[Journal of the Minnesota Academy of Science](https://digitalcommons.morris.umn.edu/jmas)

Volume 13 | Number 1 Article 3

4-1945

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groups 2 to 7 was 58, 45, 83, 96, 83 and 86 per cent of the amount entering similar muscle of normal animals. The amount entering the muscle which had been previously occluded in each of these groups was 96, 83, 169, 224, 162 and 134 per cent of the normal calculated on a basis of dry weight of muscle. Considerable elevation of the phosphate content of the plasma occurred in groups 4, 5, 6 and 7. If the elevated phosphate of the plasma is considered it appears that the unoccluded muscle is much less permeable to plasma phosphate than normal and that the muscle previously occluded is permeable about as much as normal except in groups 6 and 7 when the blood pressure was greatly reduced.

CLASSIFICATION OF LAKE WATERS UPON THE BASIS OF HARDNESS

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Chemically, hardness is a measure of the soap-consuming power of water. Calcium, magnesium, and to a lesser extent iron and aluminum are the principal metals which in fresh waters form insoluble compounds with soap. The amount of soap used before suds are formed can be taken as an index of the total concentration of these metals. Although water hardness is of two types, temporary hardness due to carbonate salts and permanent hardness due to sulphate salts, hardness is always expressed as parts per million of calcium carbonate. Temporary hardness is so called because heating the water precipitates the disolved carbonates as scale. Sulphate salts which cause permanent hardness are not affected by heating. From the point of view of utilization for public and industrial water supply, Theroux, Eldridge and Mallman (1943) classify waters as follows:

	Total hardness expressed as p.p.m. calcium carbonate
Sufficiently soft for ordinary use	Less than 50 to 75 p.p.m.
Moderately hard	75 to 100 p.p.m.
Hardness noticeable to most persons	Greater than 150 p.p.m.
Water softeners often necessary	Greater than 200 p.p.m.

Since this classification is designed primarily for the use of water supply engineers, it is of limited value to workers in the fields of limnology and fisheries.

It has long been recognized that hard carbonate waters are often more productive of aquatic life than soft carbonate waters, and because of this several schemes have been devised by biological workers for the classification of waters upon the basis of hardness. It should be remembered that in most fresh waters the concentration of sulphate salts is low and that the term "hardness" as employed by many limnological and fisheries workers refers to carbonate or temporary hardness and is often regarded as practically synonymous with total alkalinity (methyl orange alkalinity) or bound carbon dioxide.

Birge and Juday (1911) classified Wisconsin lake waters on the basis of hardness as follows:

	Expressed as cc. bound carbon dioxide per liter	*Recalculated as p.p.m. calcium carbonate*
Soft-water lakes	Less than 5	Less than 20.3
Median class lakes	5 to 22	20.3 to 89.2
Hard-water lakes	More than 22	More than 89.2

This is a natural classification which is valid in Minnesota waters but which is not complete enough to afford adequate description and coverage of all waters in the state.

The classification of water hardness included in the Wildlife Handbook for the North Central Region (United States Department of Agriculture, 1940) seems to be a more or less arbitrary separation of waters for convenient and consistent description. It appears to have no biological basis. The scheme given in this handbook is as follows:

	Expressed as p.p.m. bound carbon dioxide	*Recalculated as p.p.m. calcium carbonate*
Very soft water	0—5	0—11.4
Soft water	5—10	11.4—22.7
Medium water	10—20	22.7—45.5
Medium hard water	20—30	45.5—68.2
Hard water	30	68.2

Botanists have long recognized the existence of three aquatic floras whose distribution is related to the chemical quality of the water. They are (1) the acid or soft-water flora, (2) the calcareous or hard-water flora, and (3) the brackish or alkali-water flora. These floras have been variously delimited and classified by such workers as Metcalf (1931), Naumann (1932), Samuelsson (1934), McAtee (1939), Martin and Uhler (1939), and Coston, Pentelow and Butcher (1936). Extensive work on Minnesota lakes (Moyle, 1945) shows that the separation between these floras in Minnesota usually has the following chemical basis:

	Total alkalinity as p.p.m. calcium carbonate	*Sulphate ion p.p.m.*
Soft-water lakes	0—40	Less than 5
Hard-water lakes	41—250	Usually less than 10
Alkali or sulphate-water lakes	More than 100	More than 50

Soft-water lakes are characterized by a scanty growth of larger aquatic plants and typically support such rosette- or tuft-forming species as water lobelia (*Lobelia Dortmanna* L.), pipewort (*Eriocaulon septangulare* With.), quillwort (*Isoetes Braunii* Dur.), floating leaf burreed (*Sparganium fluctuans* (Morong) Robinson), and submerged bulrush (*Scirpus subterminalis* Torr.). Other characteristic species are the little yellow water lily (*Nuphar microphyllum* (Pers.) Fern.), milfoil (*Myriophyllum alterniflorum* DC.), and the spiral pondweed (*Potamogeton Spirillus* Tuckerm.). Alkali or sulphate waters are characterized by brackish-water species especially widgeon grass (*Ruppia occidentalis* Wats.), spiny naiad (*Najas marina* L.), horned pondweed (*Zannichellia palustris* L.), and bayonet grass (*Scirpus paludosus* Nels.). The hard-water lakes support a robust growth of the common pondweeds (*Potamogeton* spp.), muskgrasses (*Chara* spp.), milfoil, coontail, waterlilies and many other aquatic plants. However, the typical alkali and soft-water plants are absent.

If these botanical data are combined with other types of limnological and fisheries data for the Minnesota lakes, a more detailed classification of lake waters on the basis of hardness can be devised. The following proposed scheme is essentially a combination of the foregoing classification based upon distribution of aquatic plants with that of Birge and Juday (1911) and represents a natural arrangement for the chemical separation of Minnesota lake waters.

	Total alkalinity as p.p.m. calcium carbonate	*Sulphate ion p.p.m.*
Very soft-water lakes	0 — 20	Less than 5
Soft-water lakes	21 — 40	Less than 5
Medium hard-water lakes	41 — 90	Less than 5
Hard-water lakes	More than 91	Less than 50
Medium alkali-water lakes	More than 100	50 — 125
Alkali-water lakes	More than 100	More than 125

In regions generally low in sulphate salts the last two categories can be disregarded and since it appears from Minnesota fish pond production data that sulphates in low concentrations such as those of the first four categories have little if any effect on productivity, sulphate analyses are essential only where alkali waters may be expected to occur.

The bases for the foregoing classifications are as follows:

Very soft-water lakes.— General productivity low; larger aquatic plant growth sparse and that mostly limited to typical soft-water species; deep lakes are often trout water with oxygen below the thermocline; lakes generally unsuited to centrarchid fishes and walleye pike; plankton sparse; no blue-green algal bloom or free-floating vegetation, such as duckweeds, unless there is pollution. Unfertilized fish ponds with this type of water are usually not productive. Plants typical of this type of water are the rosette-forming species *Lobelia Dortmanna, Eriocaulon septangulare, Isoetes Braunii* and such slender species as *Potamogeton Spirillus, Myriophyllum alterni-*

florum, and *Nitella* sp. The more robust submerged plants are noticeably absent. *Sagittaria* spp. frequently developed only juvenile leaves (phyllodes) in water of this type.

Soft-water lakes.—General productivity fair to good; aquatic plants, especially pondweeds, more abundant than in preceding type; deep lakes usually have oxygen below the thermocline and often support a cisco or trout population; lakes of this type often have a good walleye pike population but in Minnesota are usually not productive of panfish; usually no blue-green algal bloom; free-floating aquatic plants are lacking or very rare; several fish ponds with waters of this type have proven to be moderately productive. Typical plants are the soft-water species mentioned for the preceding group plus the more robust aquatic plants such as *Potamogeton amplifolius, P. alpinus, P. natans, P. epihydrus, Nuphar microphyllum,* and *Vallisneria americana*. Typical hard-water species such as *Potamogeton pectinatus, P. Richardsonii,* and *Chara* spp. are usually lacking or make poor growth.

Medium hard-water lakes.—General productivity good; some of the most productive Minnesota lakes fall in this category; larger aquatic plants abundant and robust, the larger potamogetons being the predominant members of the flora; typical soft-water species are absent; some waters in this category have summer oxygen depletion below thermocline, others do not and support tullibee populations; there are few trout lakes with water of this type but many good panfish and walleye pike waters; harder waters of this category often have moderate blue-green algal blooms and free-floating vegetation is fairly common. Some of the more productive Minnesota fish ponds have been those with medium hard waters. Typical plants of this water type are *Nuphar variegatum, Nymphaea odorata, Potamogeton amplifolius, P. natans, P. strictifolius, P. Robbinsii, Bidens Beckii, Pontederia cordata, Eleocharis palustris* var. *major*, as well as many other robust species more typical of harder waters.

Hard-water lakes.—General productivity good; many of the best Minnesota walleye pike and panfish lakes are in this category; larger aquatic plants robust and abundant but often limited to water less than 10 feet deep because of heavy plankton production; deep lakes usually have summer oxygen depletion below the thermocline; lakes often have a heavy blue-green algal bloom and free-floating plants such as duckweeds and *Ceratophyllum demersum* are abundant. Many fish ponds with this type of water have produced well. Typical plants of this type of water are *Potamogeton pectinatus, P. Richardsonii, P. praelongus, Najas flexilis, Chara* spp., *Ceratophyllum demersum, Myriophyllum exalbescens,* and *Potamogeton gramineus* forma *myriophyllus*.

Medium alkali-water lakes.—General productivity good; many good panfish lakes, some walleye lakes, and carp and bullhead waters fall in this category; larger aquatic plants are usually abundant and robust and generally similar to the preceding water type except that some members of the alkali flora appear; there are no deep lakes of this type in Minnesota and some are so shallow that winter oxygen depletion can usually be expected; a heavy blue-green algal bloom is usual in summer and duckweeds are often abundant in bays. The production of fish ponds with water of this type has been moderately good to good. Typical aquatic plants of waters of this type are *Potamogeton pectinatus, P. Richardsonii, P. foliosus, Najas flexilis, Chara* spp., with the typical alkali-water plants *Ruppia occidentalis, Najas marina,* and *Zannichellia palustris.*

Alkali-water lakes.— General productivity good for lakes within the sulphate range found in Minnesota fishing waters (less than 300 p.p.m. of SO_4 ion); aquatic plant growth often heavy but of a few species compared to hard carbonate waters; there are no deep lakes of this type in Minnesota, all being shallow prairie lakes; summer blue-green algal blooms are common although small lakes with a very high sulphate concentration may remain clear; duckweeds and *Ceratophyllum* often abundant; most larger aquatic plants typical of hard carbonate waters grow poorly when the sulphate ion concentration exceeds 300 parts per million; fish ponds with a sulphate ion concentration above 250 parts per million usually have not produced well. Typical plants are *Ruppia occidentalis, Najas marina, Zannichellia palustris, Potamogeton pectinatus, P. Richardsonii, Najas flexilis,* and *Chara* spp. Data from areas with waters having higher salt concentrations than those found in Minnesota (Metcalf, 1931) show that the vegetation becomes increasingly limited as the concentration of alkali salts increases.

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