CONSERVATION AND MANAGEMENT OF LAKES: A REVIEW OF TECHNIQUES FOR CONTROLLING EUTROPHICATION

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Three Days Training Course on
HYDROLOGICAL INVESTIGATIONS FOR CONSERVATION AND MANAGEMENT OF LAKES
(26-28 March, 2012)

CONSERVATION AND MANAGEMENT OF LAKES: A REVIEW OF TECHNIQUES FOR CONTROLLING EUTROPHICATION

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INTRODUCTION

With the exponential growth of population on one hand and decreasing availability of freshwater on the other, proper management of available sources of freshwater has become very significant in recent times. This is particularly so because, the impacts of ever extending human activities on water bodies during the last century have resulted in considerable deterioration of water quality and impairment of daily water uses in many freshwater bodies. Since lakes are one of the prime sources of freshwater, conservation and proper management of lakes has also assumed a great significance in recent times.

Lakes are bodies of standing waters (lentic waterbodies). The relative lack of motion of the lake water makes lake basin a sediment trap. Sediment brings nutrients with them which hasten the growth of aquatic plants, a process called eutrophication. Eutrophication, represents the natural aging of the lake. The process of natural eutrophication usually takes hundreds of thousands of years to occur and is largely irreversible. Lakes undergoing such natural eutrophication generally have good water quality throughout much of their existence. However, human settlement in the catchment and subsequent interference such as change in land use, development of agriculture, urbanization and industrialization etc. dramatically affect the process of natural eutrophication. This artificially induced eutrophication, some times referred to as accelerated eutrophication or anthropogenic eutrophication or cultural eutrophication or manmade eutrophication is now becoming a major problem in most lakes.

CONSERVATION AND MANAGEMENT

The need to manage and restore the culturally degraded and eutrophic lakes has mainly arisen to avoid their untimely death. However, before we proceed to the aspect of overcoming this problem, it is important to understand the terms like management and restoration as they are commonly associated with the lake conservation programmes. Cookes et al. (1993) have differentiated between these terms. Restoration, according to them is an active attempt to return an ecosystem to an earlier condition following degradation, resulting from any kind of disturbance. Restoration involves repair of ecological damage, a return of species and processes to their former states, and is holistic in its approach to returning the lake and its watershed (including surrounding wetlands) to an approximation of pre-disturbance conditions. Management, on the other hand, involves an attempt to remedy, or improve, or change conditions, usually of some specific lake component, often with human uses in mind. Management often does not deal with the causes of the lake's disturbance but with ameliorating the effects of some of the symptoms. The focus is usually on a specific community, species, or problem.

EUTROPHICATION IN LAKES

Although, the terms eutrophic and oligotrophic were introduced to lakes in the first quarter of the 20th century, eutrophication actually attracted the attention of researchers and mangers since the middle or latter part of the 20th century as they realized that plant nutrients entering and accumulating in lakes as a result of the industrial revolution of the 20th century were causing changes in a matter of decades which naturally would occur over centuries or longer. The problem of eutrophication, however, became more familiar in 1960's with people in highly industrialized and populated countries became aware of the considerable changes in water quality such as changing colours and increasing turbidity due to anthropogenic eutrophication.

Initially eutrophication was thought as an irreversible process. Intensive research and experiments have been carried out since then to understand the causes and processes of these environmental changes and also to find effective remediation measures. An International Symposia on Eutrophication was organized in 1965 at Madison, Wisconsin and again in 1968 at Uppsala, Sweden. The work by Vollenweider (1968) on the scientific fundamental of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorous, provided a valuable basis and stimulus for the subsequent extensive research and enactment of effective counter measures to solve the problem of eutrophication. The Clean Lake Programme of the U.S. EPA further intensified the research related to techniques of eutrophication control. The Organization for Economic Cooperation and Development (OECD) also undertook extensive study on the problem of eutrophication. Numerous reviews and conference proceedings were published in the 1970's. As a product of these conferences and the intense concern about eutrophication and lake and reservoir protection and management, a new professional society, the North American Lake Management Society (NALMS) was founded In 1980. In 1985, a new professional periodical, "Lake and Reservoir Management", appeared under the sponsorship of NALMS and in 1988, a book titled "The Lake and Reservoir Restoration Guidance Manual" was published by the U.S. EPA CLP.

Definition of Eutrophication

Eutrophication is one of the manifestations of degraded water quality of lakes. It describes the biological effects of an increase in concentration of plant nutrients on lakes manifested through the excessive growth of aquatic plants, both attached and planktonic to levels that are considered to be an interference with desirable water uses. Three general designations of productivity are used for lakes. Lakes with low productivity are called oligotrophic, those with intermediate productivity are called mesotrophic and the ones with high productivity levels are referred to as eutrophic.

A precise definition of eutrophication is difficult because a description of the trophic nature of any water body is usually made relative to a previous condition or to a reference state of lower nutrient concentration, called mesotrophic (intermediate) or oligotrophic (low in nutrients). Thoman and Mueller (1987) defined eutrophication as "the input of organic and inorganic nutrients into a body of water which stimulates the growth of algae or rooted aquatic plants resulting in the interference with desirable water uses of aesthetics, recreation, fish maintenance, and water supply". OECD (1982), defined eutrophication as "the nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, among which increased production of algae and macrophytes, deterioration of water quality and other symptomatic changes, are found to be undesirable and interfere with water uses".

Characteristics of Eutrophication

Table 1 summarizes the characteristics of the oligotrophic and eutrophic lakes. As shown in the Table, oligotrophic lakes and reservoirs are usually characterized by low nutrient concentrations in the water column, a diverse plant and animal community, a low level of primary productivity and biomass, and good overall water quality for most uses. By contrast, eutrophic water bodies have a high level of primary productivity and biomass, frequent occurrence of algal blooms, anoxic bottom waters during thermal stratification, often fewer types of plant an animal species, enhanced growth of littoral zone aquatic plants and poor water quality for many uses. However, it should be noted that the undesirable qualities associated with the eutrophic water bodies are not due directly to enhanced levels of nutrients or in-lake productivity but rather to the resultant impacts of these factors on the overall water quality and water use. Thus, for many lakes which are used for fish production, higher productivity may actually be a desirable characteristics.

It should also be noted that characteristics of oligotrophic and eutrophic water bodies are basically similar in temperate and tropical/subtropical regions. The differences that do exist between these two settings are related primarily to the difference in magnitude and /or timing rather than substance. However, not all symptoms of eutrophication normally observed in temperate lakes occur in tropical/sub-tropical lakes. It is not that the eutrophication process is influenced by the different factors in tropical systems, but rather that the eutrophication symptoms in these systems may not be indicative of the same water quality and or trophic status as in temperate lakes. Compared to the temperate zone, tropical lakes and reservoirs are characterized by a more limited annual temperature variation. The mean annual temperature (approximately 25°C) is higher than in temperate zones which are approximately 10-15°C, so that growing seasons generally extends throughout the year. Stable temperature gradients are also produced although they are generally less pronounced than in the temperate lakes. Oxygen depletion in the hypolimnion can occur in tropical lakes regardless of their trophic status. Consequently hypolimnetic oxygen depletion has little meaning as a trophic state indicator. Because of more favourable year round growing season, tropical lakes productivity is usually higher than the temperate lakes. Phytoplankton blooms can occur at any time of the year therefore, without following an annual cycle.

Table 1. General characteristics of oligotrophic and eutrophic lakes and reservoirs

S.N.	Parameter	Type of water body	
		Oligotrophic	Eutrophic
1.	Aquatic plant and animal production	Low	High
2.	Number of plant and animal species	Many	Many; can be substantially reduced in hypertrophic water
3.	General level of bio-mass	Low	High
4.	Occurrence of algal bloom	Rare	Frequent
5.	Relative quantity of green and blue algae	Low	High
6.	Oxygen content of bottom water	High throughout the year	Can be low or absent during thermal stratification
7.	Total salt content of water (specific conductance)	Usually low	Sometimes very high
8.	Mean depth of water body	Often deep	Often shallow
9.	Volume of hypolimnion	Often large	Can be small or large
10.	Water quality for most uses	Good	Often poor
11.	Impairment of multipurpose use	Normally little impairment	Often considerable impairment

Factors Affecting Eutrophication

Phosphorous or other inorganic nutrients brought to the lake from the various sources are used by the aquatic plants and converted into organic plant material through the process of photosynthesis. The energy for photosynthesis is supplied by the solar radiation. Therefore, the eutrophication of a given water body may vary depending on the geographical location of the surface water, the degree of penetration of the solar radiation to different depths, the magnitude and type of nutrient inputs, and the particulars of the water movement through flow transport and dispersion. Since the aquatic plants may vary widely in species composition, the impact of each of these factors may differ widely. For example, some species may require significantly less light and nutrients for growth than others. Some forms may remain rooted, others may be buoyant, while still other form may sink under different physiological conditions.

Concept of Limiting Nutrients

Based on the limited evidences initially it was widely assumed that phosphorus and to a lesser extent, nitrogen were the elements most likely to limit the production of algal biomass in fresh waters. Efforts to improve lake and reservoirs were therefore directed towards reducing the concentration of these elements in them through advanced waste treatment diversion, and bans on the sale of phosphorus-containing detergents in some countries. Phosphorus limitation of algal biomass was challenged in the mid 1970's by proponents of the hypothesis that carbon was the limiting element. This was based on the fact that carbon is the major element in living tissue and it is present in algal cells in proportion to nitrogen and phosphorous in a ration of about 106:16:1. Considerable research was then carried out to test this hypothesis and it was confirmed that carbon limitation of algal production only occurs at the height of photosynthesis in low alkalinity waters and that limitation only becomes important when these naturally infertile waters experience enhanced levels of nitrogen and phosphorous. It is now clear that phosphorus is most often the limiting nutrient and that carbon or nitrogen are only briefly or rarely the limiting nutrients. In majority of the temperate lakes phosphorous is the limiting nutrient and its availability controls the use of nitrogen and carbon from the atmosphere. Further it has been found that for large lakes that have significant inputs of non-point source nutrients, phosphorous controls growth. Smaller lakes that may have significant point source inputs may be nitrogen limited, but can be made to be phosphorous limited by phosphorous removal at the treatment plants. Silicon is found to be limiting for diatom growth under certain conditions. It has also been observed that nitrogen is limiting in many African lakes. Thus, limiting nutrient varies from region to region and from lake to lake, although studies indicate that phosphorous is the major limiting nutrient in most lakes.

The findings about phosphorus limitation of algal biomass in most studies led many lake managers to base their approach to lake and reservoir restoration and management on controlling the concentration of phosphorus. While this emphasis on phosphorus has been very useful, and has led directly to significant lake and reservoir improvements, it has often restricted the view of eutrophication and its control to simply that of external nutrient income and algal biomass. It should be worth mentioning here that the nutrient sources to a lake are not always point sources. There are quite often a considerable mixture of point and diffuse sources. Except for heavily urbanized catchments, point sources are usually most important in the supply of phosphorous whereas diffuse sources are more important for the supply of nitrogen.

Consequences of Eutrophication

Eutrophication has serious biological and ecological consequences. It can also have significant negative, health, social and economic impacts on man's use of lake water. Increases in the supply and availability of nutrients in water bodies affect the rate of primary production of plants, the magnitude of standing crop biomass achieved and the relative proportion of different species. Plant production is then available for animals production (consumers) either directly as living plant biomass or indirectly after the after the death, as detritus. Thus, nutrient effects on any consumer component of an aquatic community are indirect through an alteration in the amount, or relative abundance, and nature of their food supply, which may alter the balance of the lake ecosystem.

Eutrophication produces an excess of algae and macrophytes in water bodies that can cause certain water use problems in water supplies, corrosion of hydroelectric equipment and upsets of different water treatment processes, due to the reduction of the dissolved oxygen content, accumulation of ammonia in the water columns and resuspension of certain metals (Fe, Mn) from the sediments under anaerobic conditions. In eutrophied reservoirs, the high level of organic substances combined with the application of chlorine for drinking water supplies can generate substances potentially harmful to health.

Depletion of oxygen in the hypolimnia of eutrophic lakes is one of the first signs of eutrophication. Anoxia can produce several undesirable changes in lake quality, including accelerated internal recycling of nutrients, solubilization of metals that are undesirable in water supplies etc. Phytoplankton and weeds settle to the bottom of the water system and create a sediment oxygen demand (SOD) which in turn results in low values of DO in the hypolimnion of lakes. This may also cause the death of bottom fish. The increased production of algal mats and macrophytes cause aesthetic and recreational interference such as discoloration, odour problems, taste problems, and loss of aesthetic beauty of the lake. Thus, cultural eutrophication can render the water unsuitable for many uses, or else require that the water be treated prior to its use by humans, which is often expensive and time consuming.

A summary of intended water uses and the optimal versus minimally acceptable trophic state for such uses is provided in Table 2.

Table 2. Intended lake and reservoir water uses as related to trophic conditions

Desired utilization	Trophic status	
	Required	Still tolerable
Drinking Water production	Oligotrophic	Mesotrophic
Bathing purposes	Mesotrophic	Slightly eutrophic
Fish culture	Oligotrophic	Mesotrophic-eutrophic
Providing process water	Mesotrophic	Slightly eutrophic
Water sports (without bathing)	Mesotrophic	Eutrophic
Irrigation	----	Strongly eutrophic
Energy production	----	Strongly eutrophic

CONTROL AND MANAGEMENT OF EUTROPHICATION

The effective control of lake and reservoir eutrophication is linked strongly to control of the basic causative factor, namely, the input of excessive quantities of aquatic plant nutrients. Based on the limiting nutrient concept, practical experience suggests an effective, long-term eutrophication control measure is to reduce the external phosphorus load to the water body. Alternatively, one may divert the phosphorus load around or away from the lake or reservoir. This latter method will protect the water body of concern, but can cause eutrophication problems in downstream rivers, lakes and reservoirs. Thus, the basic problem is not eliminated if nutrient diversion is the only eutrophication control method used. It is simply transferred to another location.

Reduction of the external phosphorus load may not be feasible in a given situation. In such cases one may have to consider control programmes which attempt to treat the symptoms or impacts of eutrophication. These latter methods will not eliminate the basic problem, since they ignore the basic cause. Nevertheless, in some situations, it may not be possible to initiate necessary nutrient control programmes. In these cases, control programmes based on treating the symptoms of eutrophication may be the only control alternative, and do offer varying degrees of relief from the negative impacts of eutrophication.

The various available techniques of eutrophication control and management are discussed below:

Control of External Phosphorus Load

It is important to know the major phosphorus sources in the drainage basin and the way in which the phosphorus enters the water body.

Direct Reduction of Phosphorus at the Source

Phosphate elimination by chemical precipitation during the sewage treatment process

Municipal sewage can be treated in a mechanical-biological treatment plant, using chemical precipitation methods to eliminate the phosphate. Phosphates are precipitated from municipal wastewater with use of aluminum or iron salts, or lime. In a mechanical–biological treatment plant, the precipitant may be added (1) prior to the mechanical step (pre-precipitation); (2) during the biological treatment step (simultaneous precipitation); or (3) after the biological step in separate flocculation and settling tank (post-precipitation). These procedures will reduce the effluent phosphorus concentration to about 1mg/1, depending on the chemical dosage used and the flocculation behavior of the sewage. Swedish treatment plants show better results with post-precipitation. Effluent phosphorus concentrations as low as 0.2-0.45 mg/1 are common. However, pilot plant studies in Brazil, utilizing combined biological and chemical treatment of wastewaters, have resulted in effluent phosphorus concentrations down to 0.1mg/1.

Restriction of detergent phosphates

It is possible to restrict the quantity of phosphates in detergents, assuming suitable phosphate substitutes are available. Ideally, such alternative compounds must not cause new environmental problems or ones worse than existed with the use of phosphates. Phosphate substitutes should also not interfere with sewage treatment processes or with water treatment for drinking purposes. Moreover, the potential environmental impacts of phosphate substitutes must be taken into account. Laws regulating the amount of phosphate in detergents do exist in some countries. For example Switzerland does not allow any phosphates in detergents.

Land use controls

This method involves the restriction ("protected zones")or control of land use activities in a drainage basin which result in the runoff of nutrients to a lake or reservoir. This approach has been used in Germany as well as in other countries for the protection of drinking water supplies. It may be one of the most effective overall methods for attempting to control nutrient inputs to lakes since it does not allow activities in the drainage basin which would generate nutrients. A drawback to this approach, however, is the need for appropriate institutional and legislative frameworks.

Treatment of Tributary Influent Waters

Pre-reservoirs

A reduction of nutrients in tributaries and reservoirs can be achieved with the use of 'bioreactors.' These basins retain nutrient-rich water for a short period of time prior to its entering the main body of a reservoir, thereby accentuating the opportunity for algal growth in the basins. Pre-reservoirs (called pre-impoundments or cascade reservoirs in some countries) are a type of bioreactor, their original purpose being to prevent the main reservoir from becoming rapidly filled with silt. The phosphorus becomes fixed in the increased algal biomass in the pre-reservoir, thereby being largely retained in the pre-reservoir via sedimentation. Several pre-reservoirs can even be connected in series, to form a system capable of removing nearly all the phosphorus in the influent waters. Researchers have quoted even a 96% removal of phosphorus using the pre-reservoirs. The use of pre-reservoirs has been developed to a substantial degree in the Germany.

Direct addition of phosphorus-precipitating chemicals to the influent waters

The external nutrient load to a lake also can be reduced by the direct addition of chemicals such as iron salts which precipitate phosphates to the influent water at the point the water flows into the lake. This procedure has been used successfully in Germany and Netherlands. It is most suitable for shallow reservoirs with a high phosphorus load (e.g. 10-50 g/m yr) especially in those cases where it is too expensive to pre-treat inflowing waters. For water bodies with short water retention periods (e.g. one month), application of trivalent iron or aluminum salts are reported to give better results.

Filtration of tributary water through an aluminum oxide filter

This is relatively a newer method of phosphorus removal from small tributaries and uses activated alumina columns. This method is useful mainly with small flows (<50 1/s) of phosphorus-rich waters which do not fluctuate greatly. The activated alumina is a technical grade aluminum oxide, from which products of varying interior surface sizes can be obtained. Products with an interior surface of 200-300 m/g have a high absorptive capacity. The absorptive capacity of this material for phosphate is higher than its capacity for all other substances present in natural waters

Canalization/Diversion of Wastewaters

Diversion of waste waters

When the nutrient load to a water body comes mainly from very localized sources in the drainage basin, one can collect the nutrient-laden waters in sewer pipes and divert them, either to a conventional municipal wastewater treatment plant located below the lake or to a stream or lake below the lake of concern. However, simply diverting untreated waters to a downstream site is only a temporary measure since it merely moves the problem to another location, rather than treating it. Nevertheless, wastewater diversion can be effective in some cases. It has been used for the protection of may lakes in Europe, particularly in Sweden and Denmark. This technique has also been used in the United States.

Seepage trenches

Seepage trenches (as well as pit latrines) operate on the principle that phosphorus is removed when water passes through soil. The process is most effective when fine-grained sandy clays are present in the soil. The phosphorus becomes bound in the upper soil layers. Seepage trenches are useful at sites where the quantities of effluent are low, and where the fluctuations in runoff are limited. It requires a drainage basin sufficiently small that extensive storm waters do not cause flood overflows from tributaries draining the basin. Seepage trenches can be used for tributaries having a flow not exceeding 100 l/s, and in a modified way below individual pollution sources (e.g. farms, pastures) if the slope is adequate and the soil composition allows seepage. Overall, this system is an economic, natural and satisfactory way of eliminating phosphorus.

In-Lake Eutrophication Control Methods

These methods are used for treating the in-lake symptoms of eutrophication. However, they are usually not as effective over the long term as external nutrient control measures, and may have to be applied repeatedly. Nevertheless, the in-lake methods are effective for at least some period of time, and may even be the most reasonable approach in situations where it is too costly or otherwise unfeasible to build municipal wastewater treatment plants. They also offer supplementary control measures in cases where the primary control programme is inadequate to achieve the control goals. Major in-lake control measures are:

Nutrient Inactivation

This method involves the addition of phosphorus precipitating chemicals (e.g. iron or aluminum salts) directly to a lake. These chemicals inactivate or immobilize the phosphorus. Drawbacks are the possible toxic effects of the added chemicals on biota, and the temporary nature of this treatment.

Flow Augmentation/Flushing

Algae can only accumulate to nuisance levels in a lake when the algal growth rate is faster than the rate of water renewal (i.e. the flushing rate). In some cases, therefore, one can attempt to reduce the accumulation of algae in a lake or reservoir by increasing the water flow-through rate (i.e. decreasing the water retention time). This method involves the transport of additional water (usually of low nutrient content) to a lake, thereby increasing its flushing rate. The increased flushing rate reduces the opportunity for biomass accumulation, while the increased water volume dilutes the in-lake nutrient levels. Flushing is particularly important in reservoirs where withdrawal of water from selected depths is possible. Because of this possibility lower water layers with a high nutrient content can bypass the algal-rich upper water layer by undercurrents. Also, direct dilution or reduction of algal crops can be achieved by flushing. A drawback is the need for large quantities of low nutrient content waters.

Hypolimnetic Aeration

If nutrient-rich sediments can not be removed, one can attempt to reduce or inhibit the release of nutrients from sediments by producing an oxidizing (i.e. non-reducing) environment at the sediment surface. This can be achieved easily in most deep lakes by aerating (oxygenating) the hypolimnion. Hypolimnetic aeration, is a lake management technique designed to overcome hypolimnetic anoxia and its associated problems. It was first developed in Austria. The method of hypolimnetic aeration involves the introduction of oxygen to the hypolimnetic waters in a manner that preserves the thermocline. Maintaining oxygenated conditions in the hypolimnion reduces the release of phosphorus and other reduced materials from the sediment into the water column.

Undesirable substances can become concentrated in the hypolimnion during the thermal stratification period. Complete mixing of the hypolimnetic waters, accompanied by oxygen enrichment, can oxidize the undesirable reduced compounds, thereby rendering them harmless. Maintenance of the thermocline also ensures that planktonic algae in the epilimnion are not transported into the hypolimnion. If such transport occurred, the suitability of the hypolimnetic water for drinking water purposes would be considerably decreased. Moreover, it also inhibits a transport of nutrients from the sediment-water interface to the epilimnion, which could occur if air bubbles resulting from a complete mixing of the lake waters rise to the surface. Various techniques have been developed to effect such hypolimnic aeration without disturbance of the thermocline

The ability of this method to effectively limit algal growths over a long period of time, however, has not yet been demonstrated. The effect may be inadequate if the sediments contain large amounts of unoxidized organic and inorganic substances. Further, the technology for this method has not yet been accepted on a global scale. There are several designs for hypolimnetic which can be grouped them into three categories: mechanical agitation, injection of pure oxygen, and injection of air, either through a full or partial air lift design or through a down-flow injection design. Mechanical agitation involves drawing off water from the hypolimnion, aerating it on shore or on the lake surface by means of a splash basin., and returning the water to depth with minimal increase in temperature. This has not been a popular system because of the poor gas exchange efficiency. Injection of air via air – lift systems has been the most popular for hypolimnetic aeration. Full air-lift brings bottom water to the surface by forcing compressed air into the bottom of an inner cylinder. The rising bubbles drive the air-water mixture to the surface exposing water to the atmosphere. And then returns it to the hypolimnion via an outer cylinder after first venting the air bubbles.

Partial air-lift aerates hypolimnetic water in place, with water and air bubbles being separated at depth and the air discharged at the surface. The partial air-lift design, is also a frequently used system, possibly because of its great commercial availability.

Hypolimnetic aeration may not operate satisfactorily if the water body is too shallow. Although stratification may exist, the density gradient may not be sufficient to resist thermocline erosion and complete mixing. Therefore, hypolimnetic aeration is not recommended if maximum depth is less than 12 to 15 m and/or the hypolimnetic volume is relatively small. Hypolimnetic aeration has some undesirable effects as well. It can cause super saturation of hypolimnetic water with N_2 content can be potentially damaging for fish. Hypolimnetic aeration may increase eddy diffusion of nutrients into the epilimnion even though stratification is maintained, this may increase the phytoplankton biomass, composed mostly of blue-greens.

Circulation

This method is similar to hypolimnetic aeration except that the hypolimnetic aeration is sufficiently vigorous that the themrmocline is not preserved. The primary goal is to induce a mixing of the waterbody, thereby causing its destratification. The advantages and drawbacks of this method are similar to those of hypolimnetic aeration. A technically related method is epilimmnetic circulation. However, the aim of this latter method is not to add oxygen to water, rather , it is to prevent algal growth by circulating the algae out of the zone of light penetration for extended periods.

Selective Removal of Hypolimnetic Waters

This method involves the withdrawal of nutrient-rich water from the hypolimnion. This withdrawal effectively reduces the hypolimnetic volume, as well as the overall nutrient content of the water body. This procedure is generally applicable, however, only to small, deep lakes and to reservoirs in which waters can be withdrawn or discharged from selected depths. In deep lakes, the euphotic zone usually is far from the bottom sediments, so that any phosphorus released from the sediments is not immediately available for algal growth (provided the lake remains stratified). The released nutrients will become available to algae only when the water becomes mixed (e.g. at autumn overturn). It is possible to remove the water lying immediately above the sediments from such lakes and reservoirs with a pipe, using the principle of a syphon. This method has been used effectively in a few lakes in Austria.

Lake Level Drawdown

This method involves lowering the water level in the lake so that some or all of the bottom sediments are exposed to the atmosphere. Lake drawdown is used mainly for control of macrophytes and attached algae, and can be accompanied by dredging or by application of sediment covers. Drawbacks are the destruction of susceptible biota and the need to maintain the lake at low water levels or empty for extended periods of time.

Covering Bottom Sediments

It has been suggested that sediment nutrient release can be reduced or prevented by covering the sediments with an inert material. This method, thus, involves covering the lake-bottom sediments with plastic sheeting or particulate materials (e.g. fly ash) to prevent sediment-water nutrient exchange, and to reduce macrophyte growths. Drawbacks of this method are the associated costs and the possible effects of particulate materials on biota. This method is also not effective, when the applied layer is only a few centimeters thick, since sediment-dwelling organisms are capable of mixing the applied layer with the underlying sediment layers. Theoretically, this biological mixing problem could be solved by using fly ash from power plants, because ash material forms a cement-like layer on top of the sediment. Furthermore, the ash is able to bind phosphates. Unfortunately, however, fly ash also contains toxic substances (e.g. boron, selenium, molybdenum, arsenic and mercury) which restrict its use. Covering the bottom sediments with plastic sheeting is considered to be more elaborate than covering the bottom sediment with loose materials such as ash. Therefore, it is useful primarily for very small lakes.

Sediment Removal (Dredging)

Procedures for reducing the internal loading (regeneration) of phosphorus in lakes include all measures designed to reduce or restrict the release of nutrients from the bottom sediments. They also include measures for the removal of the released nutrients from water body before they can get into the trophogenic zone. The most effective in–lake sediment nutrient control measure is to dredge them. This method involves the dredging (removal) of nutrient-rich sediment from the lake bottom. Removal of the sediments will reduce the internal loading of nutrients and other material (e.g. toxic substances). This method has been effective in lakes which have experienced severe nutrient enrichment over a long period of time. Dredging has been successfully used in several lake restoration projects. Drawbacks are the associated expenses, the potential effects of dredging on biota, and sediment disposal problems. A suitable area for the deposition of the dredged sediments also must be available to use this approach most effectively. However, if the sediments contain elevated levels of heavy metals, its deposition in other regions may be hindered or prohibited. .

The control of phosphorus release from sediments is very important in shallow lakes, primarily because the zone of maximum algal productivity in such waterbodies borders directly on the sediments.

Harvesting

This method involves the cutting and removal of nuisance growths of macrophytes and attached algae mechanically from a water body. This method involves the selective cutting or mowing of dense growths of macrophytes, which are then collected (harvested) mechanically and usually disposed of elsewhere. Various kinds of mowing machinery have been developed to cut the plant shoots. This method is often very useful for alleviating, at least temporarily extensive macrophyte growths in the littoral zones of lakes and reservoirs. It provides immediate relief from conditions which impair swimming, boating and water-skiing. Drawbacks are the associated expenses, the need for repeated application, and vegetation disposal problems. It it usually energy-and labor-intensive method.

Biological control (Bio-Manipulation)

This method involves the use of specific organisms to control growths of algae and or other components of the food web. Examples include the use of fish to control macrophytes and the use of zooplankton to control phytoplankton. However, extreme caution is advised in introducing foreign or exotic species to a given water body, since they may severely upset it ecological structure. Effective control of phytoplankton by zooplankton grazing can be enhanced by stocking a water body with carnivorous fish. These fish prey on smaller fish, thereby allowing larger species to dominate the zooplankton. The increased zooplankton grazing rate helps keep phytoplankton populations relatively small. This effect can be important in lakes primarily used for drinking water, since some of the small zooplankton can not be removed easily using the usual method of treating water with oxidizing agents, particularly chlorine.

Chemical Control

This method involves the application of specific chemical to water bodies to kill undesirable aquatic plants. It is possible, however, to attempt to change the composition of the algal flora by changing the environmental conditions in the waterbody, even without reducing the nutrient influx. This can be done, for example, by changing the pH of the water. It is also possible to change an algal population dominated by blue-green algae to one dominated by green algae by decreasing the pH value, since blue-green algae apparently prefer a higher pH. Thus, a decrease in the pH gives the green algae a competitive advantage. Further, blue-green algae also are susceptible to specific viruses when the pH is low.

Algae have been controlled in many countries in the past by the application to a water body of chemicals toxic to algae. A common algaecide is copper sulfate. However, such measures should be used only in extreme cases, so that one does not inadvertently contaminate a lake or reservoir with the chemicals. The killing of large quantities of algae with the use of these substances, and their subsequent decay, also can overload the oxygen balance of a lake. Furthermore, when such chemicals are applied over long period of time at relatively low concentrations, it can result in the growth of strains of algae which are resistant to the chemicals. Several herbicides have been used to combat macrophyte growths. In contrast to algae, the use of herbicides can be useful in tropical lakes covered with floating plants, such as Eichhornia and Pistia. In such cases, the reoccurrence of the plants can be inhibited for long periods of time with just one spraying operation. It is even more effective if the re-introduction of such plants to the water body can be prohibited. Drawbacks of this method are the associated expenses, the temporary nature of this method, and possible toxicity effects on other biota

Control of Sunlight

In this method algal growths is controlled is by controlling the amount of sunlight energy available for photosynthesis. Two approaches for attempting to induce light limitation of algal growth in a lake or reservoir are:

1. Decreasing light penetration into the water column; and

2. Mixing the water body, in order to move the algae to deeper, darker parts of the water body.

Decreasing light penetration into the water column can be achieved by:

1. Covering the water body with opaque sheeting or floats,
2. Adding light-absorbing pigments (e.g. foodstuff dyes) to the water body and
3. Spreading plastic beads or soot on the water body.

A practical limitation to this approach is that only relatively small water bodies can be effectively covered or dosed with light-shielding or light-absorbing materials. Furthermore, some algal species are capable of persisting for relatively long periods of time in the dark.

Control of Non-Point Sources of Nutrients in the lake Catchment

Nutrient control in the lake catchment area refers to control of non-point or diffuse sources of nutrients. They are diffuse in character and often difficult to quantify. Available evidence suggests that the nutrient inputs to lakes and reservoirs in many developing countries arise primarily from non-point sources in the drainage basin.

Control of Urban Non-Point Nutrient Sources

Urban runoff can have a significant impact on the quality of receiving bodies of waters by polluting the ground water, by disturbing treatment processes in waste water treatment plants during periods of floods, by overflows from combined sewer system and by direct loading of receiving waters from separate sewer systems. A primary goal for treatment of such non-point nutrient sources is to treat the pollution at its sources; namely, reducing the amount of nutrients and other pollution in the runoff waters. This can be achieved by such measures as improved street sweeping practices. A decrease in the use of pesticides and fertilizers in gardening activities can be of help. Domestic sewer systems also can be connected to site treatments, in the form of circulation tanks (which are effective in containing coarse particulate matters).

Control of agricultural non-point sources

In attempting to reduce the potential impacts of agricultural activities on the eutrophication of lakes, two major control goals are:

1. Application of natural and mineral fertilizers in a manner that inhibits their transport and entrance into water bodies (including maximizing the uptake of applied fertilizer by crops) and,
2. Prevention of soil erosion to the maximum degree.

Agricultural nutrient control measures include the proper construction and operation of suitable manure depots, as well as development and adoption of guidelines for the proper application of manure and fertilizer. The amount of fertilizer used should not exceed the actual need of the crop grown, as determined by appropriate soil tests. Measures to decrease erosion, and associated nutrient loss, include vegetative buffer strips, contour cultivation, cross slope tillage and strip cropping.

CONCLUDING REMARKS

Eutrophication is a complex process. It is affected by various factors. The present extent of scientific knowledge is still not sufficient to plan a foolproof eutrophication control programme. As such, no single approach or control measure can successfully treat all cases. Nevertheless the present knowledge is sufficient to develop a generalized approach which, if used in conjunction with an adequate monitoring programme and continuing scrutiny of the measured data, will work in majority of the cases. The most feasible control option in a given situation will vary from location to location, depending on the circumstances. It is generally believed that the control of external nutrient especially phosphorous represents the most effective, long term strategy for controlling eutrophication. Nevertheless, it is important to be realistic in selecting specific control measures, both in terms of how much reduction in external phosphorous loads can be expected and how much such control measures will be likely to cost. It must be recognized that it may not be possible to achieve the desired water quality and trophic condition in all cases, even after the implementation of the most feasible phosphorous control efforts. If so, additional control efforts (often considerably more expensive) will be necessary to achieve the in-lake conditions.