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Lakes and Reservoirs

Water Quality: The Impact of Eutrophication

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Lakes and Reservoirs: Water Quality: The Impact of Eutrophication
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Lakes and Reservoirs

Water Quality: The Impact of Eutrophication

Volume 3

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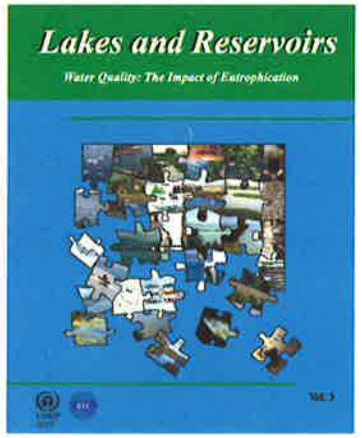

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Foreword

We are pleased to introduce Volume 3 of the Short Series on the "Planning and Management of Lakes and Reservoirs". The present Volume entitled "Water Quality: The Impact of Eutrophication" provides an overview of the problem of the enrichment of surface freshwater bodies due to organic compounds originating from urban and agricultural activities as well as from industrial effluents. Eutrophication is a process that once started is difficult to control unless immediate action is taken. Eutrophication ultimately leads to the reduction of oxygen in water, the release and accumulation of toxic substances in the water and sediments-polluting the aquatic environment, which can lead to the death of aquatic organisms, ecosystems and humans that may inadvertently drink or be exposed to the polluted water. If eutrophication has already started it is very difficult and costly to control or revert. Around the world there are some eutrophied lakes, but the majority of the world's lakes are not. This situation is changing rapidly.

Waters in eutrophic lakes and reservoirs bring enormous losses of biodiversity, reduced water quality and availability. Furthermore, such lakes and reservoirs represent a significant health hazard for humans and animals alike. This is primarily due to the explosive growth of microscopic algae which once dead and in the process of decay release one of the most powerful classes of toxins known to man: Cyanotoxins. Damage to electric power plants and recreational activities are also well recorded as negative impacts originated from these process cause large economic losses.

To control the process of eutrophication there is a need to understand the causes and the stages of development. Similarly, it is necessary to carefully assess and evaluate the technological solutions to be applied in the mitigation and remediation of the eutrophication process. In general conventional wastewater treatment systems are sufficient for the purpose although they tend to be very expensive to maintain. Alternative methods of eutrophication control and mitigation include the use of natural wetlands as well as constructed ones since they are based on the capacity of self purification of nature and are usually much cheaper to maintain and operate.

Eutrophication in many ways can be considered as a reflection in our lakes, reservoirs and rivers of the careless way in which society is dealing with its liquid wastes as well as the application of unsound land use practices. Therefore, the society as a whole needs to be aware of the problem in terms of health, finance, environment and recreation as well as the costs related to its solution. It is expected that through this publication citizens together with the authorities, industries, farmers and other members of the society can grasp the principles of this process, the effects and remediation so that proactive, co-operative action can be taken to prevent or significantly reduce the risk of surface water bodies becoming polluted through the process of eutrophication.

We hope you enjoy it.

S. A. Halls

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Why is Eutrophication Such a Serious Pollution Problem?

Eutrophication is one of the most widespread environmental problems of inland waters, and is their unnatural enrichment with two plant nutrients, phosphorus and nitrogen.

One important result of lake and reservoir enrichment is increased growth of microscopic floating plants, algae , and the formation of dense mats of larger floating plants such as water hyacinths *(Photos 1 and 2)* and Nile cabbage. Growth results from the process of photosynthesis which is how the plants generate organic compounds and biomass through the uptake of nutrients (nitrogen, phosphorus and others) from the soil and water. In the process light acts as the energy source and carbon dioxide dissolved in water as the carbon source. As a result of the photosynthetic process oxygen is also produced.

When the plants die they decompose due to bacterial and fungi activity; in the process oxygen is consumed and the nutrients are released together with carbon dioxide and energy. In many lakes and reservoirs in the world plants growing in the surface during spring and summer will die during autumn and sink to the bottom where they decompose.

During spring and summer, lakes and reservoirs are often supersaturated with oxygen due to the amount of plants. The oxygen surplus is released to the atmosphere and no longer available to decompose organic matter. This causes oxygen depletion or anoxia in the deeper layers of lakes, particularly in autumn. Oxygen depletion is therefore caused by the shifts in time and space between photosynthesis and decomposition. In tropical areas the same process takes place, but seasonally speaking it is not as representative as in temperate areas because temperature and daylight duration is very similar throughout the year.

At certain times, lakes may form a thermocline some metres below the surface *(Fig. 1)*. In the thermocline the temperature declines several degrees over a few metres and divides the lake into two zones an upper warmer one (epilimnion), and a lower colder one (hypolimnion). Lakes in temperate regions are lakes with a depth of about five to 10 meters or more and typically form a thermocline during the summer time, therefore they stratify. Shallow tropical lakes can also stratify, but stratification can be broken down by strong winds.

A thermocline prevents the upper and lower layers of the lake from mixing. The result is a change in vertical oxygen concentrations, as shown in Fig. 1, where concentration is high in the upper layer or epilimnion and very low in the lower layer or hypolimnion (the low oxygen concentration may degrade water quality downstream of the lake or reservoir, particularly downstream of reservoirs with short retention times, as mentioned in Volume 1, p.15).

Oxygen depletion often leads to complete deoxygenation or anoxia in the deep layers of the lake or reservoirs also because oxygen poorly dissolves in water. In shallow lakes and where plant production is high, deoxygenation of the sediment and water occur frequently too (black sediment, *Photo 3*). Such conditions kill fish and invertebrates *(Photo 4)*. Moreover, ammonia and hydrogen sulfide originated from

Photo 3: Black sediment from the bottom of a lake.

Photo 1: Algal bloom in a lake.

Photo 2: Overgrowth of floating aquatic plants.

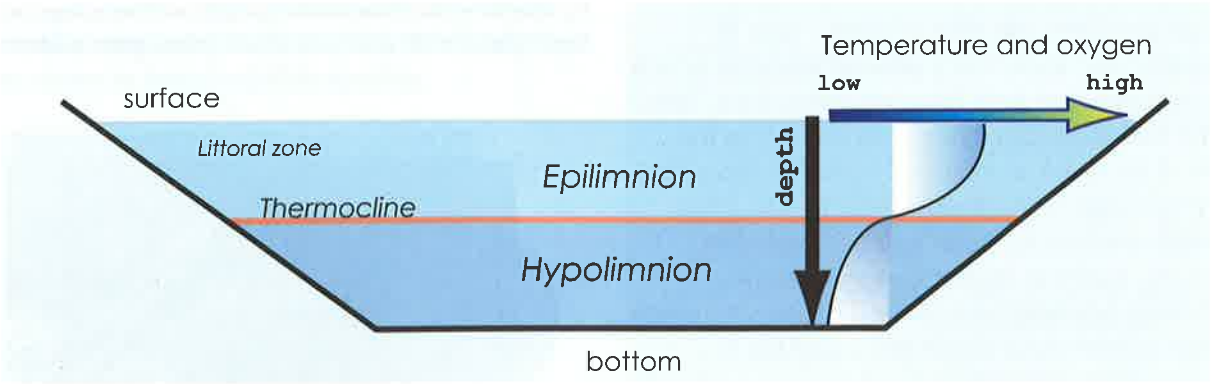


Fig. 1: Thermocline and the relationship between temperature/oxygen and depth in lakes within temperate regions.

Photo 4: Fish mortality due to lack of oxygen in an Indonesian lake.

bacterial activity can be released from sediments under conditions of anoxia, and their concentrations can rise to levels which adversely affect plants and animals as they act as poisonous gases (also hydroelectrical power facilities in reservoirs often suffer because of the corrosive power of hydrogen sulfide). Phosphorus and ammonia may also be released into the water, further enriching it with nutrients.

Some particular type of algae, which grow in highly nutrient enriched lakes and reservoirs (blue-green algae or cyanobacteria, *Photos 5 and 6* and so-called dinoflagelates which produces red tide, *Photos 7 and 8*), release in the water very powerful toxins which are poisonous at very low concentrations. Some of the toxins produce negative effects on the liver of life stock at minimal concentrations but they can lead to the death of cattle and other animals even to humans when ingested in drinking water at higher concentrations. Although one way to treat and disinfect surface waters where these algae grow and/or to prevent high concentration of organic matter is to use chlorine, unfortunately this leads to the formation of compounds which may produce or induce cancer - a serious threat to the safety of drinking water supplies.

High concentrations of nitrogen in the form of nitrate in water can also cause public health problems. They can inhibit the ability of infants to incorporate oxygen into their blood and so result in a condition called the blue baby syndrome or methemoglobinemia. For this to occur, nitrate levels must be above 10 mg per liter in drinking water. The condition can be life-threatening.

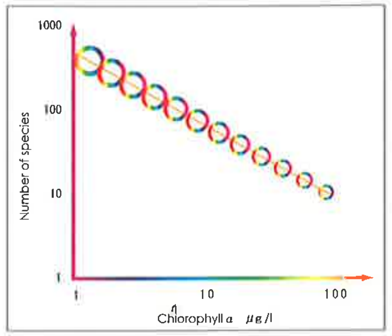
Photos 5 and 6: Macro- and microscopic views of Microcystis aeruginosa.

One of the main problems occurring as a result of algal blooms or other aquatic plants (disproportionate growth, *Photo 9*) is the reduction in transparency in the water which reduces the recreational value of lakes, particularly for swimming and boating. Water hyacinth and Nile cabbage can cover large areas near the shore and can float into open water

Photos 7 and 8: Macro- and microscopic views of Uroglena americana, a culprit of red tide.

spreading at times over the entire surface. These mats can block light to submerged plants and produce large quantities of dead organic matter that can lead to low oxygen concentrations and the emission of unpleasant gases such as methane and hydrogen sulfide due to its decomposition or decay. Masses of these plants can restrict access for fishing or recreational uses of lakes and reservoirs and can block irrigation and navigation channels.

Fig. 2: Relationship between number of species and volume of chlorophyll a.



Shifts in the abundance of, and significant reduction in diversity of species (biodiversity) of aquatic organisms within a lake or reservoir may also be caused by eutrophication *(Fig. 2)*. This results from the changes in the water and food quality together with decreased oxygen concentration which often alter the composition of the fish fauna from more to less desirable species.

Photo 9: Eutrophied waters (left down) in Barra Bonita reservoir, São Paulo, Brazil.

Nevertheless, yields of certain species of fish tend to increase as eutrophication increases since there is more food available. However, oxygen depletion and high ammonia concentrations under hypereutrophic conditions can lead to decreases in fish yields as eutrophication rises.

In the following Table 1 the general effects of eutrophication in the aquatic environment are presented.

Table 1. Effects of eutrophication

- Anoxia (no oxygen present) which kills fish and invertebrates and also leads to release of unpleasant and injurious gases.
- Algal blooms and uncontrolled growth of other aquatic plants.
- Production of toxic substances by some species of blue-green algae.
- High concentrations of organic matter which if treated with chlorine can create carcinogenic compounds.
- Deterioration of recreational value of a lake or reservoir due to decreased water transparency.
- Restricted access for fishing, angling and recreational activities due to plant accumulation.
- Decreased number of species and diversity of plants and animals (biodiversity).
- Shifts in fish species composition from more to less desirable species (in economic terms and protein intake).
- Oxygen depletion particularly in the deeper layers during the autumn in temperate lakes and reservoirs.
- Decreased fish yields caused by significant oxygen depletion in the water column and bottom water layers of lakes and reservoirs.

How Bad is Eutrophication at Present?

Background comments on lake pollution

The demand for surface water for many purposes is increasing globally, mainly due to population growth and irrigation, particularly in arid and semi-arid regions. Eutrophication often becomes apparent to the public as populations increase in density. The total impact of humans on nature is probably about eight times higher today than 40-50 years ago, given the growth in population, in industrial and agricultural production, and in technological development (we use more chemicals, traffic density has increased, etc.).

The International Lake Environment Committee (ILEC), in cooperation with the United Nations Environment Programme (UNEP), undertook a project entitled "Survey of the State of the World Lakes". This aimed to collect and compile environmental data on many important lakes of the world.

Sets of detailed data from 217 lakes worldwide were gathered as a result of this project. Through this project it was possible to identify six major environmental problems, all having a significant impact on water quality, eutrophication being one of them *(Table 2)*. In addition, all six environmental problems are interrelated and to a certain extent compound the problems. All are caused by the same three basic factors *(Fig. 3)*.

Table 2. Major environmental problems occurring in lakes throughout the world

- Low water-level due to the over-use of water from lakes resulting in a pronounced deterioration of water quality and adverse changes in the ecosystems.
- Rapid siltation in lakes and reservoirs caused by accelerated soil erosion resulting from the overuse or misuse of arable and grazing lands and forests within their drainage areas.
- Acidification of lakes due to acid precipitation, resulting in the extinction of fish and the degradation of ecosystems.
- Contamination of the water, sediment and organisms with toxic chemicals originated from agriculture (pesticides) and industrial wastes.
- Eutrophication from inputs of nitrogen and/or phosphorus compounds discharged from industries, agricultural land, homes, urban and road surfaces etc., and resulting in heavy blooms of phytoplankton, deterioration of water quality, and a decrease of biodiversity.
- In extreme cases, the complete collapse of aquatic ecosystems.

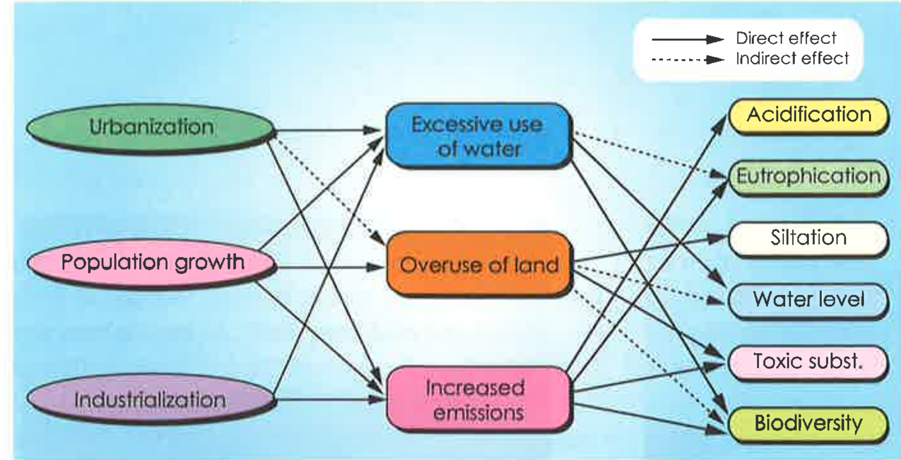


Fig. 3: Urbanization, population growth and industrialization are amongst the basic factors which cause environmental problems in lakes and reservoirs.

Examples

All 217 lakes included in the ILEC survey showed an increase in the level of eutrophication over the past 50 years. For a number of lakes in industrialized countries, wastewater treatment to remove nitrogen and/or phosphorus has stopped water-quality degradation. By 2000 nutrient inputs to 66 world lakes were reduced. Even so, most are still more eutrophied (nutrients concentration is higher) today than they were 50-60 years ago. This is so for Lake Biwa in Japan *(Photo 10)*, Lake Constance on the border between Germany, Switzerland and Austria *(Photo 11)*, Lake Balaton in Hungary *(Photo 12)*, Lake Mälleran in Sweden *(Photo 13)*, the Great Lakes in North America (See P. 18, *Photos 25 and 26*) and a number of North European lakes.

In eutrophied lakes and reservoirs when measures have been taken to improve water quality by reducing or removing nitrogen and/or phosphorus without effect, it is largely due to the enormous amounts of nutrients stored in sediments being constantly released into the water. This shows the need to avoid nutrient loading into the water bodies as early as possible by proper management and planning practices. Still, it has often been difficult to reduce nutrient inputs of diffuse source such as drainage water and erosion from agriculture or dumping grounds; this cannot be collected for treatment, unlike point source pollution from industrial or municipal wastewater. Point source pollution can be treated by 'end-of-pipe-technology', i.e., environmental technology.

Photo 11: General view of Lake Constance, Germany, Switzerland and Austria.

Photo 10: General view of Lake Biwa, Japan.

Photo 12: General view of Lake Balaton, Hungary.

Photo 13: General view of Lake Mälleran, Sweden.

The best examples of success in treating eutrophication are where diversion of wastewater was used from a lake in an area with little agriculture. Lake Washington is an example (*Photo 14*). Figure 4 shows declining phosphorus concentrations in this lake after the diversion which was completed in 1967. It is important to realize that on occasions diversions do not solve the problem as it removes it downstream.

Photo 14: General view of Lake Washington, U.S.A.

Almost all lakes still show increasing eutrophication, including most lakes in developing countries, which lack pollution abatement because they cannot afford it. Lake Dianchi (*Photo 15*) near Kunming in China, and Lake Taihu, near Wuxi in China are lakes suffering from extreme eutrophication or are hyper-eutrophied. In these lakes vast areas are covered by dense algal blooms like green dye and fish-breeding has been almost totally abandoned because there is no oxygen for them to breath, mainly in autumn. Almost all native water plants and many fish species have been killed. Snails die from lack of oxygen in the bottom water and in addition due to the poor water quality it is very difficult to supply water for domestic use that meets legal standards.

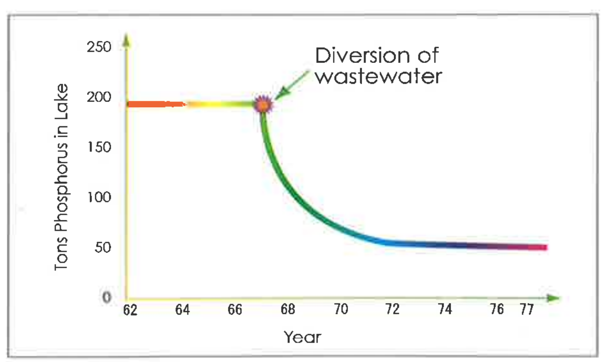


Fig. 4: Diversion of wastewaters proves to be effective in the reduction of phosphorus in freshwater bodies.

Even large lakes suffer from eutrophication. In Lake Victoria in Africa, for example, dense mats of water hyacinth float on huge surface areas. This problem has been somewhat reduced by biological methods - a beetle feeding on water hyacinths was introduced (*Photo 16*, beetle). Parts of the lake, near Kisumu and Kampala show oxygen depletion and reduced transparency. Many *Haplochromis* (*Photo 17*) fish species known locally as "furu" have become extinct, and the fish catch overall is declining with unfortunate results as fish is the major protein source for the lake's coastal populations (*Photo 18*).

Even Lake Baikal (*Photo 19*), the largest freshwater body in the world and 1.7 km deep, shows signs of eutrophication: decreased transparency and increased concentrations of algae and nutrients.

Photos 15 and 16: Excessive growth of water hyacinth in Lake Dianchi, China, and the weevil N. eichhornaiae utilized in Lake Victoria to control the growth of this plant.

A solution to eutrophication in the developing countries is urgent since stopping eutrophication becomes more and more difficult and expensive every year it is postponed due to increasing nutrient accumulation in sediments.

Photo 18: Fish used to be caught in Lake Victoria.

Photo 17: Haplochromis or 'furu' fish from Lake Victoria.

Photo 19: General view of Lake Baikal, Russia.

Where Nutrients Come from and How they Cause Eutrophication

Where nutrients come from

What are the sources of nutrients causing eutrophication of lakes and reservoirs? There are many sources. All activities in the entire drainage area of a lake or reservoir are reflected directly or indirectly in the water quality of these water bodies. A lake or reservoir may, however, be naturally eutrophied when situated in a fertile area with naturally nutrient enriched soils. In many lakes and reservoirs wastewater is the main source since untreated wastewater or wastewater treated only by a conventional mechanical-biological methods still contains nitrogen (25-40 mg per liter) and phosphorus (6-10 mg per liter). Both nitrogen and phosphorus can be removed by well-known technology - phosphorus by addition of a chemical that precipitates phosphate though a chemical reaction, and nitrogen usually by biological means through micro-organism activity. Nitrogen costs more money and also, technically speaking, is more difficult to remove than phosphorus.

Drainage water from agricultural land also contains phosphorus and nitrogen. It usually has much more nitrogen because phosphorus is usually bound to soil components. Extensive use of fertilizers results in significant concentrations of nutrients particularly nitrogen, in agricultural runoff. If eroded soil reaches the lake, both phosphorus and the nitrogen in the soil contribute to eutrophication. Erosion is often caused by deforestation which also results from unwise planning and management of the resource.

Wetlands are increasingly used to solve the problem of diffuse pollution from agriculture which cause eutrophication *(Photo 20)*. Nitrate is converted in wetlands to free nitrogen and released to the air. This is not harmful, as free nitrogen compromises about 4/5ths of the atmosphere. Phosphorus is adsorbed by wetland soils and, like nitrogen, is taken up by the plants. Both nitrogen and phosphorus may therefore be removed by wetlands. In addition, it is often also necessary to control fertilizer usage in agricultural practices as the majority may end up in the drainage area, if the diffuse pollution from nutrients is to be reduced sufficiently to improve water quality.

Photo 20: General view of a wetland.

Photo 21: Aerial view of fsh pens in Laguna de Bay, Philippines.

Rain water contains phosphorus and nitrogen from air pollution. As nitrogen is more mobile in the atmosphere than phosphorus, it is usually over 20 times more concentrated than phosphorus. Nitrogen can only be reduced in rain water by extensive controls of the air pollution in the entire region. One can safely say that the main sources of pollution in the atmosphere are from industries and automobile exhaust without proper filtering systems.

When lakes are used for aquaculture, excess fish food pollutes the water as complete use of the food cannot be achieved *(Photo 21)*. Nitrogen and phosphorus present in the excess food is dissolved or suspended in the water. The use of lakes for aquaculture therefore needs careful environmental planning and management practices by the owners and workers.

The sediment of a lake - its muddy bottom layer - contains relatively high concentrations of nitrogen and phosphorus. These can be released to water, particularly under conditions of low oxygen concentrations. The nutrients in the sediment come from the past settling of algae and dead organic matter. The nutrients released from sediments are referred to as the lake's internal loading.

Figure 5 sketches the sources of nutrients: externally from wastewater, agricultural drainage water, erosion and rain, and internally from activities in the lake itself, e.g. aquaculture and sediment release.

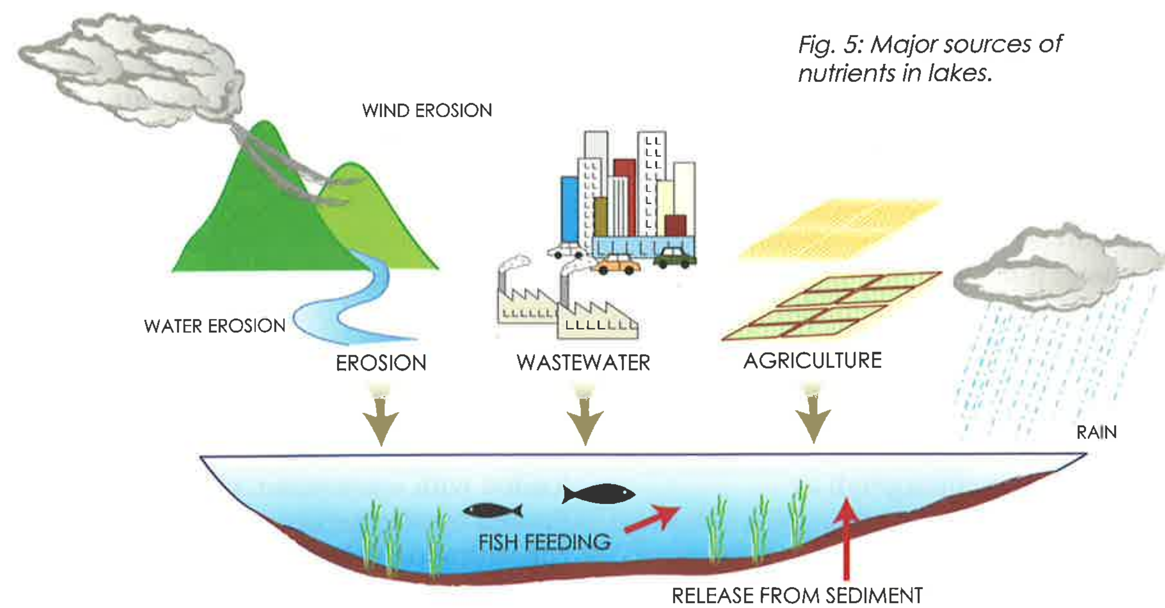


Fig. 5: Major sources of nutrients in lakes.

TABLE 3. A classification of lakes according to the extent of their eutrophication

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Average total phosphorus	8.0	26.7	84.4	> 200
Average total nitrogen	661	753	1875	high
Average Chlorophyll *a*	1.7	4.7	14.3	>100, range 100-200>
Chlorophyll *a*, peak concentration	4.2	16.1	42.6	> 500

All values expressed as µg/l

It is possible but very expensive to remove the upper nutrient-rich layer of sediment. Covering sediments with clay to seal them and thereby reduce internal loading has also been tried. Even when nutrients are removed in large amounts from wastewater, agricultural drainage water and rain, it often takes much time before nutrient concentrations fall in the upper sediment layer because they are still present in the water environment. Early reduction or elimination of nutrient sources is therefore very important.

Lakes and reservoirs can be classified according to the extent of their eutrophication (or nutrients enrichment) into four main classes: oligotrophic, mesotrophic, eutrophic and hypereutrophic *(Table 3)*. This classification results from extensive examination of eutrophication in countries within the Organization for Economic Cooperation and Development (OECD) in the 1970s and early 1980s. It is based on concentrations of phosphorus, nitrogen and chlorophyll *a* (the green plant pigment needed in photosynthesis). Chlorophyll *a* roughly indicates the concentration of plant biomass (on average 1% of algae biomass is chlorophyll *a*).

Factors that limit eutrophication

Table 4 shows the average composition of freshwater plants on a wet basis (when they are not dried): the plants require all listed components in the approximate percentages indicated. Generally, nitrogen (0.7%) and/or phosphorus (0.09%) are usually the first components depleted when plants form following photosynthesis. These two nutrients are less abundant in water than other elements needed, relative to their composition in plants. About eight times more nitrogen is required than phosphorus. Phosphorus thus limits eutrophication if nitrogen is more than eight times as abundant as phosphorus, while nitrogen limits eutrophication if its concentration is less than eight times as abundant as phosphorus.

Untreated wastewater and wastewater treated by mechanical-biological methods contain about 32 mg/L nitrogen and about 8 mg/L phosphorus on average. In a lake heavily loaded with wastewater, eutrophication is limited by nitrogen, as the nitrogen concentration in the discharged wastewater is only four times the phosphorus concentration. Such lakes often display extensive blooms of blue-green algae as unsightly surface scum *(Photo 22)*. Some species of blue-green algae use nitrogen directly from the air and grow, although dissolved nitrogen is limiting. Lakes that receive natural tributaries and drainage water from agriculture, however, have high nitrogen concentrations and are therefore usually limited by phosphorus.

The central question is not to determine which nutrient is limiting but to determine which nutrient can most easily be made limiting. As phosphorus is more easily and less expensively removed from wastewater than nitrogen, in many cases (but not all) the best environmental management strategy for lakes and reservoirs is to remove as much phosphorus as possible from wastewater.

TABLE 4. Average freshwater plant composition on a wet basis

Element	Plant content
Oxygen	80.5
Hydrogen	9.7
Carbon	6.5
Silicon	1.3
Nitrogen	0.7
Calcium	0.4
Potassium	0.3
Phosphorus	0.09
Magnesium	0.07
Sulphur	0.06
Chlorine	0.06
Sodium	0.04
Iron	0.02
Boron	0.001
Manganese	0.0007
Zinc	0.0003
Copper	0.0001
Molybdenum	0.00005
Cobalt	0.000002

All values expressed as percentages

Photo 22: Growth of blue-green algae on the shore of a lake.

Water Quality Management and Eutrophication in Some Lakes Around the World

Lake Biwa

The eutrophication of Lake Biwa *(Photo 23)* began in the 1960s when the post-war economic growth of Japan began. The plant biomass concentration in the 1980s was about 10 times than that in the 1950s. 13 million people depend on the water supply from the Lake Biwa/Yodo River system. Since 1969, unpleasant odors in tap water from Lake Biwa has annoyed users every summer.

Plankton biomass peaked in the late 1970s, when blooms of red algae also appeared as a "freshwater red tide". This has occurred almost annually since then. Blooms of blue-green algae have appeared since 1983, a sign of more advanced eutrophication.

Trends in the degradation of water quality in Lake Biwa have now more or less leveled off, following cooperative efforts of the residents and local government of Shiga Prefecture. Advanced wastewater treatment was introduced. The use of detergents based on polyphosphates was banned. And wetlands were constructed to cope with drainage water from agriculture. As a result of these measures, the degradation of water quality stopped, but no signs of further improvements have yet appeared. A more extensive abatement of diffuse pollution is probably needed before water quality improves significantly.

Photo 23: Lake Biwa, the largest lake in Japan during summer time showing overgrowth of aquatic plants.

Lake Fure, Denmark, a typical example of water management in Northern Europe

As in many other European lakes, the eutrophication of Lake Fure began in the 1960s. Lake Fure *(Photo 24)* is situated only 15-20 km from Copenhagen in an attractive area with several lakes and forests. The population close to Lake Fure was therefore growing in the decades after the Second World War, with increased impact on the nature in the area, including lakes. At the start of the century, the transparency of the lake water was several meters, while in the late 1960s it was only 1.2 m during the spring and summer blooms.

In the early 1970s it was decided to expand treatment of the wastewater from about 30,000 inhabitants to include nutrient removal (98% removal of phosphorus). Wastewater from another 100,000 inhabitants was diverted to the sea. By these measures the phosphorus loading was reduced from 33 to 2.5 tonnes per year. The remaining phosphorus loading comes from stormwater overflow, from the treated wastewater and from diffuse sources.

As a result of these efforts, the transparency has almost doubled since the late 1960s. However, the lake has a water retention time of 20 years, which explains why even larger improvements have not yet been observed. Only a little more than 20 years have passed since measures were commenced, and two to four retention times are usually needed to see the full effect of the measures taken. While, the external phosphorus loading (mainly wastewater) has been reduced to 2.5 t/y, the internal loading, i.e. the loading from the sediment is still about 12 t/y. Consequently, other methods have been considered to restore the lake (see the list of methods in Table 5). However, on a long term basis, it is still beneficial to reduce external loads of phosphorus to less than 1 t/y. This can done by proper treatment of stormwater overflow, and by increasing phosphorus removal efficiency by the wastewater treatment to 99% or more. In Lake Fure, diffuse pollution is less important, as the lake is more or less surrounded by wetlands and forest.

Extensive wastewater treatment involving nutrient removal has been introduced for many lakes in northern Europe, but, as Lake Fure shows, a long time will elapse before the full effect of this treatment can be observed. In addition, further reduction of nutrients is needed before an adequate reduction in eutrophication can be expected. In most cases, non-point, diffuse pollution will be needed to be reduced considerably - clearly a much more difficult task than reducing point source pollution.

Photo 24: General view of Lake Fure, Denmark.

North American Great Lakes

Approximately 30% of Canada's population and 20% of the population of the U.S. live in the Great Lakes drainage basin, some 520,000 km². The Great Lakes comprise: Lake Superior, Lake Michigan, Lake Ontario, Lake Erie and Lake Huron. 24 million people depend on these lakes for drinking water. Industrial growth in the 1940s and 1950s resulted in oil pollution and eutrophication accelerated in the 1960s. By the late 1960s, water quality had deteriorated to a critical level. Massive algal blooms were frequent, and severe oxygen depletion occurred, even in the central bottom water of Lake Erie *(Photo 25)*. Massive fish die-offs took place in Lake Michigan and Lake Ontario.

In response to this situation, specific effluent standards were established in the early 1970s. Phosphorus removal was introduced in wastewater treatment plants, and phosphorus content in laundry detergent was reduced from 30-40% to 5%.

By the early 1980s, the phosphorus loading approached the target established 10 years earlier. In Lake Erie and Lake Ontario *(Photo 26)* it was reduced by one-fifth, but overall the reductions in the Upper Great Lakes were only about 50%. These reductions were also reflected in the total phosphorus concentrations and phytoplankton concentrations in the open water of Lakes Erie and Ontario. These reductions were only to about one-third of the 1970 peak values. Again, reductions of non-point sources of phosphorus and nitrogen to the same extent as for municipal wastewater were not possible. However, measures to abate eutrophication of the Great Lakes are among the most successful lake management case studies, because point source pollution was the major source of nutrients discharged to the lakes.

Photos 25 and 26: General views of Lake Erie and Lake Ontario, Canada and U.S.A.

Environmental Education and Political Awareness

Lesson learnt

The few, partial success stories concerning eutrophication abatement have all involved strong public support by citizens and stakeholders combined with effective legislative measures and monitoring programs. The best results were obtained when control measures began early and long before hyper-eutrophication occurred. Generally, problems involving point sources were relatively easily solved, while those involving non-point diffuse sources were more difficult to resolve.

Although water authorities can construct wastewater treatment plants with adequate nutrient removal, a constant awareness about water quality can only be maintained by public engagement. Remember, too, that the final reduction of nutrients to a lake requires effective reduction of diffuse sources and this must involve the wider community. For full success, citizens must be partners in the environmental management strategy.

Using less detergents and detergents with no or little polyphosphates *(Photo 27)* can reduce phosphorus loads considerably. A "Laundry can be cheap" campaign in Poland was aimed at the whole Polish population and was very successful. The phosphorus loading in many towns and villages fell by more than 20%. The results of the campaign were monitored to encourage stakeholders to continue efforts. The campaign also increased the general environmental awareness of the public and in particular concerning the direct effects of laundry detergent on eutrophication.

Reduction of non-point pollution in areas with extensive agriculture requires the construction of wetlands as a buffer between fields and rivers and lakes. This is, however, not sufficient of itself, but must be supported by a massive campaign to persuade farmers to use less fertilizers (note: the last 10-20% of fertilizers applied has almost no effect on agricultural yield, but can contribute significantly to nutrient concentrations in drainage water). A campaign in Denmark in the early 1990s resulted in some reduction of diffuse pollution, probably because the farmers calculated that they saved money by reducing fertilizers. The reduction, however, was not sufficient and a green tax on fertilizers has been considered. It has not yet been introduced.

Photo 27: Phosphorus and phosphorus-free washing powder in Japan.

Public awareness

Active participation by citizens in abating eutrophication is impossible without their understanding of the problem. This requires environmental education of citizens. Table 5 overviews a number of possibilities on how to introduce environmental education and to increase public awareness. In many industrialized countries, a number of leaflets and booklets on environmental information are distributed free to the public. These give information needed by citizens to enjoy their environment and to take an active part in the debate *(Photo 28).*

In 1987, UNESCO defined environmental education as follows: Environmental education is a permanent process in which individuals gain awareness of their environment and acquire the knowledge, values, skills, experiences and also the determination which enable them to act - individually and collectively - to solve present and future environmental problems. It is therefore a continuous, lifelong process.

Table 5. Various levels of environmental education that can be used to increase public awareness.

- Ombudsman for environment (supported by the local universities and research institutes to provide the scientific and technical background to enforce legislation. The system has been used successfully in the State of São Paulo, Brazil).
- The entire population (campaigns, distribution of leaflets, booklets and information packs about specific environmental problems, information to the public by NGOs).
- Primary and Secondary school education (introduced in a number of countries, often in the form of local or regional projects).
- Other educational establishments (integrated in biology and chemistry).
- Universities (compulsory part in science and economics at many universities).
- Scouting associations (use of Green Games and Eco-Camp).
- Decision-makers (use of informational campaigns on a regional basis).

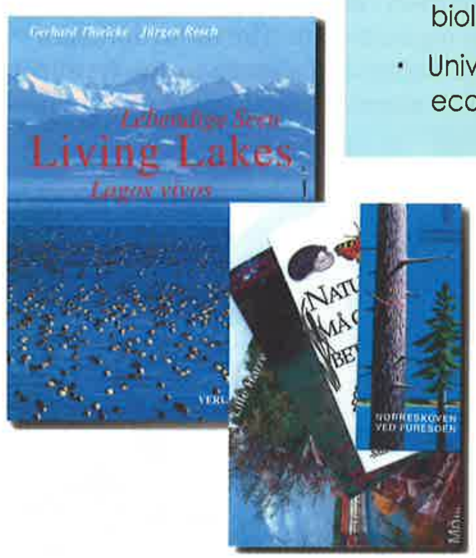


Photo 28: Environmental education and public awareness publications and leaflets in different countries.

Social, Cultural, Institutional and Economic Aspects of Eutrophication

The economic value of water resources

Water resources are environmental assets and therefore have a price. There are market-based methods to estimate costs and benefits, and these make it possible to use cost-benefit analysis as a useful tool to assess the economic effects of abatement of eutrophication or other pollution problems. Benefits range from higher quality drinking water and reduced health risks *(Photo 29)* to improved recreational uses *(Photo 30)*. The effects on human health from the lack of sanitation and the chronic effects of toxic algal blooms are two of the many indirect effects resulting from eutrophication. Numerous cost-benefit analyses of pollution abatement have clearly demonstrated that the total costs to society of 'no pollution reduction' is much higher than at least a 'reasonable pollution reduction'.

Photo 29: Clean water flowing from a drinking fountain in Venice, Italy.

Photo 30: Some recreational use of lakes.

Consequently, it is necessary to examine the prevention of pollution and restoration of water quality in lakes and reservoirs from an economic standpoint. The result of such examinations should be applied to assess effluent charges and green taxes. International experience shows that these economic instruments are reasonably effective in improving water quality and solving related water pollution problems. Thus, effective planning and management of lakes and reservoirs depends not only on a sound understanding of these water-bodies as ecological systems but also of their value to people as recreational areas and water resources.

In the past, several management strategies were developed and applied to solve problems of decreasing surface and groundwater quality. These were often a response to acute critical situations resulting in increased costs of water. The demand for good quality fresh water was only solved partially and locally; this was because too few resources were allocated too late to solve the problems. Early prevention is by far the cheapest method to avoid later pollution.

The need to integrate social and cultural issues in a new management strategy

A new management approach is needed which integrates scientific and technological knowledge with social, cultural and political issues for sustainable development of water resources for human needs. The implementation of the watershed concept by establishing national and international Watershed Committees is fundamental in developing effective management strategies for lakes and reservoirs. Based on the ecosystem concept and an integrated planning approach, the training of decision-makers and managers is an indispensable component in this strategy.

It is often not safe to consume water in developing countries. Changes to perceptions of the value of water to meet changes in the management of water resources, the need of the aquatic environment and the entire ecosystems in these countries are needed. It will be difficult to make such changes given current inertia towards the value of water, but public awareness and environmental education are steps in the right direction.

Many factors affect water quality in developing countries, particularly increasing eutrophication: industrialization, urban development, new land-use practices and change in the use of water. Given these changes, it is important to integrate hydrological, social, economic and cultural aspects with scientifically-based knowledge of lakes and reservoirs. The social aspects of eutrophication are often overwhelming in developing countries. The loss of jobs resulting from heavy fish kills due to oxygen depletion is just one example of a massive social impact resulting from eutrophication.

A new management strategy should recommend several alternatives to present practices. For instance, one should recommend that soil erosion can be stopped or at least reduced by stopping deforestation and burning techniques *(Photo 31)* in farming. Implementing prevention, control and management of eutrophication within an integrated strategy can provide new job opportunities and tools for economic development, with corresponding social benefits.

Photo 31: Deforestation, erosion and open-mining activities which cause freshwater quality degradation.

The Future

How can we conserve our lakes and reservoirs from eutrophication with a growing population, growing urbanization and growing industrial production? That is an enormous challenge. It is clear from examples given in this booklet that it is not an easy task and that end-of-pipe technology is not sufficient. The latter can solve problems associated with industrial and municipal wastewater, but it cannot solve all problems, i.e., eliminate all sources of pollutants. That will require specific solutions based on 'soft' technology (e.g. construction of wetlands and buffer zones) and involve public awareness and cooperation. Close cooperation with those in agriculture and industry is also important, as they can also reduce pollution significantly, e.g. by application of cleaner technology. Green taxes may give sufficient economic incentive. Finally, it is essential for success to begin as early as possible, when the first signs of adverse changes appear because prevention is better and cheaper than restoration. In other words, a wide spectrum of methods needs to be applied to solve lake and reservoir pollution problems.

The restoration of polluted lakes is another activity that is increasingly used in industrialized countries. A survey of common methods is given in Table 6. Some are expensive, for instance removal of nutrient-rich sediments, while others, for instance biomanipulation, are useless if the lake is too

Table 6. Survey of the most commonly used methods of lake restoration

- Covering sediments. Preventing release of nutrients from sediments.
- Removing nutrient-rich sediment. This is expensive and therefore only useful for small lakes.
- Aerating the hypolimnion. This reduces the release of nutrients from sediments.
- Biomanipulation, e.g. small fish feeding on zooplankton are removed and big fish feeding on small fish are stocked. The result is that zooplankton, which feed on phytoplankton, become more abundant and therefore phytoplankton are less abundant.
- Using chemicals e.g. copper sulfate, to kill algae. This method is not recommended because the lake becomes contaminated with a toxic chemical: solving one problem creates another.

eutrophic. For effective lake management, restoration, however, has to work hand in hand with the removal of nutrient sources to treat both causes and symptoms.

Pollution abatement is expensive, particularly when it involves advanced environmental technology to significantly reduce nutrient loadings. This is the cost of an increased population density, urbanization and production. Will developing countries be able to pay?

Fortunately, developing countries can learn from the mistakes of the industrialized countries: get started as early as possible and use the full range of methods. Methods based on soft technology are usually not costly, but for success the public must understand the problem and how countermeasures work. Therefore, all developing countries should be encouraged to start environmental education of its citizens as soon as possible so as to lay the groundwork for a more comprehensive application of methods based on soft technology.

All developing countries are in tropical and sub-tropical regions. Here, waste stabilization ponds (1-3 m deep basins, where the wastewater is maintained for 2-3 weeks) and wetlands for wastewater treatment are most effective.

Photo 32: Lake Tanganyika, one of a few relatively less impacted lakes in the world.

We *can* solve the problems of pollution in lakes and reservoirs (see Fig. 3) in developing countries, but a wider application of soft technology and cleaner technology is needed than of environmental technology.

Application of the cheaper restoration methods could also be considered, provided that they are used in conjunction with methods that eliminate causes.

The environmental strategy indicated cannot be realized only with a large amount of financial resources, but also through proper environmental education and understanding at all levels, from undergraduate schools to universities, and from decision-makers to all citizens. General environmental expertise and 'know how' must be transferred to the developing countries to make sure that mistakes made by industrialized countries are not repeated and to ensure that sound, environmental planning starts as early as possible. Massive urbanization always makes it more difficult to solve water-quality problems afterwards, whereas a proper allocation of activities in the entire drainage area facilitates a more cost-effective solution. There are still a few lakes in the world that have not yet been affected by man to any significant extent *(Photo 32)*. By proper environmental and ecologically sound planning, it is possible to avoid eutrophication, and other pollution problems, but it requires urgent action now not later.

GLOSSARY:

Anoxia, anoxic conditions: no oxygen present.
Biomanipulation: Change in biological structure by removing and/or stocking living organisms.
Chlorophyll *a*: the green pigment in plants that promotes photosynthesis.
Eutrophication: nutrient rich.
External loading: nutrients from outside the lake, for instance nutrients in wastewater discharge to the lake, or nutrients from agricultural drainage water.
Internal loading: nutrients from the lake itself, for instance release of nutrients or toxic substances from the sediment (the muddy bottom layer) of the lake.
Mechanical-biological treatment: treatment of wastewater by settling of suspended matter together with the use of microorganisms to decompose organic matter. Only minor amounts of nutrients (nitrogen and phosphorus) are removed by this treatment.
Non-point pollution: diffuse pollution mainly from agriculture or dumping grounds. It is difficult to collect for treatment.
Photosynthesis: formation of plant biomass from nutrients with solar radiation as the energy source.
Phytoplankton: free-floating microscopic plants.
Point pollution: polluted water from a defined point. It can be collected as industrial or municipal wastewater and treated by what is often called end-of-pipe technology (environmental technology).
Sediment: the bottom and often muddy layer of a lake.
Thermocline: the level dividing a lake into two layers, an upper warmer one **(epilimnion)** and a lower colder one **(hypolimnion)**. The temperature usually drops several degrees centigrade over just a few meters at this level.
Zooplankton: microscopic to very small free-floating animals.

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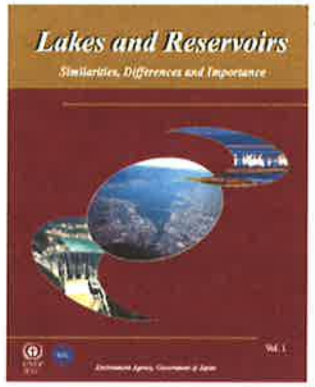

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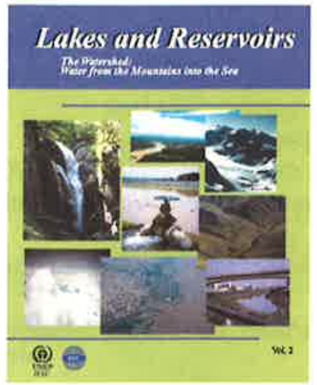

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