CONSERVATION AND MANAGEMENT OF LAKES

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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 valuable natural resources. They are being used as natural centres of civilization and to cater the civilian needs. They serve variety of purposes like domestic purposes, drinking water, irrigation, commercial purposes, aqua-culture, recreation, transport etc. In many regions they are the only source of water. Many saline lakes like the Sambhar Lake in Rajasthan support the salt industry. Lakes are also otherwise source of many rare minerals. Many lakes support exclusive flora and fauna and thus play a vital ecological role. In India, many lakes are related with different socio-cultural activities. Many cities have been built on the piles of lakes. Thus, for their socio-economic values, lakes are quite often referred to as catalysts in the development of a region.

WHAT IS A LAKE?

Quite often the term "lake" is used as a synonym for natural lakes, reservoirs, tanks and ponds. That is, any form of inland surface water body is called a lake. However, a lake is different from a reservoir, pond and tank in some respects. Firstly, like ponds, lakes are natural water bodies unlike the reservoirs and tanks. A lake is formed because of some geological process, as water fills any natural depression and as such they have a natural shoreline along their periphery. Because of the continuous action of the waves, this shoreline is barren. Ponds are also natural in origin but because of their relative smaller size, the waves generated are not big enough, so that their shoreline is not barren and is occupied by vegetation. Moreover, pond water is also extensively occupied by vegetation. The reservoirs and tanks, on the other hand are artificially created, the reservoir; by damming a river valley and the tanks; by artificial excavation. There are other technical differences also. To quote a few, for example, output from the lakes is near the surface whereas outlet of a reservoir is at one of the several depths. Lower most depression in a lake can occur anywhere in its basin but the maximum depth of the reservoir is always near the dam. A reservoir bottom has a regular slope from head to tail while in lakes, the bottom slopes is not uniform. Reservoirs also have greater areal water loads and shorter residence times than lakes. Lakes are generally located in the centre of the drainage basin and hence the tributary input to it enters at several points. By contrast, reservoirs are usually constructed at the downstream end of the drainage basin. Because of these differences certain hydrological and ecological processes may vary between these water bodies. Bio-chemical analysis needs different sampling strategies to be followed for reservoirs and natural lakes. So, do the lakes mean only natural lakes or even manmade lakes? It appears that although there are some differences in certain hydrological and ecological processes, the differences are not very much significant except is some respects. As such, even two natural lakes would behave differently if their morphology or climatic settings are different. It should also be noted that a demarcation between natural lake and a natural pond on the basis of size is yet to be established. Thus, in my view, although lake should technically mean only natural lakes, for the purpose of research and management, all these water bodies should be classified and studied under lakes only, while still keeping in mind their technical differences.

LAKE AS A HYDROLOGIC UNIT

Lakes form an important component of the Hydrologic cycle. The precipitation falling over the earth ultimately reaches the oceans and is evaporated back to the atmosphere not before it visits lakes through the rivers and streams. In case of closed lakes, water is directly evaporated without meeting the oceans unless and until there is a considerable seepage to other open water body or stream. Calculated on the global basis, the residence time of lake is 21 years and that of river is 2.1 years. Thus, lakes provide a natural storage without artificial barrier for water, during their movement in the hydrologic cycle. The lake storage provides a viable means to accelerate or enhance recharge of known ground water supplies. Lakes, especially if they are large, can influence the surrounding climate. Large lakes owing to their volume have more capacity to accept heat.

Hydrologic characteristics of lakes vary considerably because of differences in the depth, length, width, surface area, shape, basin material, climate, nature of inflows and outflows, and other factors. Lakes may have some common features but often exhibit strikingly different performance characteristics. This individuality has environmental values and as such it presents the problem of having to understand both the general nature of the system and variations due to local conditions. This means that each lake requires it own hydrologic model.

LAKE AS AN ECOSYSTEM

A lake is an ecosystem in itself. A lake ecosystem, like any other ecosystem, has both living (biotic) and nonliving (a-biotic) components (Fig. 1). The physico-chemical properties of the lake water and the various physical phenomena such as radiant energy, water motions etc form the abiotic environment while the lake flora and fauna form the biotic component of the lake ecosystem. The living components fix, circulate, transform and accumulate the energy and matter by photosynthesis, decomposition, herbivory predation, parasitism and other activities, forming complex food webs. The nonliving components flux and cycle the energy and matter through hydrological processes such as evaporation, precipitation, erosion and deposition and water movements. Solar energy is the only significant source of energy for the lake ecosystems.

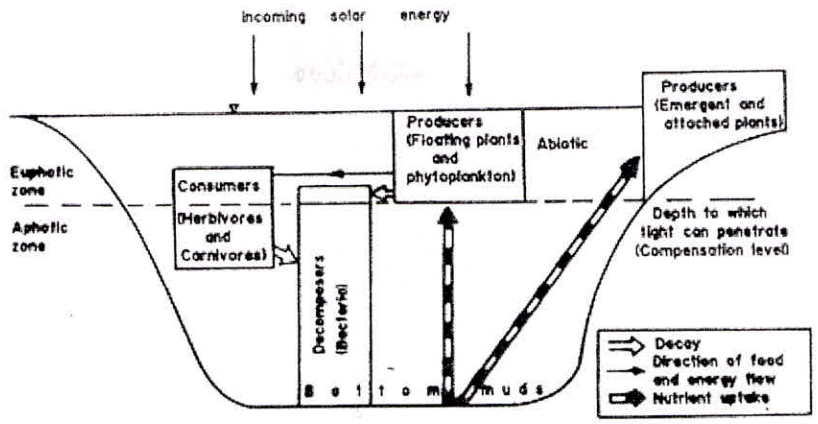

Figure1. The lake ecosystem

Unlike most terrestrial ecosystems, the lake ecosystem has definite boundaries. The shoreline serves as the lateral boundary. The air-water interface as the upper boundary and, the maximum sediment depth as the lower boundary. Lake ecosystems are open ecosystems relative to various fluxes, and as such their metabolism and biochemistry strongly reflect the inputs and outputs of energy, water and chemicals from their surroundings. Input and output of energy and matter from lakes further connect the lake ecosystem with other ecosystems in the biosphere (lake-catchment interaction).

MAJOR PROBLEMS OF LAKES

Eutrophication

At birth, lakes are deficient in nutrients and hence, are unable to support aquatic life. At this stage they are referred to as oligotrophic water bodies. With passage of time nutrients brought by sediments from the catchment get accumulated in them and their productivity increases. Through bacterial and other decompositions of the sediments, the water bodies become rich in nutrients on which phytoplankton thrive. With increase in phytoplankton and food supply, the zooplankton and other forms of animals also increase. Thus, with increase in species diversity and biological productivity, these water bodies pass from oligotrophic phase through the mesotrophic phase into the eutrophic phase (Fig. 2). Eutrophication, thus, denotes the addition of nutrients and consequent increased productivity level of a water body. It describes the biological effects of an increase in concentration of plant nutrients, usually nitrogen and phosphorous, but sometimes others such as silicon, potassium, calcium, iron or manganese, on the aquatic ecosystem. It represents the natural aging process of the lake. This process usually takes many hundreds of thousands of years to occur. Lakes undergoing such a natural eutrophication generally have a good water quality and exhibit diverse biological community throughout much of their existence. However, human interference in the catchment changes the natural eutrophication dramatically through increased rates of nutrient input. This artificial eutrophication is called cultural eutrophication and, is the main cause of concern for most lakes.

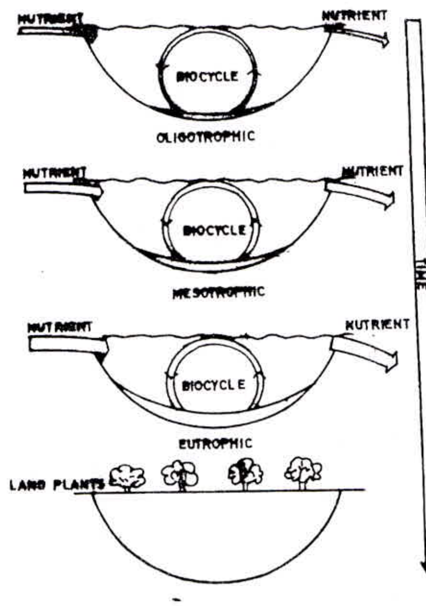

Figure2. Different stages leading to eutrophication in lakes

Nutrients are added to the lake water primarily through the lake catchment and the atmosphere. The nutrient sources may be point or non-point. The principle sources of nutrients (Fig. 3) are municipal wastes, industrial wastes, agricultural runoff, forest runoff, Urban and sub-urban runoff and atmospheric fall outs.

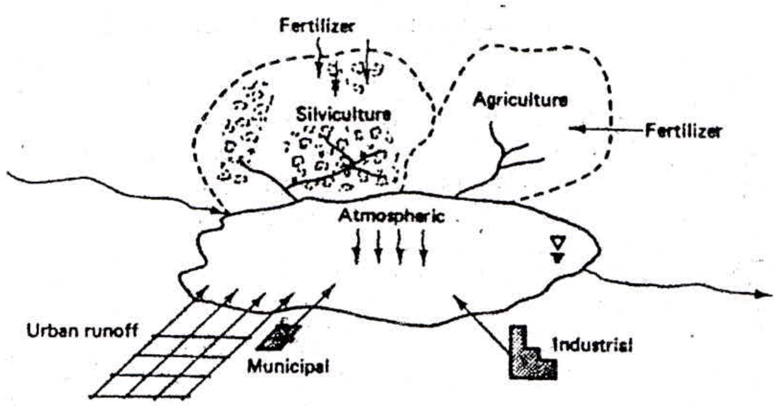

Figure3. Sources of nutrients in eutrophication problems

Fig. 4 describes the basic process of phytoplankton-nutrient interaction. The inorganic nutrients brought to the lakes are used by the aquatic plants and converted into organic plant material through the process of photosynthesis. The energy for photosynthesis is supplied bythe solar radiation. As the water temperature increases, the nutrients in dissolved form areutilized by the plankton causing an increase in the phytoplankton biomass. This process continues until nutrients reach levels that will no longer support the growth and increase in phytoplankton biomass ceases. Decline in phytoplankton biomass is then observed, mainly due to predation by zooplankton. Nutrient recycling again causes the bloom. Thus, eutrophication of a lake/water body depends upon the geographical location of the water body, degree of penetration of the solar radiation to different depths, magnitude and type of nutrient inputs, and the particulars of water movement through flow transport and dispersion.

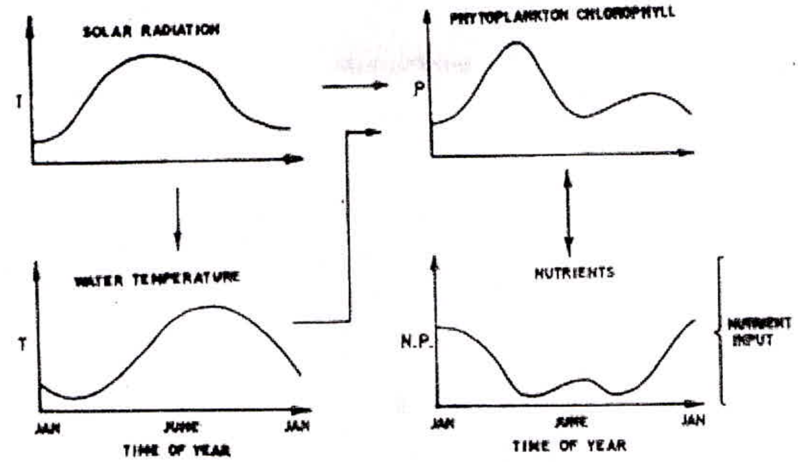

Figure4. Basic process of phytoplankton-nutrient interaction

Eutrophication has very serious consequences for the lake water use. 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, Clogging of water treatment plants, 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. Toxins produced by cynobacteria can also be a health concern. The increased production of aquatic plants, particularly macrophytesalso cause aesthetic and recreational interferences. There are also problems related to odourand taste. Eutrophication can also cause death of fish due to reduced dissolved oxygen.

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 and 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.

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

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.

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

Lake Evaporation

When the radiant energy is supplied to the lake water, kinetic energy of the surface water molecules is increased. When the water molecules attain enough kinetic energy, they escape from the water body overcoming the intermolecular forces and eject themselves into the atmosphere. If external energy is not made available, energy is removed from the water body. Continuous supply of heat energy causes accumulation of more and more vapour molecules increasing the partial vapour pressure. This continues till the level of saturation vapour pressure is reached and water molecules are rejected in the form of condensation. If the vapour pressure of air above the free water surface is already equal to saturation vapur pressure, neither evaporation nor condensation takes place and it is said to be in equilibrium state. However, in practice an equilibrium stage never exists under normal conditions. This is because the atmosphere into which evaporation takes place, is infinite and various transport processes will also operate to transport the vapour in the atmosphere both parallel as well perpendicular to the lake water surface and prevent equilibrium from occurring.

Evaporation is one of the major causes of water loss from the lakes and other water bodies. Knowledge of evaporation losses is very important and is needed for various purposes such as water resources planning and management, water availability studies, heat balance studies, temperature modeling etc. Evaporation can be deciding factors in water resources management in arid and semi-arid regions. According to Central Water Commission, India report (1988) on an average there is a loss of about 450 MCM of water every month from an area of 2,000 Sq.Km of the reservoirs which amounts to an annual loss of 5,400 MCM. The Water Management Forum (WMF), a national body of the Institution of Engineers (India), in their publication "Water Conservation by Evaporation Control, 1988" had indicated that on the Indian sub-continent the estimate total loss of water from large, medium and small storages will be to the tune of 60,000 MCM, which according to WMF would be adequate to meet the entire municipal and rural water needs of India by 2000 AD. The assessment of evaporation losses had been reviewed by CWC in 1990. According to the revised estimates, average annual evaporation from reservoirs/water bodies in India varies from 150 cm to 300 cm. The total surface area of existing large and medium storages, tanks and lakes in the country, being estimated to be 12,000 Sq.Km (likely to increase to about 25,000 Sq.Km. at the ultimate stage of development), assuming annual evaporation loss rate of 225 cm, the evaporation loss from existing water bodies works out to 27,000 MCM. In the ultimate stage, the evaporation losses may be of the order of 56,000 MCM.

Most of the shallow lakes and ponds in tropics show presence of macrophytes due to heavy pollution. Macrophytes like the water hyacinth have become a menace for many a lakes all over the world, particularly in the tropical and sub-tropical countries. A number of workers have shown that presence of aquatic plants in general enhance water loss. The evapotranspiration to open-water evaporation ratio (ET/E) for aquatic plants can be more than 1.4 and sometimes even more than 13.0. Common water hyacinth (*Eichhorniacrasspies*) is particularly known to cause heavy evapotranspiration losses. The rate of water loss due to water hyacinth is found to be much more than the open water evaporation. Different studies have shown different rates of variation ranging from 1.8 times to 13 times more. The rates are found to vary from region to region. Some researchers have observed that the ratio between evapotranspiration and free water evaporation decreases with increasing amount of solar energy and increases with increasing vapour pressure deficit. Further, it has also been demonstrated that evapotranspiration by aquatic plants is also influenced by plant canopy characteristics and nutrient availability

Sedimentation

Sedimentation is one of the serious problems of many lakes causing reduction in lake capacity and useful life of the lake. As such the knowledge of lake sedimentation process is very essential for control and management of the lake sedimentation. It is also essential for understanding the ecological behaviour of lakes. Although high concentrations of suspended matter may result in low primary production because of restricted light penetration, supply of excess nutrients to lake through sediments however, increases its productivity. The availability of dissolved oxygen in lakes may be limited due to high sediment oxygen demand. Benthos and fish are affected not only by the suspended sediments but also by the modification of habitat caused by depositional sediments. The chemical and biological activities of sediments produce heat, contributing to the heat budget of the lake. Sedimentary processes may also cause changes in the lake basin forms. The sediment character controls the chemical composition of the lake water. So, the interaction of sediments with the lake water, both within the water column and at the bed of the lakes, controls the quality of the surface water. Sediment also contains biological life. It is a substrate for bacterial activity.

Nature of sediments depends upon the rock type in the drainage basin. Siltation rates are mainly dependent upon conditions in the drainage area. Effects of drainage basin are mainly due to morphology, climate and land use. There are three main sources of sediments for lakes. Water and wind are the main natural agents which bring sediments into the lake. Organic matter produced in the lake is an internal source. Besides, there is also a problem of re-suspended bottom material.

CONSERVATION AND MANAGEMENT OF LAKES

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.

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 about1mg/l, 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/l 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 waterbodies 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 l/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 waterbody 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.

HypolimneticAeration

If nutrient-rich sediments cannot 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. Hypolimneticaeration 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 HypolimneticWaters

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 growthsare 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 controls in the lake catchment area refer 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.

Selection of Eutrophication Control Method

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.

CONTROL OF EVAPORATION FROM LAKES

Although evaporation losses are quite substantial, the evaporation control methods perhaps cannot be employed to all open surface water bodies, irrespective of their size and shape. In view of this, water conservation management by control of evaporation has so far been limited generally to drought prone and scarcity areas under specified wind speed and temperature conditions of the water bodies.

Different approaches have been developed to reduce evaporation losses from surface of water bodies. Since the basic meteorological factors affecting evaporation cannot be controlled under normal conditions, efforts have so far been concentrated on evaporation reduction by physical or chemical means. CWC, India has provided a detailed review of the various existing methods of evaporation control in their report. Some of the existing methods that can be used for lakes are:

i) use of wind breakers
ii) covering the water surface
iii) reduction of exposed water surface
iv) treatment with chemical Water Evapo Retardants (WER).

A brief description of the various methods as given in the CWC report is provided below:

Since wind is one of the most important factors which affect rate of evaporation loss from water surface, evaporation losses can be reduced by controlling wind movement over the water body. Planting of trees normal to windward direction is found to be an effective measure for checking of evaporation loss. Plants are grown around the rim of the lake in a row or rows to act as wind breaker. The spacing between plants varies from place to place, depending upon the climate and type of soil. The list of vegetation has been recommended by Indian Council for Agricultural Research, New Delhi (Technical Bulletin No. 22) for planting as wind breakers in different regions of India.

However, wind breakers are found to be useful under limited conditions for small reservoirs. In large reservoirs, wind breakers are not effective, as their effect is limited to a short distance from the rim of the reservoir, thereby exposing the inner water spread area to the hazards of wind. Another disadvantage of this method is that large quantity of water can be lost due to transpiration by the trees planted. Considering these effects, the wind breakers are commonly employed for specific high wind locations.

By Covering the surface of water bodies with fixed or floating covers considerably retards evaporation loss. These covers reflect energy inputs from atmosphere, as a result of which evaporation loss is reduced. The covers literally trap the air and prevent transfer of water vapour to outer atmosphere. Fixed covers are suitable only for relatively small storages. For large storages, floating covers or mat or spheres may be useful and effective. However, for large water surfaces the cost of covering the surface with floats is prohibitive. Further in case of reservoirs with flood outlets, there is also the danger of floats being lost over spillway or through outlets. The floating covers are thus of limited utility to larger water bodies. Floating bodies as vegetable oils, wax, wheat husk, paddy husk, wooden blocks, saw dust and thermocol boards etc. have also been tried in some studies, but results are not conclusive.

In the "Reduction of Exposed Water Surface" method shallow portions of the reservoirs are isolated or curtailed by construction of dykes. or bunds at suitable locations. Water accumulated during the monsoon season in such shallow portions is diverted or pumped to appropriate deeper pocket in summer months, so that the shallow water surface area exposed to evaporation is effectively reduced. This method is one of the recognized methods of conservation in drought areas and has been successfully tried for Lake Worth in Texas, USA. In India, this method has been tried for Nayka reservoir, supplying water to Surendranagar in Gujarat, which yielded good results.

Chemicals capable of forming a thin mono-molecular film have been found to be effective for reducing evaporation loss from water surface. The film so formed reflects energy inputs from atmosphere, as a result of which evaporation loss is reduced. The film allows enough passage of air through it and hence, aquatic life is not affected.

The film developed by using fatty alcohols of different grades has been found most useful for control of evaporation. They are generally termed as chemical water evapo-retardants (WERs) and these are available in the form of powder, solution or emulsion. Following chemicals are generally used for water evaporation retardation:

- Cetyl Alcohol (Hexadecanol) $C_{16}H_{33}OH$
- Stearyl Alcohol (Octadecanol) $C_{18}H_{37}OH$
- Ethoxylated Alcohols and Linear Alcohols
- Linoxyd CS-40
- Acilol TA 1618 (CetylStearyl Alcohol)

These chemical water evapo-retardants have the disadvantage of high cost of application. They also have another limitation of the mono-layer breaking at high wind velocities.