Eutrophication
and Trophic State

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Why Does Lake Water (Quality) Differ from Lake to Lake?

How many lakes do you know? Do you have a favorite lake (Figure 1)? Do you know a lake that you'd rather not know (Figure 2)? Chances are that you know quite a few lakes that are all different. Some invite you for a dip, some entice you to get the bass boat out, some are just gorgeous to look at—with the mountains behind and the meadows in front, or with the skyscrapers in the back, but tranquility around. So everybody knows by experience that lakes are different, but why is there such a variation? Before I summarize some aspects why water quality differs from lake to lake, water quality has to be defined and explained.

A Definition: "Water Quality"

Laymen often use water clarity and transparency to describe water quality. However, water quality is not a quantitative variable per se. Sociological studies found that people who are used to relatively clean, clear, and swimmable lakes have much higher expectations about the transparency of a "good" lake, than people living in regions with few clear lakes or few natural lakes in general. This becomes particularly obvious when comparing lakes across the continent or even between continents: south-central North Americans, central Europeans, and South Africans are used to green lakes; northern Europeans (Scandinavians), as well as northern Canadians and people from some northern and mountainous states, may be used to clear lakes.

To turn a subjective value (a "good" lake) into an objective appraisal, limnologists typically use three or four lake characteristics to describe water quality, and not just clarity. Most of these variables reflect conditions of the upper water layers (epilimnion); one reflects conditions in the bottom layer (hypolimnion). All these characteristics are based on summer conditions, since lake quality often deteriorates when temperature and light increase so that algae growth rates are at maximum, and also, because that is when humans typically are in close contact with lakes.

Transparency

This is the water quality variable people usually note first. It is mainly determined with a Secchi disk and can be measured by any person with a boat, string, and a weighted disk. Secchi disk transparency reflects algal biomass as well as water color and varies between 0 and several meters (Figure 3).

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Figure 1. Grandview Lake on the Canadian Shield, the author's favorite lake, where she lives, swims, skates, and skis.

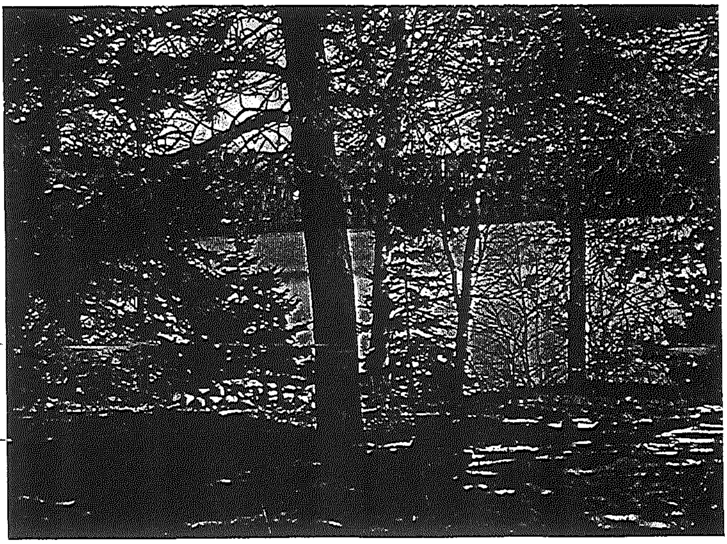

Figure 2. A highly productive, less-desirable lake.

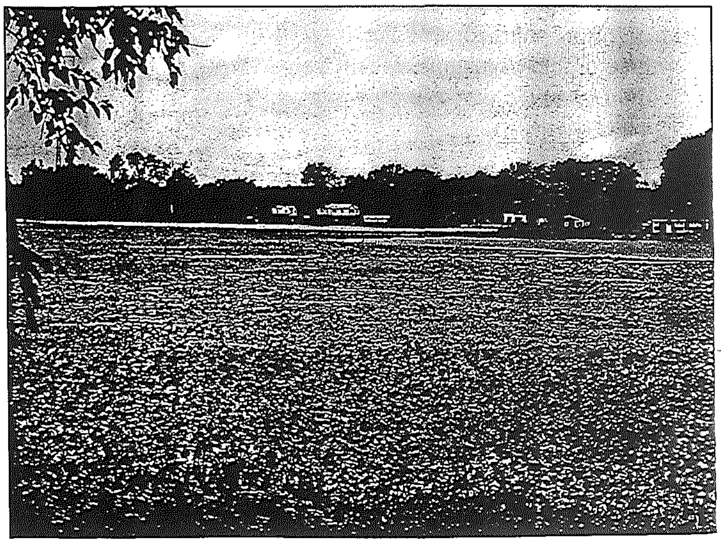

Table 1. Trophic state categories based on summer epilimnetic water quality (Nürnberg 1996).

	Oligotrophic	*Mesotrophic*	*Eutrophic*	*Hypereutrophic*
Total Phosphorus (µg/L)	< 10	10 – 30	31 – 100	> 100
Total Nitrogen (µg/L)	< 350	350 – 650	651 – 1,200	< 1,200
Chlorophyll (µg/L)	< 3.5	3.5 – 9	9.1 – 25	> 25
Secchi Disk transparency (m)	> 4	2 – 4	1 – 2.1	< 1
Anoxic Factor (d/yr)	0 – 20	20 – 40	40 – 60	> 61

pollutants can be washed into the lake when the slope is steep or the ground is relatively impervious. Generally, almost all rain that falls on a parking lot gets flushed into a nearby stream or lake, unless stormwater ponds and other holding structures are used. Similarly, runoff from adjacent fields and lawns is flushed into the lake, including soil particles and fertilizer, especially if fields are tilled vertically on a slope. Development around remote lakes without sewage-collecting structures used to fertilize many North American lakes. However, advances in septic system technology keep the effect of shoreline development to a minimum, especially if combined with sound development strategies (setbacks from shoreline, natural shorelines).

Since the location of a lake within its natural surroundings is so important to its water quality, another lake classification system was developed based on the eco-region principle (Omernik et al. 1991). This concept realizes that the trophic state of lakes varies between geological regions. A quarter of the lakes with the best water quality per region is used to represent "natural" or "background" water quality with only minimal anthropogenic influences. Corresponding water quality thresholds have been listed for many states and can be used for target-setting.

Despite the strong dependence of water quality on its location within the watershed or catchment basin, water quality has to be influenced by individual lake characteristics as well, because you can have very "clean" lakes located beside lakes that are nutrient-enriched with murky water and algal blooms.

Lake Shape (Morphometry)

Probably the most obvious difference among lakes lies in their shapes (morphometry). In general, it appears that shallow lakes tend to have higher phosphorus concentrations than deeper lakes (Figure 10). More generally, lakes can be shallow and large, shallow and small, deep and large, and deep and small. A good measure of these combinations is the lake's deviation from an idealized cone shape, i.e., the ratio of mean depth divided by the square root of the lake surface area. A small morphometric ratio means weak stratification and polymixis, a larger ratio implies summer stratification and in extreme cases, meromixis (Osgood 1988). This ratio was found repeatedly to influence water quality relationships. For example, lakes with high ratios have a tendency to have high Anoxic Factors for a given nutrient level (Nürnberg 1995), which in turn can mean prolonged self-fertilization.

Water Flow (Hydrology)

Another important influence on individual lakes is related to the hydrology, in particular, the water movement through it, also called the "flushing rate." The faster the flushing rate, the more the lake resembles a river. Reservoirs in particular often have high flushing rates. The influence of flushing rates on water quality is complicated. On one hand, flushing helps moving nutrients and pollutants quickly through the system with limited time for assimilation. On the other hand, flushing prevents a self-cleaning process of settling pollutants and nutrients to the bottom sediments. Detailed models are available that describe the influence of hydrology combined with morphometry on the fate of entering nutrients (Nürnberg 1998, 2001).

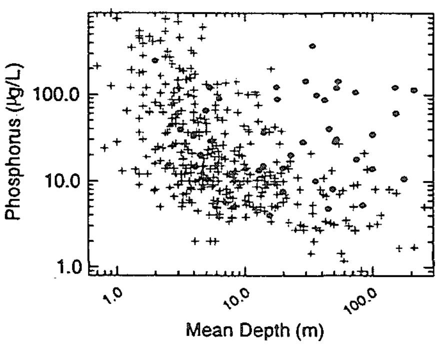

Figure 10. Summer epilimnetic total phosphorus concentration versus mean depth, where mean depth can be calculated as lake volume over lake surface area. Shallower lakes tend to have higher phosphorus concentrations than deeper lakes (crosses), except for many Central European lakes (filled circles).

Chemistry and Climate

In addition to the chemical differences between hard versus soft water lakes, lake color is a useful indicator of natural organic acids (humic and fulvic acids). Again, these characteristics are heavily influenced by the catchment geology. Once, stained lakes were believed to comprise a completely different trophic state class, "dystrophic" or low productivity. However, more recent research indicates that stained lakes behave quite similar to clear lakes, with indications that biomass and productivity (especially when considering the whole water column, including heterotrophic production by bacteria) is even increased (Nürnberg and Shaw 1998). There also is a tendency for colored lakes to have higher nutrient concentrations and hence trophic state (Figure 11, significant positive regressions of nutrients on color, about 30% of the variance explained).

Climate has always influenced lake water quality as well. The ratio of evaporation versus precipitation dictates whether a lake will become more concentrated with time, and more salty and eutrophic. Many prairie and desert lakes, such as the Great Salt Lake, UT, are known as saline lakes. Recently, changes in color were observed and traced back to climate changes. There is

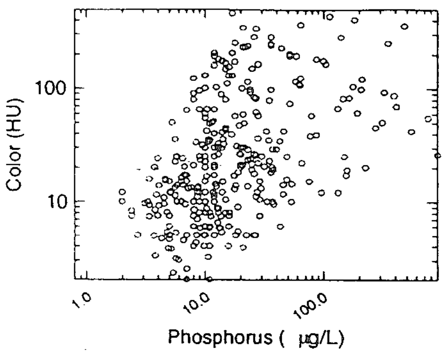

Figure 11. Average lake color and epilimnetic phosphorus concentrations.

more research investigating the effect of warmer and dryer weather on lake levels, organic acid concentration, and trophic state.

In-Lake Usage

Naturally, how a lake is treated, can influence lake water quality. Misuse—i.e., overcrowding by boaters and swimmers, dumps and spills from vessels or shoreline structures—can increase nutrient concentrations and negatively effect water clarity. On the other hand, in-lake management treatments such as chemical precipitation or withdrawal of nutrient rich hypolimnetic water can positively affect trophic state.

Science Applied: Empirical Limnology

The late Frank Rigler (Professor for Limnology at McGill University, Montreal, Quebec) always asked: "What do we know about a lake without starting a huge monitoring program? What easily obtainable information can be used to predict water quality?"

Lakes vary with respect to many characteristics, all influencing water quality and trophic state. Limnology classifies lake water quality with respect to summer surface and bottom water quality. Algae content or chlorophyll concentration, transparency or Secchi disk depth, and nutrient concentrations are used to specify surface quality, the lack of oxygen (anoxia) is quantified to estimate hypolimnetic water quality. These variables are all dependent on each other and on certain other lake characteristics such as morphometry and hydrology. As these relationships are predictable and quantifiable, they can be used to forecast lake water quality and its impact on future scenarios (for example, the impact of increased development; for a more detailed description, see Nürnberg and LaZerte 2001). In this way, water quality can be modeled for individual lakes and specific conditions even if we only know some basic information, e.g., the location of a lake on a map. The map would give us the general watershed characteristics (including approximate geochemistry and usage of the watershed sub-areas), the lake's size and shape, and the climate. All these variables could then be used in empirical models to make predictions about the water quality, just as Frank Rigler demanded.

Further Reading

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