LECTURE-2

Introduction to Lakes & Their Hydrology

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INTRODUCTION

Water in rivers and lakes amount to be less than 1% of (by volume) the world's water budget but its importance to life and human geography is enormous. It is estimated that the world's lakes contain about four times more fresh water than its river, yet curiously enough they are more euphoiral. Still lakes are used extensively in many countries as the natural centers of civilization. In India, even during Maurya period (320 BC) a major reservoir called Sudarshana Lake was made at the floor of Mount Girnar in Western India (Winderlich et al., 1987).

A lake plays a significant role in shaping the hydrological, ecological, environmental, socio-economical balance of that region and the country as a whole. Lake is also a place for sanctuary for migrating birds, development of flora and fauna and an excellent spot for habitation of aquatic biota which are important for maintaining the ecological and environmental balance and the hydrological cycle

Lakes in general represent additional storage capacity of hydrologic systems. Natural or artificial changes in storage either in quality or quantity of water alters not only the stream flow regime but also the water balances of the region. Alteration of flow regime and quality of lake water, a common problem faced anywhere, arising from increase in demand and several developmental activities, result in the hampering of activities supported by lakes. There are also side effects of ecological imbalances in the region.

In a global prospective, important ecological problems connected with lakes are:

- Lowering of lake level due to over use of water.
- Rapid siltation caused by accelerated soil erosion in the catchment.
- Acidification of lake water due to acid precipitation.
- Concentration with toxic chemicals.
- Eutrophication.
- Disintegration of aquatic system is a possible end result of any of the above.

Importance of lakes

Being the valuable natural resources lakes have always been of great importance to mankind. From ancient times they have been providing water for domestic purposes. Since long, lake water is being used for industrial and irrigation purposes. Lake is also one of the means of transport and has always attracted the attention of human beings from the recreational point of view. Some of saline lakes are useful sources of some important minerals as well. In short, a lake is a sort of catalyst in the development of a city, region and the country as a whole. But unfortunately the popularity of lakes often leads to its deterioration. The increased input of industrial and domestic waste and other sediments not only hampers capacity of the lake but also cause an increase in the productivity of the lake which causes the biological and chemical changes in the lake water leading to hazards like death of fish, obnoxious odor and unsightly conditions.

Definition of lakes

A lake is easy to visualize because of its definitive boundary like other types of storage in the hydrological cycle. Lakes are natural reservoirs in which water is temporarily stored during its passage to Sea. They receive water as precipitation on their surface, from surface influence and from ground water entering as springs. Lake loses water in the form of evaporation from its surface, streams taking out from the lake, contribution to ground water through fracture etc. They disappear through a process of natural eutrophication involving the filling up of the lake with nutrient containing sediments. The process of cultural or manmade eutrophication is much faster than the slow rate of natural eutrophication. Many among these nutrients are beyond the control and most frequent are carbon, hydrogen, oxygen, nitrogen, phosphorous, calcium, magnesium and sulphur etc. The distinction between lake and river is quiet obvious but there are examples of local fanning of rivers, though called oxbow lake, still it is neither lake nor river. Another distinction between lake and reservoir is that the later is a manmade lake or a natural lake which has been augmented with some type of regulation equipment.

As defined by Zumberge and Ayers (vide Chow, 1964), a lake is an inland body of water filled or partially filled by a water body whose surface dimensions are sufficiently large enough to sustain waves capable of producing a barren wave swept shore. From the geologic point of view, a lake consists of two distinct parts, the basin and the water body. It is obvious that the later could not exist without the former and both should be taken into account in any workable definition. From the hydrological point of view, a lake should be distinguished from a wide river section. In brief, a water body should fill the following requirements to be a lake:

- It should fill or partially fill a basin or several connected basins.
- It should have essentially the same water level in all parts with the exception of relatively short occasions caused by wind, thick ice cover, large inflows etc.
- It should have so small an inflow to volume ratio that considerable portion of suspended sediment is captured.
- It should have a size exceeding a specified area e.g. 0.01 sq. Km at mean water level.

Origin of lakes

Depressions are first of all formed on the earth's surface under favorable conditions, some of these contain water and are therefore, described as lakes. The topographic depressions, which accommodate lakes, are known as lake basins. Different number of various natural events creates lakes. Natural agencies like wind, water etc. individually and collectively produce at least temporarily some depressions on the land surface. Most lakes however have been produced by glacial, volcanic or tectonic processes. They commonly occur above the mean sea level and the basin always have their bottom below the water table. Their life expectancy may vary from a short spell of two floods to millions of years.

It has been estimated that there are about three million lakes on Earth. They have total area of about 2.7 X 10 km^2 and volume of water equaling 165.8 X 10 m^3. (Bowen 1982). Most of the world's water lakes occur on three continents - North America, Africa and Asia and account for 25%, 30% and 20% respectively of the world's water resources and more than 10% of the world's fresh surface water.

Most of the lakes are minor in size and very few are large. The term "large" and small lakes are relative and arbitrary. For the convenience of the investigators and suit a specific study, some threshold values of surface area of a lake (500 sq. Km) or volume of a lake (10 Cu. Km.) is designated to demarcate between a large and small lakes (Nace, 1978). The lakes with areas more than 350 $miles^2$ (901 km^2) or even less than 35 $miles^2$ (90.7 km^2) are exceptional. The large lakes i.e. lakes with more than 500 km^2 surface area account for 93% of the total surface area of the fresh water in the world and 88% of the total water volume of the world (Munawr 1987). 89% of these lakes are found in the northern hemisphere while large lakes of southern hemisphere are located mostly in the African Rift valleys.

Classification of lakes

Classification based on region of lakes

The regional classification of lakes are tropical, temperate and cold climate. Tropical lakes have summer temperature of 25 to 30 degree C and a winter temperature of 16 to 20 degree C. Temperate lakes have summer temperature of 16 to 20 degree C and winter temperature of 4 to 8 degree C. Cold climate lakes have a summer temperature of 4 to 8 degree C and winter temperature of 0 to 4 degree C.

Classification based on biological properties of lakes

This classification is based either on the concentration of the plant in the lake or on the productivity of the organic matter or algal population in the lake.

Oligotrophic Lakes - These lakes are at their lowest trophic level and are usually deep having large volumes of relatively clear water. They have a low concentration of nutrient elements such as nitrogen and phosphorous. Rock weathering, sediment transport and atmospheric precipitation are the major sources of pollution for an oligotrophic lake. The dissolved organic carbon content of these lakes is very less generally in the range of 1 to 3 mg/liter. The concentration of nutrients results in few plants and hence a low rate of organic production by photosynthesis.

Eutrophic Lakes - Eutrophic lakes are at the highest trophic level and are rich in plant with high concentration of plankton due to high productivity. Concentration is above 20 micro grams per liter. Organic matter is either internal (produced in lakes) or allocthonous (transported from environment). The water of these lakes is murky with suspended plankton and depleted in oxygen at depth. They have a narrow hypolimnion and deep epilimnion.

Mesotrophic Lake - This is a transient state of lake from oligotrophic to eutrophic stage. These lakes have intermediate properties between those of oligotrophic and eutrophic lakes. Their major properties are moderate fertility, adequate aquatic plant population, greenish water and moderate production of phytoplankton. The dissolved oxygen content is 2 to 4 mg/liter.

Dystophic Lakes - These are shallow brown water lakes. Brown color is due to the organic matter. They have either very few or no organism except a few aquatic plants found occasionally. They contain hydrogen sulfide and ammonia. Their N/P concentration is very high. They have a low pH. Metallic pollution is present. Their oxygen content is 20 to 50 mg/liter. Fishes are absent.

Classification based on chemical nature of lake water

On the basis of the chemical nature of its water, its carbon dioxide and calcium contents, the lakes are classified as

Acidic Lakes - The water of these lakes generally have pH values of 6 or less. They contain hydrogen-calcium-magnesium-sulfate waters. Sulfate concentration is generally 3 to 5 times more than that of the fresh water lakes. Acidification of lakes occur due to acidification of dilute fresh waters or because of acid precipitation. Acid lakes are characterized by steep slopes and cracked bedrock with little vegetation and soil development. In this way they receive precipitation virtually unaffected by the soil.

Saline Lakes - All saline lakes are formed by closed lakes under desert or semi arid condition where the evaporation rate is too high and there is a lack of inflow to present the subsequent discharge of salts to the seas. Saline lakes are often highly alkaline and exhibit a high pH, higher than 10. These lakes are the source of economically important chemicals such as sodium, borax, potassium, zeolite. etc.

Fresh Water Lakes - These lakes also differ widely in contents but tend to assume the dissolved solid characteristics of the water of the in-flowing stream. The pH of the water ranges from 6 to 8 and they generally have calcium-magnesium-bicarbonate waters.

Classification based on carbon dioxide content of lake water

Soft Water Lakes - These lakes are common in the region of low lands. Their water have a low carbon dioxide content; nearly about 200 ppm. pH is from 4 to 6.

Medium Water Lakes - These lakes have a pH of around 7. The free gaseous carbon dioxide in these lakes varies widely, frequently showing supersaturation relative to partial pressure of the gas in the atmosphere. These lakes, though has a relatively less mass of living matter per unit area, often harbor a greater variety of plants and animals.

Hard Water Lakes - These lakes occur in regions where the substrata contain easily dissolved minerals. These lakes are characterized by negative values for free carbondioxide due to withdrawal of bicarbonates at a higher rate than the bicarbonates that are precipitated. These lakes have a high pH values of 8.5 and 10.

Classification based on calcium content in the lake water

Reid & Wood (1976) have reported that W. Ohle, a German limnologist, gave the following scheme of lake classification in 1934 on the basis of their calcium content:

(i) **Poor Lakes** - Calcium content less than 10 mg/liter.
(ii) **Medium Lakes** - Calcium content from 10 to 25 mg/liter.
(iii) **Rich Lakes** - Calcium content more than 25 mg/liter.

Hydrology of lakes

Hydrologic characteristics of lakes very considerably because of difference in depth, breadth, width, surface area, basin material, surrounding ground cover, reservoir, prevailing winds, climate, surface inflows and outflows and other factors. Lakes may have some common features but often exhibit different performance characteristics. This individuality has environmental value and as such it presents the problem of understanding both, the general nature of the system and variations due to local conditions (Zumberg and Ayers vide chow 1964). Hence each lake requires its own hydrologic models and these model need to be characterized by different degree of variance from a generalized conceptual model.

Heat storage in lakes act to stabilize the air temperature minimizing and lagging variation in adjacent region both in winter and summer (Linsley et al. 1980). Lakes also exhibit interesting thermal stratification like reservoirs. In order to evaluate the lake problems and more realistic approach for their management, heat budget, nutrient budget and water budget of lakes are needed. Lakes also exist in all sizes and it is obvious that a small pond of 0.01 km^2 is totally different in most ways than lake of 50 km^2. For example, one of the Great Lakes in North America with surface area of around 50,000 km^2. Climate, geology and antropogenic influences are other factors that make each lake unique. This has to be realized while we are studying lake hydrology and try to make general comments about the behavior and characteristics of lakes.

Effect of lakes on various hydrological parameters of the catchment

Lakes influence the local hydrology either directly or indirectly. In hydrologic cycle, the water passing through the lake will be filtered both with respect to its physical properties (including velocity) and its chemical properties. The water balance of lakes is different than that of the rest of the drainage basin. Hence water balance of a drainage basin having high percentage of lakes will be different than low percentage dittos. Because of storage of large mass of water, a lake moderates flood and climate factor in the region. Smaller the lake, the more responsive it is to changes in energy inputs. Small lakes behave as a single system, but almost all large lakes respond as a complex of sub-basins, each of which may be significantly different in size, form and depth. The large free surface area of the lake provides a great contact area between water and air and thus evaporation is enhanced. It is an accepted fact that large lakes possess specific system characteristics that distinguish them form small lakes.

LAKE PROCESSES

The lake processes include sediment release, biochemical recycling, mixing etc

Sedimentation in lakes

The importance of sedimentation for lake ecology can be seen from two angles. On the one hand there is plenty of life in the bottom sediments of a lake, because biological life are better in sediment than in water. On the other hand because of abundance of life in sediments, there is a great contribution to the lake system from the benthic community. Siltation rates of a lake are essentially dependent on the conditions of the drainage area. There are also other factors, mainly morphological and hydrodynamics that are influential. Steep areas with large relief tend to have stronger time variations in their sediment load and they also carry coarse particles. Man's influence is mainly due to varying land use. While sediment transport in channel/rivers is totally dependent on the gravity driven flow and its characteristics, the situation in lakes is different and like that of coastal sediment transport. In lakes, wave is normally much more important than aperiodic wind driven currents. Because of the sediment content of the incoming river, its current system is quiet important for the whole sediment water interaction system as shown Fig. 1. Another special feature of lake sediment problem is the large content of organic materials due to large portion of cohesive sediment in the water. Because of this the sediment characteristic are much more complicated than for friction material for which the particle size is often important.

In lakes there are areas dominated by either erosion, transport or sedimentation. If the bottom area is defined as the sedimentation type, particles once deposited will stay there for ever; for erosion type the deposited material will be resuspended in a very short time; while for transport bottom type the material will be removed but it may take some time before it happens. The way the different types of bottom areas are found practically is by testing the hardness of the bottom, with the sediment bottom showing a very soft surface while the erosion bottom is quiet hard.

There are three sources for sedimentation in a water column of a lake. These are incoming river water, organic material produced in the water and suspended bottom material. The sediments brought into a lake by an incoming river is dumped close to the river mouth, eventually resulting in delta formation. If there is fair amount of sediments in the river water entering in the lake, the river plume plunges to some equilibrium level, while entraining lake water.

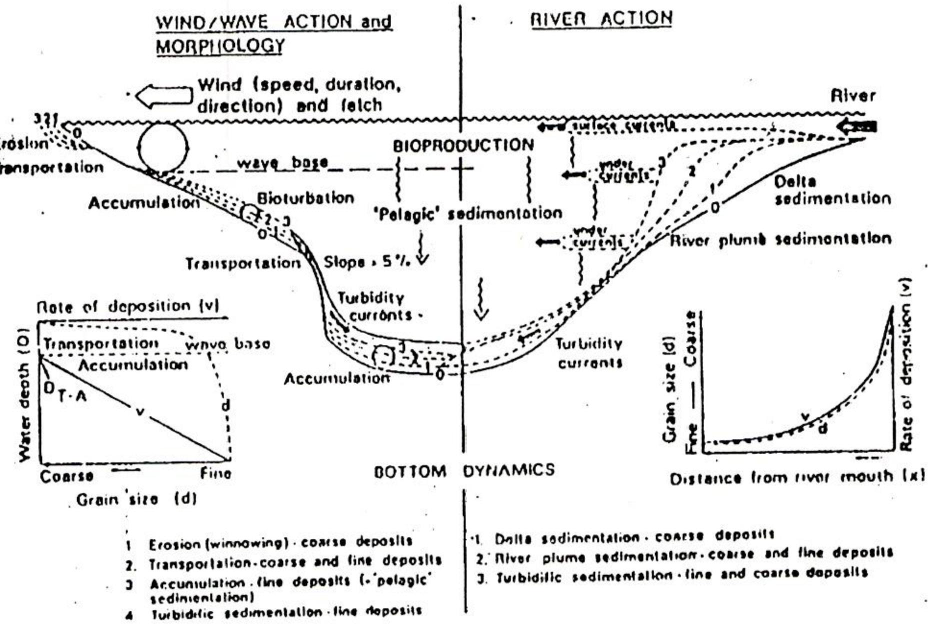

Fig. 1. Schematic illustration of major sedimentological and bottom dynamic processes in a lake

If there is little wind action, the river plume takes a path that is influenced by the morphometry and possibly the Coriolis Force. Even if this pattern might be upset by wind driven currents, it normally prevails in the long term. Once the sediment has settled there is a chance that it will return back to the water column through resuspension. This process is usually governed by the balance between the hydrodynamics forces seeking to move the particle and the stabilizing force due to gravity. Once the sediment have been resuspended, they gets redistributed in the lake according to the current pattern and the diffusive character of the flow. When the energy level is reduced due to decrease in wind speed, the sediments settle to the bottom. This sequence of events is repeated for every storm. The result is that near shore area is void of fine sediment which accumulate in the deeper areas. How much sediment in a lake will pass right through the lake is governed by the flow rate and the particle diameter.

Thermal stratification in lakes

Cycles of thermal stratification or destratification can be observed in most natural or man made bodies of water such as lakes or reservoir or impoundment which are exposed to an environment with continuously changing meteorological conditions. Solar and atmospheric radiation that penetrate a lake and are observed at different depths, tend to establish a stable temperature gradient, a process that is partially eroded by turbulent mixing due to through flows and by heat loss and wind shear at the surface. During a period of prevailing heat input i.e. in spring and summer, these counteracting processes lead to the development of a two layered temperature structure in a lake. A warm, usually well mixed upper layer (epilimnion) overlays a cool, stagnant lower layer (hypolimnion) and it is separated from it by a strong temperature gradient (thermocline). The hypolimnion does not undergo direct reaeration from the atmosphere and may become devoid of dissolved oxygen if the levels of the organic matter are high.

Under anoxic conditions, reduction of various compounds in the sediments may occur converting them into soluble reduced forms which diffuses into the hypolimnion. Substances produced in this way include ammonia, nitrate, phosphate, sulfide, silicate, iron, calcium and manganese compounds. When heat loss becomes predominant i.e. during fall, the epilmnion cools and grows deeper, there by eroding and sinking the thermocline. When the surface layers reach a temperature at which they are denser than the water of the hypolimnion, there is an "overturning" of the lake water which occurs quiet quickly and results in a vertical mixing of the lake water and the lake eventually returns to its initial isothermal conditions. A typical vertical temperature profile and the processes involved in its development are shown in Fig. 2. Thermal stratification does not usually occur in large lakes unless the depth is at least 10 meters and in very deep lakes, it may persist throughout the winter also. It normally does not arise in small, shallow lakes, particularly where there is a high rate of flow.

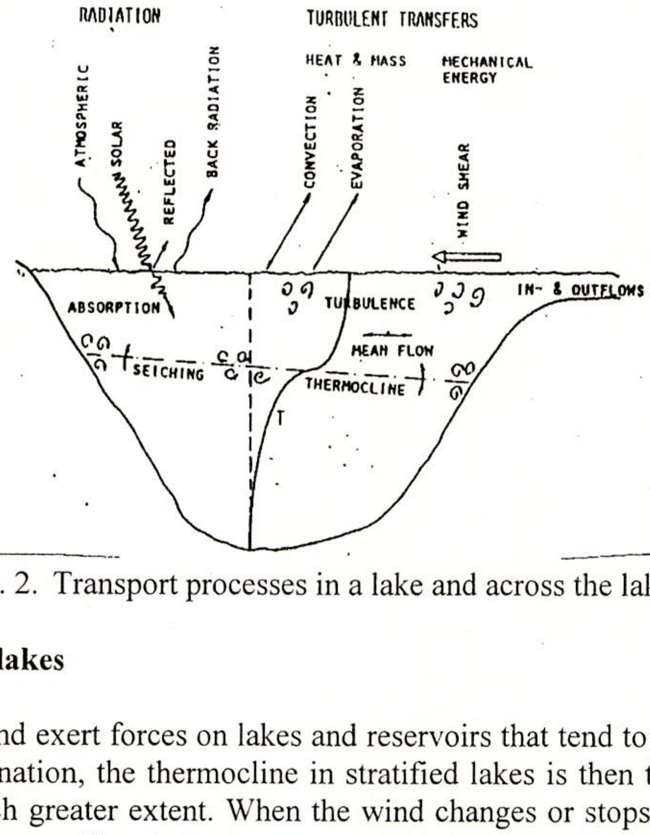

Fig. 2. Transport processes in a lake and across the lake surface

Water mixing in lakes

Wind exert forces on lakes and reservoirs that tend to tilt the surface. As a result of this inclination, the thermocline in stratified lakes is then tilted in the opposite direction to a much greater extent. When the wind changes or stops, the surface and the thermocline starts to oscillate but when the oscillation, called seiches, have died out after some time, the body of water returns to its original one dimensional thermal structure apart from some mixing due to currents associated with seiches. In the case of strong steady winds, the displacement of the thermocline may be so large that the hypolimnion is uncovered at one end of the lake, and thus the assumption of one dimensional system no longer remains valid. An empirical formulae for calculating the wind speed (M.I.T. Report) relating the inclination of the surface and the mean water depth is,

If $W > 2.10^3\hat{u}$ (d. h. delta p/L. p), a one dimensional representation is no longer possible, where d = depth of epilmnion. Limiting wind speed for average sized lakes in mid-latitude locations range in the order of 10 m/s.

Eutrophication

The word "eutrophy" is generally taken to mean "nutrient rich" and is used sometimes a contrast to dystrophic (ill-nourished). Eutrophication. Known as the natural aging process of standing water, has dramatically increased since the sixties, mostly in industrial countries with intensified agriculture, due to excessive antropogenic input loads of plant nutrient, phosphorous and nitrogen. Therefore as contrast to natural eutrophication, the recent problem is termed antropogenic or man made eutrophication. This is usually observed as the excessive growth of phytoplankton that turns standing water and sluggish streams into green known by the lay public as "algae bloom", a term frequently used by scientist as well. It is frequently associated by the increased growth of attached algae or macrophytes.

Eutrophication is a natural process in many lakes and ponds which have a rich supply of nutrients, and it also occurs as a part of the aging phenomena of lakes, as the nutrients accumulate through the natural process of ecological succession. Eutrophication escalates rapidly when abnormally high amounts of nutrients from sewage, fertilizers, animal wastes and detergent enter streams and lakes, causing excessive growth of phytoplankton and other aquatic weeds. The growth of phytoplankton expressed as primary productivity which is expressed as carbon produced per unit area of the lake per unit period of time (e.g. g. Cm^{-2} Yr^{-1}) is high leading to relatively high concentrations of dissolved organic matter (DOM) in the lake water. This supports a population of heterotrophic bacteria that decomposes organic matter and deplete the dissolved oxygen content of the water. In deep lakes, in the hypolimnion, this oxygen depletion might create anaerobic condition that gives rise to undesirable biological and chemical processes and may result in fish kills. Nevertheless, eutrophication is often associated with increased fish production but the species composition changes unfavorably.

Tropic Stage of Lakes

Lakes are considered to undergo a process of aging which has been characterized by three quantitative defined conditions; they are namely; (i) Oligotrophic (ii) Mesotrophic and (iii) Eutrohic.

Oligotrophic indicates a non productive water. It is associated with low biological activity, and is usually related to geologically young bodies of water Water quality is excellent in this case.

Mesotrophic indicates a water with average productive and is associated with biological activity but is still balanced system. Water quality is adequate for most beneficial use but may be deteriorating towards the eutrophic state.

Eutrophic indicates a highly productive water. Excessive biological activity causes large fluctuations in environmental parameters. The eutrophic condition of a lake represents the opposite end of the aging process. water quality is usually significantly degraded.

The boundaries between the three stages are not defined and may vary with regions of the nation and beneficial uses of lake waters. The basic factors which are involved in the eutrophication of the lake are (i) Loads, (ii) Nutrients, (iii) Phytoplankton, (iv) Transport, and (v) bottom processes (vi) Lake temperature.

Although about 16-20 elements are necessary for the growth of fresh water plants (among other, carbon, silicon, calcium, potassium, magnesium, etc.), antrophogenic eutrophication is most exclusively due to over enrichment of phosphorous and nitrogen resulting from increased nutrient loads from a variety of point and non point sources (e.g. and industrial waste waters, agricultural runoff water, residential urban run off waters, atmospheric fall out on the lake surface).

In natural lake ecosystems, one or some of the plant nutrients, mostly phosphorous, sometime nitrogen, and much more rarely silicon, are present in so low concentrations that it/they limit the growth of phytoplankton, thus exercising control over the aquatic ecosystem as a whole. The "growth limiting factor" for the majority of the lakes is phosphorous or more precisely the bio-P available forms of phosphorous. The bio-available form, the P form that algae can take up, is either taken as orthophosphate phosphorous Po_4 - P or termed as the dissolved inorganic phosphorous (DIP) or just the bio-available phosphorous (BAP), which is meant to include more than one phosphorous form; DIP - a certain fraction of TP-DIP.

WATER BALANCES OF LAKES

Water balance relationships form the basis for rational, deterministic hydrological forecasting models and are necessary for

- Forecast of lake levels for shorelines, property utilization, and navigation.
- Design, selection and operation of forecasting models.
- Predicting environmental impacts i.e. preservation of living resources of a lake through maintenance of water quality standards.
- Valuable information base for effective management.
- Global studies of climate variability.

Water balance studies of lakes are required for proper use, conservation and harnessing lake water. The water exchange in lakes is much slower than in rivers. On a global basis and in terms of the total water of the earth, the lake water is ten times more than the river water. Incidentally, the average residences time for rivers and lakes are 2.1 years and 21 years respectively and these indicate the slower water exchange process in a lake than a river. Water quantity and quality considerations are directly linked. Water balance studies are basic necessity for doing nutrient budgeting which in turn helps to assess the cause of lake deterioration and to devise successful strategies for lake amelioration. Conceptually, the nutrient budgeting is similar to the water budgeting - an accounting of inputs, storage outputs.

Following aspects should be taken care of while computing the water balance of a lake:

- Water inflow from rivers and drainage areas along perimeter of the lake.
- Peculiarities in the formation and fall out of precipitation on the water surface.
- Water outflow from a lake.
- Peculiarities of water losses through evaporation from the water surface.
- Peculiarities in hydrology of watersheds.

The water balance study of lake provides very useful information about the availability of water in lakes at any time. The water balance equation of a lake for any time interval is basically a continuity equation and can be expressed as follows:

$$Ds = Is + Iu + Pi - Qs\square - Qu - Ei \qquad (1)$$

where

Ds	=	Change in water storage
Is	=	Surface inflow
Iu	=	Subsurface Inflow
Pi	=	Lake precipitation
Qs	=	Surface outflow
Qu	=	Subsurface outflow
Ei	=	Lake evaporation

Various parameters considered for water balance of lakes would have to be studied in details to have the knowledge about input of water and water utilized for various agricultural, industrial and domestic purposes and also other natural losses resulting in drying up of the lake. The relative magnitude of the water balance components vary from place to place and season to season.

Lakes can be divided into two main categories :

- Open (exorheic) lakes with outflow and
- Closed (endorheic) lakes without outflow

Lakes with intermittent (ephemeral) outflow during high storage constitute an intermediate category.

For large lakes it is often convenient to divide the surface inflow (Is) into inflow from gauged streams (Iu) and lateral inflow from direct runoff or ungauged streams (Iug) i.e

$$Is = Iu + Iug \qquad (2)$$

For lakes with a surface area varying considerably during water level fluctuations, it is preferable to express the components of the water balance equation in volumetric measurements. For lakes with a nearly constant surface area, it is more convenient to express water balance components in units of depth of water relative to the mean surface area of the lake.

Water balances for open lakes

Water balance equation for open lakes for a period of zero net storage can be written as

$$Is + Pi + Iu = Qs + Ei + Qu \quad (3)$$

This equation can be applied to short period of time over which the measured storage change is zero, to a long period over which Ds is negligible in comparison to other terms in the equation, or to long term mean annual water balances.

The water balances equation for an open lake when storage changes and subsurface flows are negligible can be expressed as

$$Is + Pi = Ei \quad (4)$$

When only an approximate computation of the water balance is required for the purpose of routine control of water inflow and outflow, a simplified water balance equation can be used for intervals when precipitation and evaporation are negligible.

$$äI = äO + D \quad (5)$$

where

äI = sum of input components of the water balance equation

äO = sum of output components of the water balance equation

Equation (5) is suitable for small lakes with large inflow and outflow i.e. when there is a high rate of water exchange. Equation (5) becomes less reliable for larger (area) water bodies and shorter time periods, when the error in estimates of Ds may exceed the total inflow.

Theoretically, the equations described above can be used to compute water balance in any lake without extensive marshy area. Practically, however, most shallow lakes involve significant marshy zones. In these lakes the water loss to the air occur both from the open water surface and by evapotranspiration from the marsh zone. Thus the water balance equation should also take into consideration the evapotranspiration from the marsh zone.

Water balance for closed lakes

Closed lakes are internal drainage area. Under congenial climatic conditions, runoff water accumulates in the deepest parts of these lakes and closed lakes are formed. Like the fresh water lakes, the closed lakes are supplied with water mainly through surface inflow and precipitation. But, this water is spent in different ways : - for a fresh water lake with an outlet it contributes to runoff and to a lesser degree to evaporation; in closed lakes without an outlet it evaporates entirely. There are regions in which streams are common, but end in dry valley or in lakes without outlets, lakes are less common in these regions. In desert and semi-arid localities, streams are rare, and as would be expected, lakes are also less. But there could be lakes in such areas which are land locked and water escapes only through evaporation or seepage under conditions of high evaporation and low precipitation. Closed lakes are usually saline. In such lakes, often ground water plays an important role in framing the salt balance.

Errors in determination of water balances of lakes

Errors in measuring and estimating hydrologic components interacting with lakes can have a significant impact on calculations of water balance of lakes. The errors are particularly serious if one or more components are calculated as the residual term, and the errors in the measured components are not considered in interpretation of that residual term.

If a hydrologic component, such as ground water, is calculated as the residual of the budget equation, it must be appreciated that the residual can be only one side of the equation, and that it is a net value. Therefore, especially for flow through situations, the residual value can seriously underestimate actual quantities of water moving through the lake bed. When estimating errors in calculations of hydrologic components, it is important to evaluate the errors in interpretation of point data, such as aerial averaging technique, as well as the errors in gauging. A rain gage or evaporation pan might be fairly accurate but if it is a number of kilometers from the lake, care must be exercised in adjusting the gauged value to the lake of interest

Accuracy of water budget decreases as shorter time frames are considered. Therefore, errors associated with annual estimates of a hydrologic component should not be applied to short term values. The concept of "residence time" or equivalent should be used with caution, particularly for stratified lake. In order to study the water balance of lake, following data need to be collected:

- Precipitation at different locations in the catchment area
- Evaporation rate in the lake and catchment area of the lake.
- Change in storage i.e. water level monitoring at ends (both) of the lake.
- Surface outflow - The data of lake water which is being drawn for different purposes i.e. irrigation, drinking, industrial use etc.

All the above components of the water balance should be estimated independently on the basis of required data. The shorter the time interval, the more stringent is the requirement of accuracy for the computation or measurements of the water balance components. Efforts will also be made to monitor/determine the inflow to the lake due to surface/subsurface inflow. However, if it is not possible to determine the inflow by direct means, the indirect methods would be used to calculate the same.

Methodology for water balance studies

The following parameters of the water balance equation must be determined for estimating the water balance of a lake.

Lake precipitation (Pi)

Precipitation into a lake can be estimated from the rain gauges installed all around the lake, upstream as well as downstream portions and average values of all the gauges will be taken as the value for lake precipitation.

Surface inflows (Is)

The surface inflows into a lake can be subdivided into channelized inflow and non channelized overland flow. Continuous observation of discharge in channel/rivers flowing into a lake should be carried out. In case of a perennial river, rating curves will be computed for calculating the discharge values for any time period.

Automatic water level recorder would be installed in the rivers/stream in order to have a continuous record of the discharge. To compute the discharge from the small and seasonally flowing nalah, Pigmy type current meters would be used. A relationship between precipitation and discharge through such inflows would be developed from which discharge can be computed.

Isotopic techniques (Dincer, 1968, Allison et.al. 1979, IAEA, 1983) can also be used for the measurement of inflow into the lake through visible gullies, nalah and springs. Either a gamma ray radioisotope such as Br-82 or tritium can be mixed at a suitable place in the in flowing channel. The dilution of the radioisotope can be measured after a certain distance (known as the mixing length) by using a rate meter/scaler if gamma ray tracer is injected or by collecting water samples and analyzing the diluted activity with the help of liquid scintillation counter, if the tritium is injected.

Lake evaporation (Ei)

Potential evaporation for the lake can be measured through the evaporation sensors in the data logger. A Pan Evaporation Meter should also be installed at the lake site. Isotopic methods for estimation of evaporation will involve collection of lake water samples from different depths and at different times and measurement of concentration of O_{18} or Deuterium in each sample. From the variation in the isotopic composition at the surface of the lake, indirect estimates of evaporation can be obtained through empirical relations developed for this purpose.

Surface outflow (Qs)

The volume of water being withdrawn from the lake for different purpose should be collected from the concerned authorities which would be used in the water balance equation directly. Stream taking off from the lake should be gauged and discharge measured.

Sub-surface inflow (Iu) and outflow (Qu)

The study of stable isotopic composition of lake water at different depths may be useful in the identification of sources of water i.e. whether the water is from ground water or surface water including the mixing percentage. In this respect, the water samples of different streams emerging out at number of places all around the lake and within the approach zone would be collected for the study of stable isotopic composition. The details of the methodology of stable isotopic techniques have been reported by Kumar and Sinha (1994), in case of artificial lakes.

Storage changes

The storage changes in the lake should be computed from water level fluctuations in the lake for which the data would be recorded from the automatic water level recorder installed at the end/control points of the lake.

HYDRODYNAMICS OF LAKES

The movement of water in a lake is of interest for a number of reasons. Generally this interest is motivated by some ecological/environmental needs. Quiet often, temperature (seen as a concentration of heat) is one of the variables of interest because it is of fundamental importance for all chemical and biological processes. Knowledge of hydrodynamics of lake is essential to know the spread of a substance from a spill or the mixing of the effluent on vertical exchange of nutrients etc. Amongst all factors of lake behavior, an extremely important factor is the morphology of lake. On a more general note, the movement of lake water may be classified according to time and length scales as shown in Fig. 3. Although the classification according to scales might be useful at times, another way of classifying water movement in a lake is the separation between periodic and a periodic movements. Basically there are four modes of periodic movement. The smallest scale is the ripple on the surface connected with surface tension. The second type of wave motion is especially of importance in connection with sedimentation. The water movements caused by waves at the bottom will cause shear stress at the bottom which in turn cause upliftment of the sediment from the bottom and suspension in water.

In general lakes have a two dimensional layout with the depth being at least two orders of magnitude smaller than the horizontal dimensions. Aperiodic motions in a lake have some generating mechanism and there are some factors that influence the motion once it has been initiated. There is another modifying factor that works in the opposite direction. This factor has to do with the temperature/density conditions usually found in a temperate lake. For a long period of the year there is stratification in the lake with warm, lighter water flowing on the top of the heavier water as shown in Fig. 4. Although the density difference is quiet small (of the order of 1 kg/m^3 i.e. 0.1 %) they are still very important. The density difference imposes some restraint on the vertical exchange. When stratification is present, there is only limited vertical exchange while the horizontal exchange is quiet strong.

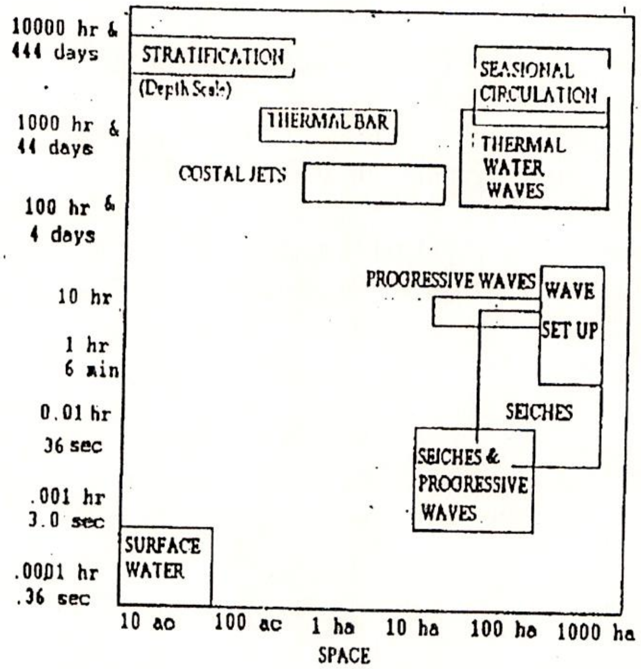

Fig. 3. Scale of physical lake phenomena indicated at space and time

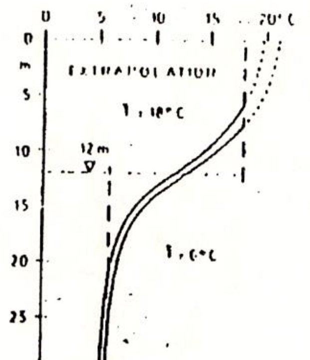

Fig. 4. Vertical temperature distribution in Lake of Zurich (Source, Nace, 1978)

A special case is the thermal bar phenomenon associated with 4 degree isotherm shown in Fig. 5. For very large lakes, air pressure related motion, river induced circulation may also occur. Wind on the water surface is equivalent to transfer of momentum from the air to water and is basically a boundary layer phenomenon. If the idealized situation of a vertically uniform wind passing over a lake is considered, there will be a developing boundary layer on both sides of the surface. This is important not only for wind stress but also for velocity profiles in the water. Wind stress is expressed in terms of wind speed

$$\tau = C_d \, p \, w^2 \qquad (6)$$

Where τ is shear stress, w is the wind speed (usually referred to 10 m elevation), C_d is the drag coefficient. Commonly used approximation of a uniform wind stress over a lake can result in quiet erroneous current pattern being computed. In order to compute with any detail, the wind driven circulation in a natural lake (i.e. with a non idealized geometry), it is necessary to resort to numerical modelling.

Another feature of wind driven flow is the set up i.e. the inclination of the water surface which is the result of the stress moving the water towards the lee side of the lake. The resulting difference in water level is quiet small but they might be of interest, because they are the origin of the large-scale periodic motions called seiches.

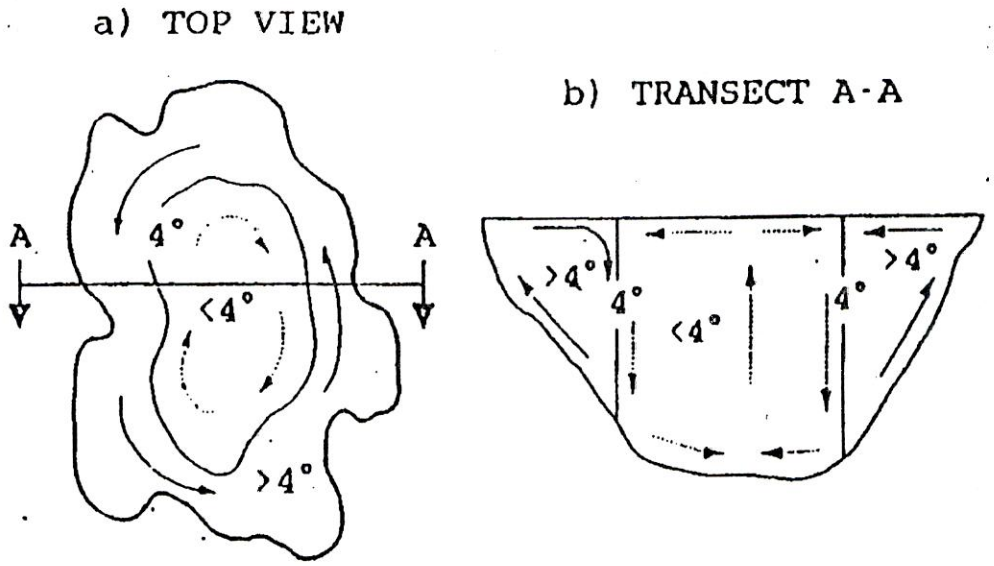

Fig. 5. Schematic pattern of the general density-induced circulation during spring in a large temperate lake (a) Primary circulation (b) Secondary circulation

If the wind stops blowing suddenly, the situation is not in force equilibrium and there will be a resorting force due to gravity. If there were no dumping, this would result in an everlasting sloshing motion. Because of the friction against the bottom, the motion will gradually die away. Overturning of lake water might be enough to move bottom sediments. Another type of periodic motion is the large scale movements of the whole water body resulting in surface oscillation i.e. seiche motion. The fourth type of wave like motion is the movement of the thermocline.

Currents are produced by the action of wind blowing across the lake, but can also be produced by inflows and outflows. A more important aspect of inflow and outflows for water quality management is in terms of the location at which the inflows terminate and from which outflows originate. For any of these currents, vertical distributions are most influenced by vertical profiles of the current (i.e. the current shear).

A further factor for design is the occurrence of wind driven waves and Seiches which may, at times, predominate over the wind driven turbulent structure.

Methodology for study of hydrodynamics of lakes

By Temperature Measurement

In order to study the hydrodynamics of lakes, the in-situ temperature survey should be carried out at different location distributed all over the lake along different sections of the lake.

By Isotopic Investigations

Water samples for stable isotope composition should also be collected from different depths and locations in a similar pattern as followed in case of samples collected for water quality analysis. The analysis of O_{18} in these samples should be carried out. These results should be interpreted to study the hydrodynamics of lakes.

Hydro-meteorological Observations

In order to study hydrodynamics of a lake various hydro-meteorological parameters for the lake and its catchment have to be observed for a long period of time.

LAKE WATER QUALITY ASPECTS

Unlike river water which is unidimensional, lake behavior is three dimensional. A lake may be characterized by morphometric, hydrological, chemical, biological and sedimentological parameters depending on its age, history, climate and water budget. Each lake develops its own response to combined factors causing major variations in water quality in both time and space. Some of the important factors giving rise to spatial and temporal variations in distribution of the quality of lake waters are mentioned below:

Water budget

The composition of the water in the lake is influenced by the water budget. However, it is not only the sole deciding factor because there is an interchange between sediment and water and an build up of organic matter by biological activity. The major inputs are usually tributary of rivers and streams which may carry a range of materials of natural and artificial origin. There may be point discharge directly into the lake as well as diffuse discharge form land drainage influenced by agricultural activities. There may also be sub lacustrine water from underground sources and rainfall which may also introduce foreign matter.

Most of the output are a direct reversal of inputs. The major output will be the river through which the lake discharges and there may be abstraction for public and industrial use. After use the abstracted water will be returned to the lake. There may also be sub-lacustrine movement of water out of the lake into the adjoining aquifers. Finally there will be loss of water from evaporation.

a) Stratification and water mixing

Another important characteristic of lakes is thermal stratification caused by the influence of temperature on water density. In temperate regins, during spring and summer the surface layers of the water become warmer and their density decreases. They float upon the colder and denser water below and there is a resistance to vertical mixing. The warm surface layer is known as the epilimnion and the colder water which is trapped underneath is the hypolimnion. The epilimnion can be mixed by wind and surface currents and maintains a fairly even temperature. Between the two layers is a shallow zone where the temperature changes from that of the epilimnion to that of the hypolimnion. This zone is called the metamilion or the thermocline. The hypolimnion does not undergo direct reaeration from the atmosphere and may get depleted of dissolved oxygen if the levels of organic matter are high. Under anoxic conditions, reduction of various compounds in the sediments can occur converting them into soluble reduced forms which diffuse into the hypolimnion. Substances produced in this way include ammonia, nitrate, phosphate, sulfide, silicate, iron and manganese compounds.

b) Seasonal and vertical variation of biological activities

The biota in the lake greatly influence the quality of waters, the effect vary according to the age of the lake. The activity of most immediate consequence is photosynthesis carried out, mainly by phytoplankton, in the upper layer of the lake. This results in an uptake of nutrients such as nitrogen, phosphorous and silica with a production of oxygen and an adsorption of carbon dioxide giving rise to an increase in pH. In cold climate regions, the photosynthesis cycle follows a marked seasonal pattern with a winter minimum and summer maximum, while in tropics, the algal productivity, and its influence on water chemistry is more evenly distributed.

Sampling for water quality study

Sampling is a vital part of studies of natural composition and is perhaps the major source of error in the whole process of obtaining water quality information. In any type of study in which only small samples of the whole substance under consideration may be examined, there is inherent uncertainty because of possible sampling error. The extent to which a small sample may be considered to be reliably representative of a large volume of material depends on several factors. These include, the homogeneity of the material being sampled, the number of samples, the manner of collection and the size of the individual samples.

The sampling from lakes is not so easy due to the heterogeneity of the water mass. Thermal stratification and associated changes in water composition are among the most frequently observed effects. A single sample from a lake can be assumed to represent only the spot within the water body from which they come. In order to overcome this difficulty, lake may be divided into different zones and series of samples may be taken from each zone. Water samples may be classified as :

Grab Samples: Grab samples are collected at particular time and place. These samples may be collected at different places and at different time interval. These samples are analyzed separately.

Composite Samples: Composite samples are the mixture of many grab samples collected at fixed points over a period of time. There are used for determining those parameters which remain unchanged with time.

Integrated Samples: These are the mixture of grab samples collected from different sampling points at a fixed time.

Sampling stations

The choice of sampling stations is influenced by the various uses of the water and their location, relative magnitude and importance, need for data collection on the lake characteristics such as volume, surface area, mean depth, water renewal time together with such information as is available on the thermal, bathymetric, hydraulic and ecological characteristics. Fig. 6 illustrate the location of sampling site for lakes along with the criteria for the choice of different sites. There is usually a high degree of dispersion and dilution of discharge into a lake and sampling stations concerned with specific uses may measure and detect impacts more readily if they are located fairly close to the effluent point. If a lake is divided into bays and basins, more than one station will be needed. As a guideline, the number of sampling points could be equal to the rounded value of the log of the lake area in square km. Information obtained from the survey of a water intake from a lake for drinking water, industry or agriculture can not reflect the overall quality of this water body which should be determined from the vertical profiles.

Lake sampling is normally carried out form a boat. The station is usually determined from a combination of landmarks on the shore and depth profile with echo sounding. Precise identification of the station each time is not easy but this is usually immaterial because of the good lateral mixing. A number of samples need to be taken at vertical intervals.

The following minimum sampling locations must be maintained :

- Two depths (surface and bottom) if lake depth does not exceed 10 m.
- Three depths (Surface, thermocline and bottom) for lakes not deeper than 30 m.
- Four depths (surface, thermocline, upper hypolimnion, bottom for lakes of at least 30 m. depth.
- For lakes deeper than 100 m. additional depths may be considered.

Many lakes exhibit the seasonal thermal stratification. When stratification exists a number of samples need to be taken vertically in the lake according to the position of the metamilion or thermocline. A vertical profile of the stratification may be plotted from a series of vertical temperature measurements. The minimum sampling position is shown in Fig. 6. Samples should be taken

- Immediately below the water surface.
- Immediately above the epilimnion.
- Immediately below the eplimnion
- Mid hypolimnion.
- One meter above the sediment/water interface.

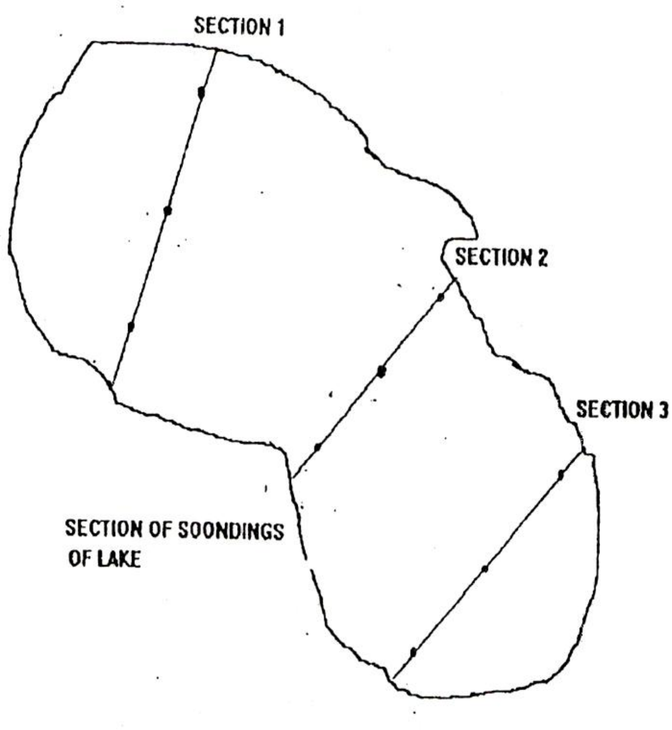

Fig. 6. Sampling locations in a lake

Sampling procedure

The water samples are collected in high density polythene bottles. Before collecting the samples, bottles are rinsed with dilute nitric acid and then with double distilled water and finally with water samples. The following plastic bottles would be filled at every sampling location:

- 500 ml for measurement of temperature, pH, electrical conductivity and total dissolved solids in the field.
- 250 ml for chemical analysis of nitrate.
- 1000 ml for the analysis of acidity/alkalinity, hardness, chloride, sulfate, phosphorous, sodium, potassium, calcium and magnesium etc.
- 125 ml. for the analysis of DO and BOD.

Sampling frequency

In lakes the mass of water and good lateral mixing provide an inertia against rapid changes resulting from modifications in inputs and outputs. Many lakes exhibit marked seasonal variations due to the thermal stratification, overturn and biological activity. For lakes the sampling should be done for five consecutive days during the warmest part of the year and five consecutive days once every quarter. For lake impact stations near to the used point, where variability is likely to be greater than in the main body of the lake, the sampling could be increased. Special cases include temperature-zone lakes that experience These should be sampled at least six times a year.

Samples handling and preservation

For the pollution survey, samples should be collected and stored in clean plastic or glass bottles fitted with screw caps. Plastic container are generally preferred for inorganic samples and glass is preferred for organic samples. Plastic bottles must not be used for organic samples and certain trace metals because it is known that they introduce interference and have absorption characteristics. In general, the shorter the time that elapses between the collection of a sample and its analysis, the more reliable will be the analytical results. For certain constituents and physical values, immediate analysis in the field is required in order to obtain reliable results because the composition of the sample almost will certainly change before it arrives at the laboratory. However, some samples can be satisfactorily preserved by chilling or by adding suitable acid.

Water quality parameters

The parameters which characterize water quality may be classified in terms of the kinds of measurements, viz. physical properties (e.g. temperature, electrical conductivity, color, turbidity), inorganic chemical compound (e.g. dissolved oxygen, chloride, alkalinity, fluoride, phosphorous, nitrogen, metals), organic chemicals (e.g. phenols, chlorinated hydrocarbons, poly-cyclic aromatic hydrocarbons and pesticides), and biological components, both microbiological such as facile coliforms, and macrobiotic, such as worms, plankton, and fish, which can indicate the ecological health of the aquatic environment. Some of the physio-chemical parameters are; pH, Conductivity, Temperature, Dissolved Oxygen (DO), Alkalinity, Hardness, Chlorides, Sulphate, Nitrogen

Measurements and methods

Determination of temperature, pH, specific conductance and turbidity should be made in the field by means of portable meters. For other parameters sample should be preserved by adding an appropriate reagent. The preserved samples should be stored at 4 degree C. in sampling kits and brought to the laboratory for detailed analysis. Chemical analysis of the sample is carried out as per Standard Methods (ALPHA, 1961) for the analysis of water and wastewater. A brief description about some of the most commonly used parameters is given below :

- Solids are determined by gravimetric method.
- Chloride is estimated by argentometric method in the form of silver chloride.
- Acidity/Alkalinity is determined by titrimetric method using phenolphthalein and methyl orange indicators.
- Total hardness and calcium hardness are determined by EDTA titrimetric method while magnesium hardness is calculate be deducting calcium hardness from total hardness. Calcium (as Ca++) may be calculated by multiplying calcium hardness with .401 while magnesium (as Mg++) by multiplying magnesium hardness with 0.243.
- Nitrogen in the form of ammonia, nitrate and nitrite is determined by using ion-specific electrodes or spectrometric methods.
- Sodium and potassium are determined by flame-emission method using flame photometer or by atomic absorption spectrometry.
- Phosphate is estimated by Stannous chloride method in the form of molybdenum blue while sulphate by turbidimetric method in the form of barium sulphate crystals.
- Trace elements are determined by atomic absorption or atomic emission methods.

REMOTE SENSING APPLICATION IN LAKE STUDY

Some of the hydrological aspects of the lake can be analyzed through remote sensing techniques. Remote sensing has certain advantages in identifying sources of water pollution, dispersion and dilution pattern in a water body. Remote sensing data are the measure of reflectance or emitted energy from the surface or near surface of water bodies such as lake. Various Remote Sensing missions provide data from variety of sensors operating in different region of electromagnetic radiation (EMR). Remote sensing data from satellite is based on interaction of EMR from sun with various surface features, which interact in different fashion with the incident EMR and hence give rise to contrast in the remotely sensed data.

Satellite images of water bodies readily reflect turbidity, which is caused by high concentration of algae, silt, and other suspended materials in water. Remote sensing of reflected solar radiation provide timely and repeated information regarding flow pattern of suspended sediments in lakes. The impreciseness of turbidity as a water quality indicator is based on the light attenuation in water by suspended sediment and organic material. Turbidity estimated from satellite data are useful for tracking the movement of water masses within large lake.

Due to the strong contrast between water and surrounding surface afforded by satellite reflective infrared observation, mapping and monitoring of surface water spread of lakes can be obtained with very good degree of accuracy. In reflective infrared region, incident radiation is absorbed by water where as surrounding land and vegetation reflect. Because of this phenomena, surface water appears black on reflective infrared images and digital mean values are lower than the surrounding land features. Application of remote sensing technique in the study of lakes is mentioned below.

Identification of lake catchment and water surface area

The boundary and map of the lake catchment area can be digitized using the digitizer. Further using any geographic information system software, the lake and its surrounding catchment area can be classified into fine classes viz. forest, water body, barren area, shadow & built-up area using supervised classification approach. Other analysis particularly in relation to water quality aspects e.g. extent of algae can also be planned using the satellite data.

Estimation of suspended solids

Conventional methods for the measurement of suspended load and pollutants both in situ and in the laboratory are expensive relative to the use of remotely sensed data. Satellite borne sensors have the capability of providing repetitive, low cost multi spectral coverage over wide areas and the potential to monitor the water quality. Shorter wavelength bands of a visible region are very useful for the quantification of suspended solids in reservoirs. These shorter wavelengths (0.4 to 0.7 um) bands are available in Landsat TM and in IRS-1A (Indian Remote Sensing Satellite -1A) sensors. Studies using IRS-1A data have been reported in literature (Chaubey & Subramanium, 1991) for estimating the concentration of suspended solids in a reservoir.

Methodology

Field Work

For the evaluation of ground truth and their correlation with remotely sensed data, water samples should be taken from the lakes in study on the day of pass of sensors over the area. In order to obtain the desired depth (water clarity depth) of sample point, a Seichie disc should be used to measure the depth at which the disc would be invisible. Water samples should be collected with the help of a depth sampler to determine the sediment concentration.

Laboratory Work

Water sample is filtered through membrane filter papers to estimate the total suspended matters. Suspended sediments of at least five water samples representing various reaches of the lake should be selected for bulk mineralogy.

Satellite Data.

IRS-1A, LISS-I (Linear Image Scanner System) geometrically corrected CCTS (Computer compatible tapes) and digital data for the lakes in the study can be procured from the National Remote Sensing Agency, Hyderabad. The image analysis can be done using the Digitizer and GIS software. The land and water interface is identified by band 4 and masked so that only water is analyzed. In general, Bands 1, 2 and 3 (0.45 to 0.68 um) of the visible region exhibit substantial grey level variation across a reservoir surface. This grey level variation, which is related to reflected energy detected by LISS-I is highly correlated with the suspended solids pattern in the lake surface water. This high correlation is due to scattering from suspended solids (primarily suspended sediment). Band 1 and 2 shows poor correlation beyond 40 ppm which indicates that they are useful for relatively clear water. The reflected solar radiation from water surface changes with the amount of suspended solids and wavelengths. The lower wavelength ranges 0.45 to 0.59 um (Band 1 and 2) does not show linearity with suspended solids beyond 40 ppm. However, as the concentration increases, the response value also increases. As the wavelength range advances from 0.45 to 0.68 um, the change in response value with change in suspended solids concentration exhibits more and more of a regular pattern.

In the concentration range between 10-50 ppm, a positive functional relation exists between the concentration of suspended solids and the visible wavelength Bands 1,2 and 3 (0.45 to 0.86 um).

Briefly, Remote Sensing Techniques can also be used for the following :

- Variation of lake water volume.
- Changes in water quality of lakes.
- Growth of algae in lakes.
- Surface inflow and outflow of the lakes.

ISOTOPE TECHNIQUES FOR LAKE STUDIES

The use of isotopes as a tool to obtain various useful hydrological information is well known among the scientific and engineering community. Nuclear models are being used in the field of hydrology for the last 50 years. In the beginning, the use of radioisotopes was more popular and even in vogue but, in the present days, due to various specific problems, the user try to employ as much as possible, the application of the environmental isotopes, mostly stable isotopes which are priceless and harmless to human being.

Basically the isotope techniques are based on two basic properties of isotopes i.e the ability to be detected in very low concentrations and their vulnerability to variations in their concentration/intensity when influenced by various natural processes or attenuated when interact with various media.

Isotopes

An isotope is the atom of an element having same atomic number but different atomic weight. The weight of an atom is denoted by symbol 'A' while atomic number by `Z'. For example, Hydrogen, Oxygen and Carbon posses three isotopes each. i.e.

^{1}H	-	Normal atom of Hydrogen with atomic number (Z) =1 and atomic weight (A) = 1.
^{2}H	-	Known as Deuterium, a stable isotope with Z = 1 and A = 2.
^{3}H	-	Known as Tritium - a radioactive isotope with z = 1 and A=3
^{16}O	-	Normal atom of oxygen with Z = 8 and A = 16.
^{17}O	-	A stable isotope of oxygen with Z = 8 and A = 17.
^{18}O	-	A stable isotope of oxygen with Z = 8 and A = 18.
^{12}C	-	Normal carbon atom with Z = 6 and A = 12.
^{13}C	-	A stable isotope of carbon with Z = 6 and A = 13.
^{14}C	-	A radioactive isotope of carbon with Z = 6 and A = 14.

Isotopes can be broadly divided into two categories. One is radioisotope (unstable) and the other is stable isotope. Radioisotopes emit alpha and beta particles and gamma radiations during their transformations from unstable to stable form. The alpha particle is doubly ionized helium atom and owing to its mass of 4, it is comparatively quiet heavy. Its penetration power is very less and is of no direct use. The beta particle is an electron ejected from the nucleus with an energy ranges from few keV to MeV, are of great use for various hydrological investigations. The gamma radiations have large penetration power and therefore can be used as an important tool for various important hydrological investigations. Many atoms also emit the neutrons when particles from other atoms are interacted. Therefore, two elements are used (Ra/Be, Am/Be etc.) to get the neutron particles which are also used as a tool for the study of soil moisture conditions.

Because of being radioactive in nature, these radioisotopes pose a threat to the human beings if they are exposed to the radiation beyond certain limit. However, the stable isotope, as they do not radiate any types of radiations, are quiet safe and can be used without any fear and concern. Nevertheless, the radioactive isotopes are harmful but they can be detected with comparatively easy and cheaper instruments while very costly instruments are required for the measurement of stable isotopes. However, because of being harmless in nature and the field work can be done by unskilled as well as skilled persons, the use of stable isotopes in hydrological investigation is increasing day by day with the increase in the facilities for their measurements at various laboratories in India too. Isotopes can also be categorized as natural and artificial isotopes. Natural isotopes can be further grouped into environmental and primordial isotopes. Environmental isotopes are further divided into two categories, i.e. radioactive and stable in nature.

Environmental isotopes

Environmental isotopes can be defined as those isotopes, both stable and radioactive (unstable) which occur in atmosphere/ environment in varying concentrations with respect to time and place over which the investigator has no direct control. The most commonly used environmental stable isotopes are Deuterium, Oxygen-18, Carbon-13. Radioisotopes such as Tritium (^3H) and Carbon-14, Silicon-32, Cs-137 and Pb-210 etc. are also used as environmental isotopes for few specific studies in hydrology. ^{32}Si is potentially attractive because its half life is in between that of ^3H and ^{14}C. Argon-39 has also been investigated and research is still in progress but the disadvantage of using both Si-32 and Argon-39 is that very large amount of water sample (a few tones) is required to make measurement.

Application of isotopes in lake study

Identification of recharge zones/sources in lake catchment area using stable isotopes

The ground water originates as precipitation. Therefore, the amount of recharge to ground water system is related to storage capacity of a system and thus determines the maximum available resources for exploitation. However, in many cases, the recharge and water flow are rather complex and more information of the actual process is desirable. The environmental isotopic methods provide a valuable approach to understand these complex phenomena as well as to test the validity of the alternative hypothesis.

Determination of water balances of lakes

Different parameters of water balance equation can be determined by using isotope techniques.

Study of hydrodynamics of lakes

Use of isotopes for study of hydrodynamics of lakes is possible.

Determination of sedimentation in lakes

Isotopes techniques are very much useful for determining the rate of sedimentation in a lake, either suspended or bed load sediments.

Determination of age and state of lakes

Radioactive as well environmental isotopes in a lake can provide very authentic information on the age and state of lake, the source of impurity etc.

Study of water quality of lakes

Periodic determination of concentration of different isotopes in lake may help in monitoring the water quality of the lake.

EQUIPMENT FOR LAKE STUDIES

Different types of equipment required for detailed investigation of a lake are mentioned in Table 1.

LAKES OF INDIA

Water in rivers and lakes amount to be about 1% of the water budget but its importance to life and human geography is enormous. It is estimated that the world's lakes contain about four times fresh water than its river. Lakes are used extensively by people in many countries as the natural centers of civilization. Following the world trend lakes have been the first priority of available natural resources for development of civilization. In India, even during Maurya period (320 BC) a major reservoir called Sudarshana lake was made at the foot of Mount Girnar in Western India (Winderlich et al., 1987). In India the lakes have been extensively utilized resulting in overexploitation.

Problems of Indian Lakes

In India, during recent years due to alteration of landscape by denuding forests, urbanization including tourist's traffic and waste discharge in the lakes, sedimentation eutrophication of lake water have increased. Even many high altitude lakes in Kashmir and in Garhwal Himalayas, which have remained clean and without eutrophication for centuries, are showing signs of deterioration. The famous Dal Lake of Kashmir, which was about 40 km^2. in the beginning of nineteenth century is presently at about 20 km^2. Almost half of Lake Renuka (Water spread of 670 Ha), the biggest lake of Himachal Pradesh in the lesser altitude of Siwaliks of Himalyan region is filled up with sedimentation. Things are much worst in the plains or in peninsular India. Upper Lake in Bhopal, Poondi, Red Hills in Madras and Osmansagar in Hyderabad, sources of drinking water for their cities have shrunk considerably in the recent past causing great hardship to the city dwellers. Not only that, in many cases lakes of smaller sizes located in the urban areas are used as a dumping spot of wastes, both solid and liquid, due to which the temperature structure of the lake changes. As a result, many lakes in India are experiencing the problem of eutrophication. Occurrence of inorganic nutrients in water and the resulting increase in plant productivity has become a serious water quality consideration all over the country.

In India, natural and/or manmade changes in storage of lakes, both in quality and quantity of water, have altered not only the stream flow regime but also the water balance of the region. Alteration of flow regime and quality of lake water, a common problem faced everywhere, arising from increase in demand and developmental activities, are resulting in the hampering of activities supported by these lakes. There are also side effects of ecological imbalances in the region. Impact of degradation is less in the initial stage but the cumulative impact in longer period proves to be deleterious. In many cases, if the state of the problems and their remedial measures is not looked into, it would be difficult to save the lakes and therefore, the adjoining area from economical, hydrological, and environmental disasters.

In national perspective, the most important ecological problems connected with lakes are;

- Lowering of level due to over use of water as a result of decreasing rainfall in the catchment.
- Rapid siltation caused by accelerated soil erosion.
- Pesticides and toxic chemicals being brought through surface inflow flow.
- Eutrophication.
- Disintegration of aquatic system.

Status of study of Indian Lakes

Study carried out so far in India before and after independence mainly with ecological, environmental, socio-economic and limnological aspects of lakes located in various corners of the country. Many Government, Semi-Governmental, Voluntary Organizations, Universities and Institutes are engaged for extending study of India's Lakes. Due to topographic and geological variations, there are numbers of lakes of different sizes located in various regions of the country. The exact statistics of number of lakes have not yet been assessed. A national inventory of lakes titled " The All-India Wetland Survey" established by the Government of India initiated a study as long as the late 1960s and could only be able to give a broad assessment of wetland areas in the country in 1984.

Lakes either small or large in size, depending upon their depth of water available and purpose of uses, are known by different names in different parts of the country like, Jheels, Bheels, Marshes and Tank etc. Lakes may be called by different names in the region, however the purpose for which they are being used or are providing services and problems faced by them are identical in nature.

Statistics of Indian Lakes and studies undertaken on Indian Lakes

The statistics of lake water resources in India are scarce. Research conducted after 1947 addressed the ecological, environmental, socio-economic and limnological aspects of lakes. Comprehensive statistics of number of lakes have not yet been assessed. A national inventory of lakes entitled " The All-India Wetland Survey" established by the Government of India initiated a study during 1960s and could only be able to give a broad assessment of wetlands in the country by 1984.

Depending upon the depth of water and uses, the lakes are known by different names in different parts of the country like, Jheels, Bheels, Marshes, Talab and Tank.

Organizations Involved in Study of Lakes of India

Various organizations in leading role to study the ecological, limnological and hydrological aspects of lakes are:

Governmental Organizations

(i) Ministry of Environment and Forests
(ii) Planning Commission
(iii) Ministry of Water Resources
(iv) Ministry of Agriculture
(v) Indian Board for Wildlife
(vi) Forest Research Institute
(vii) Ganga Water Authority
(viii) Institute of Wetland Management and Ecological Design
(ix) Environmental Monitoring Organizations
(x) National Eco-Development Board
(xi) National Institute of Oceanography in Goa

Non-Governmental Organizations

(i) Bombay, Natural History Society
(ii) WWF - India
(iii) UNDP/UNESCO
(iv) French Institute, (Pondichery)
(v) Ecological Society, (Pune)
(vi) Wildlife Preservation Society of India (Dehradun)
(vii) Tourism and Wildlife Society of India (Jaipur)
(viii) Assam Valley Wildlife Society (Guwahati)

Academic Institutions

(i) Andhra University, Visakapatnam
(ii) Annamalai University, Annamalai (Tamil Nadu)
(iii) Barkatullah University, Bhopal
(iv) D.N.R. College, Bhimavaran
(v) Guwahati University, Assam
(vi) Jawaharlal Nehru University, New Delhi
(vii) University of Jodhpur, Jodhpur
(viii) University of Kashmir, Srinagar
(ix) Osmania University, Hyderabad
(x) University of Rajasthan, Udaipur
(xi) Indian Institute of Technology, Roorkee
(xii) Saurastha University, Saurastha
(xiii) Pondichery University, Pondichery

National Institute of Hydrology is the only institute engaged in hydrological studies of lakes through its headquarters at Roorkee and also through its Regional Centers at Jammu, Patna, Guwahati, Belgaum, Kakinada, and Sagar.

Existing gaps in the study of lakes

Like problems in different sphere of Science and Engineering, many problems of lakes these days are solved with the help of models in which the analytical solutions involving several parameters and their combinations are put into algorithms. In fact, the main reasons for applying the model approach is to simplify the analytical work, though a variety of alternatives based on variable inputs of all types. Therefore the choice of suitable model should correspond with the information available for bringing out solution to the problem.

Outside India, numerous lake models have been developed for lake management and are today available to solve all spheres of lake hydrology problems. But these models are site specific. Mathematical modeling in lake management at present covers a broad range of techniques, from alogrithmized simple analytical formulae to advanced numerical schemes. Each of these models has its place in lake water management. New model approaches are being examined all over the world and new models have been set up. The amount of data available for any particular solution is rapidly increasing resulting in improved ability to identify complicated processes of lakes and facilitating the setting-up of increasingly sophisticated models. In India due to lack of detailed hydrological investigations of any lake, model for any lake has not been developed, though development of model for some of the lakes mentioned in the earlier sections is in progress.

Studies to be taken for Indian Lakes

In India, since long time attention is being paid only on research studies on limnology. Study on hydrological and/or thermal aspects of lakes still remain an unexploited field. A need is felt wherein different aspects of lake processes such as general hydrological description of lakes including water balance of lakes, sedimentation in lakes, hydrodynamics of lakes thermodynamics of lakes, interaction of lakes with the environment, influence of lakes due to stream flow, lake water interaction with the ground water & seepage and sedimentation in lakes etc. should be given due weightage in lake study. This will be for better and proper management of the lake water resources and answer to local problems the lakes are facing these days.

India is still a developing country in which most of the mass of population still depends upon the natural resources for fulfillment of most of their requirement. Lakes being the foremost in the natural resources utilized widely much attention should be given first to the deteriorating water quality of the lakes. For this purpose, any lake study should first concentrate on monitoring water quality of the lake. For each lake in India, a Lake Authority should be constituted. Lake Authority who will be responsible for conservation, development, management and sustainable use of the lake.

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Table 1. Equipment for lake study

Mapping & Surveying Equipment	
Sr.	Particulars
1	Ultra Compact Water Resistant Pam Sized GPS Receiver along with waterproof GPS Pouch
2	**GPS Co-ordinate Locator**
3	GPS based chart plotter
4	Hand Held Track Plotter
5	Opti-Logic Laser Range Finder
6	Optic-Logic Laser Hypsometers (Heights, distance and angles)
7	Electronic Altimeter (Chart altitude, barometric pressure, temperature, or forecast weather with this digital altimeter/barometer)
8	Micro Surveying Altimeter
9	Electronic Clinometer
10	Way Finder Digital Compass with temperature Sensor
11	Distance Measuring Wheels
12	Omni-directional, digital distance measure
13	Binoculars
14	Electronic Digital Theodolites
15	Hand level With Brass Tube
16	Double Right Angle Prisms
17	Non Conductive Fiber Glass Telescopic Measuring Rods (50')
18	Fiber Glass Tape
19	Tape Holster/Guard
20	Linear-Roller Type Digital Plannimeter
21	Map Measure With Magnifier
22	Area Calculator
23	Surveying Umbrella and Camping Kit
24	TDS Solo Field mapping Package
25	Electronic Total Station
26	Heavy Duty Tripods
27	Data collection system with HP-48GX Calculator
28	Automatic Transit Level
29	Hydrokool Bandanna (Relief from the heat)
30	Magnetic Locator
31	Screen Scope Pro Mirror Stereoscope
32	Mobile Stands for Maps
33	Zoom and Shoot Camera
34	Stop Watch
35	Mobile Phones

Table 1. Equipment for lake study (Contd..)

Weather Equipment	
Sr.	Particulars
1	Solar Powered Weather Station having sensors for rainfall, sunshine duration, total & net radiation, max. & Min. temperature, relative humidity, evaporation, wind speed and direction, soil moisture & temp., wind erosion, e-sense data communication, data loggers for the sensors
2	3-D Pocket Weather Station
3	Electronic All Weather Total Station
4	Tipping bucket rain gauge with data logger
5	Data logger based Evaporation Sensor
6	Turbidity probe with digital display (Imported)
7	Automatic Water Level with Data Logger
8	Datalogger based Wind Corder
9	Datalogger based Thermo-Hygro Corder
10	Hygrothermograph
11	Mechanical pyranograph
12	Digital Thermohygrometer
13	Hobo Weatherproof data loggers
14	Hobo 4-Channel External Data loggers
15	Hobo Water Temp loggers
16	Hobo Optic base Station
17	Hobo Optic Shuttle
18	Software for data processing
19	Hobo Weather Station Loggers
20	Pocket Windmeter
21	Thunder Bolt Storm Detector
22	Infrared Thermometer
23	Digital Max./Min. Thermohygrometer
24	Geiger Counter/Radiation Meter

Table 1. Equipment for lake study (Contd..)

Hydrological Equipment	
1	Digital Soil Moisture, Temp. and Salinity Meters
2	Field Guide for Soil and Stratigraphic Analysis
3	Time Domain Reflectrometer
4	Hygrometer
5	Sling Pocket Psychrometer and Psychrometric Slide Rule
6	Hydroloite Water level Indicator
7	Digital Depth Sounder
8	Depth and Temperature Recorder
9	Global Water Level Loggers
10	Water Flow Calculator
11	Student Stream Flowmeter
12	Datalogger based current meter
13	Suspended Water Current Meter Kit
14	Portable Digital Depth Sounder
15	***Portable Water Level Logger***
16	Open Stream Current Velocity Meter
17	Datalogger base Infiltrometer
18	Hand Held Grain Moisture Tester
19	Soil Salinity Tester
20	Soil pH and Moisture Meter
21	Soil Compaction Meter with built-in data logger
22	Pocket Pentrometer
23	Greenhouse Soil Testing Kit (An entire lab in one small case)
24	Sand grain Sizing Folder
25	Sand gauge
26	Soil 'ID" Finder
27	Rock Color Chart
28	Geotechnical gauge
29	Soil Color Chart
30	USDA Soil Texturing Field Flow Chart
31	Mini Soil Sampling Kit
32	***Split Core Sampler and Split Auger Sampler Kit***
Groundwater Equipment	
1	Seepage Meter
2	Water Level Indicator (Sounder)

Table 1. Equipment for lake study (Contd..)

Water Quality Equipment	
Sr.	Particulars
1	Global Waste Water Sampler
2	Global Storm Water Sampler
3	Microprocessor Portable Turbidity, Soil, Conductivity, Do, Temp. Meter
4	Waterproof pH Meter
5	Water Analysis Laboratory
6	Monitor's Handbook
7	Water Quality Monitoring Outfit
8	Water Pollution Detection Kit
9	Shallow Water Test Kit
10	DO Water Sampler
11	Vertical Well Sampler
12	Portable Electronic Balance
13	Pocket magnifier
14	Soil Gas Vapor Probe (Sample soil vapor and shallow groundwater accurately)
15	Color-N-Soil PCB Screening Kit
16	Ozone Test Card Reader
17	Air Pollution Sampling Outfit
18	Sub-surface grab Sampler
19	Telescopic Dipper
20	Swing Sampler
21	Dissolved Oxygen Meter
22	Oxygen and temperature Meter
23	Fluorescent Liquid Dye Concentrate, (0.25 lbs)
24	Universal Core Head Kit Sediment Sampler
25	Shallow Water Bottom Dredge
26	Heavyweight Deep Water Bottom Dredge
27	Sludge Sampler Kit
28	Integrating Sediment Sampler
29	Sediment Core Sampler from Bottom of Lake

Table 1. Equipment for lake study (Contd..)

LIMNOLOGICAL EQUIPMENT	
Sr.	Particulars
1	Wash Bucket for Littoral Sample
2	Vertical Well Sampler
3	D.O. Water Sampler
4	Aqua Suction Sampler
5	Aqua Scope to view Sechhi Disk Reading
6	Bottom Aquatic Kik net
7	Light Meter
8	Data Logger for Light Meter
9	Limnological Weighted Secchi Discs
10	Monofilament Bait cast Net
11	Aquacrib
12	Fish Measuring Board
13	Scissor Grip Fish Tagger
14	Pond Maintenance Assistant (CD-ROM
15	How to identify and Control Water Weeds and Algae
16	Aquatic Herbicide
17	Algaecide/Herbicide
18	Lifetime Fish Combos
19	Aquatic Weed Eradicator
20	Lake rake
21	Lake Mower
22	Boat outfit with Sonar, GPS, Transducers, Data Acquisition and Processing System