephanodiscus* spp. *Melosira granulata*	*Fragilaria crotonensis* *Ceratium hirundinella* *Pediastrum boryanum* *Coelosphaerium naegelianum* *Anabaena* sp. *Aphanizomenon flos-aquae* *Microcystis aeruginosa*	*Microcystis flos-aquae*	Approximate trophic distribution of dominant limnetic algae in lakes of western Canada. Dominance means contributing a high percentage of the phytoplankton count over much of the summer season. Species are listed in order of least to most eutrophic.	Rawson (1956)

(Continued)

Table 3 (Continued)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
BIOLOGICAL (Continued)					
Indicator desmids	*Staurastrum elogastrum* group (16 spp.)	*Micrasterias truncata* group (13 spp.)	*Cosmarium punctulatum* group (9 spp.)	The three lists represent a continum from oligotrophic to eutrophic, the division being arbitrary.	Coesel, Kwakkestein, and Verschoor (1978)
	Metrium oblongum group (12 spp.)	*Euastrum anasatum* group (17 spp.)	*Staurastrum polytrichum* group (24 spp.)		
	Staurastrum brachiatum group (12 spp.)	*Cosmarium quadratum* group (9 spp.)	*Micrasterias apiculata* group (44 spp.)		
		Closterium jenneri group (9 spp.)			
		Arthrodesmus convergens group (6 spp.)			
		Cosmarium portianum group (8 spp.)			
		Euastrum crassum group (10 spp.)			
Dominant bottom fauna	*Orthocladium* *Tanytarsus*	*Stictochironomus* *Sergentia*	*Bathothilus* *Plumosus*		Brundin (1958), cited in Stewart and Rohlich (1967)

(Continued)

Table 3 (Concluded)

Parameter or Technique	Oligotrophic	Mesotrophic	Eutrophic	Comments	References
BIOLOGICAL (Continued)					
Bottom fauna	*Tanytarsus*		*Chironomids*		Fruh et al. (1966)
Fish	Deep-dwelling, cold-water fishes (i.e., trout, salmon, and cisco)		Surface-dwelling, warmwater fishes (i.e. pike, perch, and bass)		Fruh et al. (1966)
Zooplankton	*Bosmina obtusirostris* *B. coregoni* *Diaptomus gracilus*		*Bosmina longirostris* *Diaptomus cuculata*		Fruh et al. (1966)
Compound phyto-plankton index	0-1		1.2-25.0	This index is the number of myxoplycaen, chlorococcalean, centrate, and euglenophytan species per number of Desmideae species. Should be applied to summer samples.	Nygaard (1949)
Araphidineae/Centrales (A/C ratio)	1.0	1.0-2.0	2.0	The ratio is calculated dividing the number of Araphidineae (*Fragilaria*, *Asterionella*, and *Synedra*) by the number of centrate species.	Stockner (1971)

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Taylor, W D
Trophic state of lakes and reservoirs / by W. D. Taylor ... [et al.], Environmental Monitoring and Support Laboratory, U. S. Environmental Protection Agency, Las Vegas, Nevada. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
15, [11] p. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station : E-80-3)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Interagency Agreement EPA-78-R-X0393 (EWQOS Work Unit 31594; Task IB.1)
References: p. 11-15.

1. Eutrophication. 2. Lakes. 3. Reservoirs. 4. Trophic level. I. United States. Army. Corps of Engineers. II. United States. Environmental Protection Agency. Environmental Monitoring and Support Laboratory. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; E-80-3.
TA7.W34 no.E-80-3