Hydrological Investigations for Lake Studies

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Hydrology: Hydrology is the science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle.

Surface hydrology: Related to movement of water over the ground surface. It includes overland flow, stream flow and other processes of the hydrologic cycle related to surface water (viz., precipitation, evaporation, infiltration)are also studied.

Hydrological Cycle: The hydrologic cycle is a continuous process by which water is purified by evaporation and transported from the earth's surface (including the oceans) to the atmosphere and back to the land and oceans. All of the physical, chemical and biological processes involving water as it travels through various paths in the atmosphere, over and beneath the earth's surface and through growing plants, are of interest to those who study the hydrologic cycle. The hydrologic cycle has ten processes, as given below:

- Evaporation: Water evaporates from oceans and land surface to become part of atmosphere (water vapor).
- Precipitation: Water vapor is lifted and transported in the atmosphere until it condenses and precipitates on the land or oceans.
- Interception: Precipitated water intercepted by vegetation.
- Overland flow: Precipitated water overflowing on ground surface.
- Infiltration: Precipitated water infiltrated into ground.
- Subsurface flow: Precipitated water flowing through the soil near land surface:
- Surface runoff (stream flow): Precipitated water discharged to streams
- Recharge: Deep percolation to water table
- Groundwater flow: Movement of water table deeper in soil or rock strata
- Overflow to oceans: Surface and groundwater returning to oceans

Definition of Lake: According to Zumberge and Ayers a lake is defined as "an inland basin filled or partially filled by a water body whose surface dimensions are capable of producing a barren wave swept shore"(Chow, 1964).

Lake is an ephemeral feature of the landscape and is a dynamic system. It is because that erosion and deposition begin to destroy lakes from the moment they appear. Lakes are transitory features of the earth surface and each has a birth, life and death related to certain geological and biological processes. Their life expectancy may vary from a short spell of two floods to millions of years. Lakes are the potential source of fresh water at high altitudes. The water stored in lakes is used for fulfilling domestic, agricultural and industrial needs. Apart from these, lakes also provide water for fisheries, transport, recreation and hydroelectric power generation.

From the geologic point of view, a lake consists of two distinct parts, the basin and the water body. It is obvious that the latter could not exist without the former and both should be taken into account in any workable definition. In Finnish practice, the minimum area of a lake is considered to be 0.01 km^2. As a summary, a water body should fill the following requirements to be a lake:

(i) It should fill or partially fill a basin or several connected basins.

(ii) 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.

(iii) It should have so small an inflow to volume ratio that considerable portion of suspended sediment is captured.

(iv) It should have a size exceeding a specified area, e.g. 0.01 km^2at mean sea level.

The knowledge of hydrology of lakes is essential for their proper use and conservation and management. Lake has its hydrologic response. It has cause and effect relationship with the adjoining catchment. Because of storage of large mass of water, it moderates flood and climatic factors in the region. Also the deforestation, conversion of grassland to cropland, intensification of agricultural production, land amelioration etc. in the nearby catchment area affects the microclimatic and reduces evapo-transpiration thereby increasing runoff and rates of erosion and siltation. Accelerated nutrient cycles and faster transport of soil particles increases sedimentation rate and lead to enrichment of lake water.

Important Physico-dynamic processes involved in the study of the lakes

- Water and nutrient balance
- Thermal regime and heat balance
- Eutrophication
- Sedimentation

WATER BALANCE OF LAKES

Lake waters are used for variety of purposes including the developmental activities. For the success of these programmes a regular, timely and required supply of water is essential. This is possible only with accurate estimation of the available water at any specific time to meet these demands. Thus, water balance studies enable to plan the various uses of the lake water. Water balance studies are also prerequisite to the nutrient budgeting and hence, for quantitative assessment of the eutrophication problem. The water balance of a lake is illustrated in Fig. 1. It is basically same as the water balance of any drainage basin. It is the statement of law of conservation of mass (continuity equation). A simple water balance equation for a lake can be written as

$$\Delta S = I_s + I_u + P_l - Q_s - Q_u - E_l$$

where,

ΔS = change of water storage
I_s = surface inflow
I_u = underground inflow
P_l = lake precipitation
Q_s = surface outflow
Q_u = underground outflow
E_l = lake evaporation

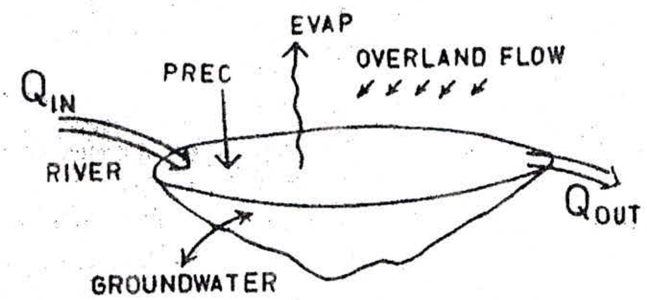


Figure 1: Water balance of a lake

Precipitation on the lake is generally not different from precipitation over the surrounding land except in case of very large lakes which affect the local climate and there by, also the precipitation on land. Thus, precipitation into a lake is usually measured by the rain-gauges located near or around the lake. Surface inflow into a lake can be subdivided into inflows from rivers and creeks and inflows from numerous small basins surrounding the lake. Part of the latter component consists of non-channelized overland flow. However, this portion is usually very small and neglected. Continuous observations of discharge should be carried out for as many inflowing rivers as possible. Surface outflow should also be measured directly. Stage discharge relationships can also be created for surface inflow and outflow. Evaporation is the most difficult component to estimate accurately. A number of methods are available to estimate lake evaporation. Energy balance method is considered to be the most accurate of all the available methods. However, estimation of energy balance terms requires intensive instrumentation, which is often not economically feasible. The most popular of the other methods are the methods based on the pan evaporation and the Penman method. The popularity of pan method is because of the fact that it is simple to use and also the data availability is generally met. However, the pan method requires locally available monthly pan coefficients. Change in lake storage can be estimated from water levels using the hypsographic curve. In the absence of hypsographic curve this term is generally estimated as residual. Groundwater components are generally neglected in lake water balance studies owing to the difficulties in their estimation. However, ground water components can be very significant in some lakes and hence, should be considered. The groundwater components can be determined by measuring ground water tables and some mapping of the lake/aquifer contact zone. Since, the water balance equation looks simple, its practical application pose many difficulties causing errors in estimation of different components. The errors in lake water balance components can be broadly classified into two groups: (i) errors of measurement and (ii) errors of regionalization. Selection of units is also important in water budgeting. If the area of the lake varies considerably as a function of water level, a volumetric unit is preferable. For lakes with a practically constant surface area, it is more convenient to express water components as the depth of a layer.

Based on water balance approach, a simple mass balance (nutrient balance) can be applied according to a continuous flow stirred tank reactor (CFSTR) model (Fig. 2a). But it is extremely complex if the effects of temperature and wind are also taken into account (Tchobanoglous and Schroeder, 1985).

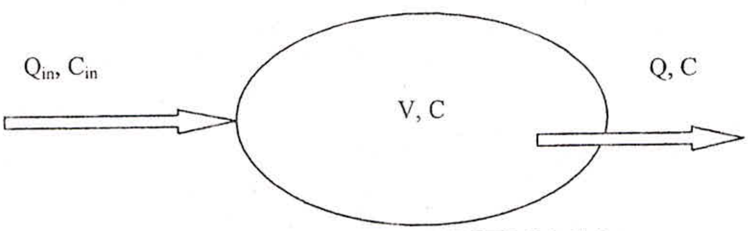


Fig. 2a: CFSTR Model

The mass balance equations for a lake can be written as:

Accumulation rate = input rate – output rate – decay rate

$$(dC/dt) * V = (Q_{in} * C_{in}) - (Q * C) - (K*C*V)$$

For steady state conditions, $Q_{in} * C_{in} = Q * C$

Heat transfer from the surface requires careful evaluation of the wind conditions and the ambient temperature variations. Convective mixing together with wind-generated mixing and stratifications make modelling very difficult. One-dimensional model work best in describing small to medium sized well-mixed water bodies, with length of the major axis less than 50 km.

Stratified and large lakes should be modelled using two or three spatial dimensions and time. Most recent modelling efforts for these utilize finite-element models for horizontal layers. Mass and energy transport between layers is described using classical hydrological approaches.

The application of CFTR model for mass balance of phosphate concentration for lake Porur (T.N.) has been shown as below (Bindhu & Mohan, 2005):

Example1: The average Phosphate-P concentration of the lake was found to be 55 μg/L, by which eutrophication has already been started. The lake receives water from the Chambrambakkom Lake at an average rate of 33 million litres per day (33 MLD). Approximately the same amount of water is being pumped daily for city water supply. The Phosphate-P concentration of the inflow was measured as 10 μg/L. If the concentration of the outflow is assumed to be the average concentration of the lake, following mass-balance can be arrived (Figure 2b).

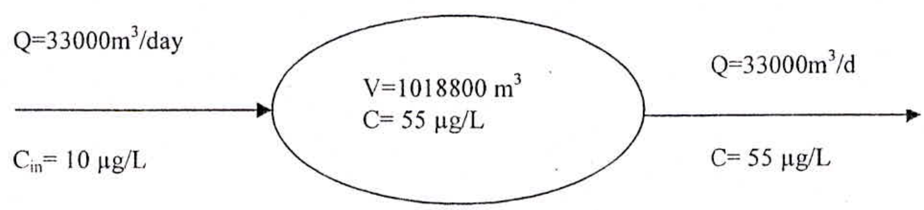


Figure 2b: Mass balance for phosphate-P

Total P in the lake = V x C = 56 kg
Daily input (by inflow) = Q x Cin = 0.33 kg
Daily output (by pumping) = Q x C= 1.815 kg
Daily accumulation in lake = 1.815 – 0.33 = 1.485 kg/day
= 542 kg/year

Thus it can be concluded that approximately 542 kg of phosphorus is being added to the lake every year through pollution. Extensive use if detergents for washing and unauthorized dumping of solid wastes on the banks of the lake are two major sources of phosphates in the lake.

Bathymetry and Morphometric Characteristics: Lake morphometry deals with the quantification and measurement of lake forms and form elements. Morphometric data are of fundamental importance in most limnological and hydrological projects. Bathymetric map of a lake is source of most morphometric data. It is constructed from hydrographic surveys conducted with echo-sounding equipment. Hydrographic surveys may be conducted with different techniques and for various purposes, e.g. to meet requirements for safe navigation. In such cases the accuracy of every detail and depth value is essential. For fishing purposes it is of interest to know the bottom roughness. For scientific purposes, in hydrological, limnological and sedimentological contexts, it is of primary interest to have a bathymetric map illustrating the general morphology of the basin as well as major topographical features.

Bathymetric survey: The range-line method is most widely used for medium to large lakes/reservoirs. Range line method usually requires relatively lesser field work and is therefore, it become less expensive than the other methods e.g. contour method. In this method, number of cross sections, called ranges, are selected to survey the lake. The most important is measurement of bed elevation at many known locations in the lake. These measurements are almost always made by measuring the water depth beneath a boat and the exact location of the boat on the lake's surface. So, two basic types of measurements are required, (i) location measurements/Sounding tracks (ii) depth measurements.

Location measurement: The basic measurement required for a lake/reservoir survey is the location of the cross sections (range line/sounding track) and points of depth measurement. It requires a base map of the lake with locations of cross section points around the lake. The location points around the lake are helpful in positioning the cross sections on the map for bathymetric survey. To get the base map of the lake along with the location of cross section points, survey of the lake surface area is to be carried out.

Plane Table Surveying, also called plane tabling, is a method of surveying in which field work and office work is done simultaneously on a plane table. The field observations are taken and recorded side by side on the sheet fixed upon the plane table and a map of the area is obtained. It is commonly employed for small and medium scale mapping. The equipment essentially needed for plane tabling is a plane table or drawing board which carries a drawing sheet and is mounted on a tripod stand and an alidade which provides line of sight and a straight graduated edge. The accessories to the plane table are a trough compass, which is used for marking the direction of the magnetic meridian on the sheet of the plane table, and a plumbing fork or U-frame with a plumb bob, used for centering the table. Besides these, the other accessories are drawing sheet, a water proof cover to protect the drawing sheet and drawing instruments like pencils, eraser and scale etc. Traversing is the main method of plane tabling and is similar to that of compass or theodolite traversing. It is used for running survey lines of a closed or open traverse. The detail may be located by offsets taken in the usual manner or by radiation or by intersection method of plane tabling. After completion of the plane table survey, surface area of the lake is determined using digital planimeter and graphic method.

Depth Measurement: The simplest way of measuring the water depth is to use a sounding weight or a pole to obtain it directly. The other method is use of sonic sounding equipment. Sounding weight can be fabricated of iron plate or angles. To determine the sedimentation rate on the basis of bathymetric survey, the shape and weight of sounding weight should be in record for future survey. Sonic sounding equipment for measurement of depth is preferred on most reservoir and lakes. The scientific depth sounding equipment currently available can be used to provide a continuous record or chart of the bottom profile. The basic components are a recorder, a transmitting and receiving transducer and a power supply. By careful calibration, a high degree of bottom profile accuracy can be maintained. The ultrasonic ecosounders are widely used for depth measurement. The principle of echo sounder is simple. An acoustic signal is sent from the transducer and is received back as an echo from the bottom. The time of travel of signal is measured and depth is calculated.

Important morphometric parameters of bathymetric surveys:

Maximum Length: Maximum length of lake is the line connecting the two most remote points on the shoreline. In regular basins this line is generally straight and concurs with the maximum effective length. It may not cross land, but it may cross islands.

Maximum Width: Maximum width of lake is defined by the straight line at a right angle to the maximum length which connects the two most remote extremities on the shoreline without crossing land. Island may be crossed.

Maximum and Mean Depth: Maximum depth (D_{max}) is the greatest known depth of the lake. Mean depth is ratio of lake volume to lake area i.e.

$$D = \frac{V}{a}$$

where, V= lake volume, m^3, a = lake area, m^2

The D-value is a most useful parameter, e.g., in models describing the productive and the trophic status of lakes.

Total Lake Area: Total lake area is area of the lake plus the area of all islands, islets and rocks within the limits of the shoreline. This area value is generally determined with a planimeter.

Volume: Volume of the lake may be determined by plotting the depth area map and the area under the curve obtained may be planimetered or otherwise measured. In another method, the area enclosed by successive pairs of depth contours are averaged and multiplied by the contour interval to yield a series of volume elements which are summed (Zumberge and Ayers, 1964).

$$V_{A1A2} = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

V_{A1A2} is volume between two adjacent depth contours, h distance apart, A_1 is the area enclosed by the upper and A_2 is area enclosed by the lower. Summation of the results of repeated successive use of the above equation will yield lake volume.

Slope: Slope of the lake basin shows pattern of lake sharpness in the bank and flatness of the lake bottom. It also reveals the pattern of sediment accumulation in different zone. Another important aspect of the study is the identification of origin of the lake. Slope of the lake basin between the adjacent depth contours and mean slope of the entire lake can be computed by using the following formula (Zumberge and Ayers, 1964).

$$S = \frac{1}{2}(C_1 + C_2)\frac{I}{A_a}$$

Where C_1 and C_2 are the lengths of the contours, I is contour interval, and A_a is area of the bottom included between the two contours.

The Hypsographic Curve - The hypsographic curve, also called the depth- area curve, is constructed by putting the depth of lake on the negative ordinate and the cumulative area of the lake on the positive abscissa. The hypsographic curve represents certain elements of the form of the basin and it may also be used in graphic determinations of the lake volume.

The Volume Curve - The volume curve illustrates the relationship between depth and volume in the same way as the hypsographic curve shows the relationship between depth and area. The cumulative volume at each depth level is given on the positive abscissa and the depth on the negative ordinate.

Important Hydrological Properties of Lake Catchments

Lake has its hydrologic response. It has cause and effect relationship with the adjoining catchment. Because of storage of large mass of water, it moderates flood and climatic factors in the region. Also the deforestation, conversion of grassland to cropland, intensification of agricultural production, land amelioration etc. in the nearby catchment area affects the microclimatic and reduces evapotranspiration thereby increasing runoff and rates of erosion and siltation. Accelerated nutrient cycles and faster transport of soil particles increases sedimentation rate and lead to enrichment of lake water. So, various physical, chemical and biological inputs manifested through the hydrology of the catchment area and affects the quality and quantity of the lake water.

To understand hydrology of a particular area, all factors which affect hydrologic cycle should be studied. Soil characteristic is one of them. The soil physico- chemical properties are required for many hydrological studies and simulation of flow process. These properties are basic input for developing an integrated watershed management program or models. Soil studies of various basins are necessary in designing of irrigation canals, and agricultural planning. In order to determine soil physico- chemical properties of a watershed, field and laboratory works are essential.

Soil Sampling: Soil Sampling is one of the most important and foremost step in collection of representative soil samples for physico-chemical analysis. Moreover the integrity of the sample must be maintained from the time of collection to the time of analysis. Undisturbed and disturbed soil samples are required in the analysis of soil for various physical parameters. The undisturbed soil samples are taken by driving ring of 53*55 mm (contents 100 cc) for determining permeability in the laboratory. For determining of bulk density and specific gravity of soil undisturbed, uncompacted soil samples should be taken using core samplers. While, disturbed soil samples are taken to determine moisture contents, porosity, water holding capacity, textural analysis and moisture retention studies using pressure plate apparatus. The depth wise soil samples to cover root zone are preferred in various studies. The field investigation to study important hydrological soil properties are given below:

(i) Infiltration: The movement of water from the surface into the soil is called infiltration. The phenomena of infiltration plays an important role in hydrologic studies as the understanding of the same enables us to estimate more effectively the amounts of runoff originating from precipitation and the results thereof can be applied more confidently to the design problems. The infiltration data is used to estimate of rainfall excess from the given precipitation so as to have an idea of the resulting flood. The infiltration characteristics of the soil is one of the dominant variables influencing irrigation. Infiltration rate is the soil characteristics determining the maximum rate at which water can enter the soil under specific conditions, including the presence of excess water. It has the dimensions of velocity. The actual rate at which water is entering the soil at any given time is termed the infiltration velocity. The rate of decrease is rapid initially and the infiltration rate tends to approach a constant value. The nearly constant rate that develops after some time has elapsed from the start of irrigation is called the *basic infiltration rate*. The typical values of basic infiltration rates for two bare soil conditions are given in Table-1. In this table, condition A is for well aggregated soils with high organic mater, open granular structure, and no evidence of surface sealing. Condition B is for poorly aggregated soils with low organic matter contents and a thin sealed layer at the surface.

Table 1. Basic Infiltration Rates for Two Bare Soil Condition (James, 1988)

Soil	Basic infiltration rate for	
	Condition A, mm/h	Condition B, mm/h
Coarse sand	19-25	8.9
Fine sands	13-19	6.4
Fine sandy loam	8.9-13	5.1
Silt loam	6.4-10.2	3.8
Clay loam	2.5-7.6	2.5

Accumulated infiltration, also called cumulative infiltration, is the total quantity of water that enters the in a given time. Infiltration rate and accumulated infiltration are the two parameters commonly used in evaluating the infiltration characteristics of soil. For design purposes, the relationship between infiltration rates and elapsed time are usually expressed by the following empirical equations:

Horton's model:

$$I=I_c+(I_0-I_c)e^{-kt} = a+be^{-kt}$$

Kostiakov's model:

$$I=bt^{-c}$$

Philip's model:

$$I= (1/2)st^{-0.5}+b = b+ct^{-0.5}$$

Green & Ampt's model:

$$I=k(1+\alpha S_c/Y)= b+c/Y$$

Where,

I= infiltration capacity, cm/hr

I_c= final constant (basic) infiltration capacity, cm/hr

I_0= initial infiltration capacity, cm/hr

Y= Cumulative infiltrated water in depth

t = elapsed time

α= porosity

s= Sorptivity as defined by Philips (1957)

S_c= Capillary suction as defined by Green & Ampt (1911)

a,b,c,k are constants used in respective infiltration models.

Under naturally, undisturbed condition in the forest, infiltration capacity is almost always high enough to preclude natural overland flow (surface runoff, in general). Occasionally under particularly intense storms, on this saturated soils, surface runoff for short distance may be observed, but such condition are rare. If the soil surface is severely disturbed, infiltration rates may suffer drastic reductions, some times to as low as zero. With varying degree of disturbance and protection, infiltration may recover to pre disturbance rate especially with adequate protection and occurrence of frost which restores permeability. Commonly used methods for determining infiltration capacity are hydrography analysis and infiltrometers studies. Infiltrometers are usually classified as rainfall simulators or flooding devices. Flooding infiltrometers are usually rings or tubes inserted in the ground. Water is applied and maintained at a constant level and observation are made on the rate of the replenishment required.

(ii) Water Holding Capacity: The water holding capacity of soil depends upon the physical and chemical nature of it. When the soil is absolutely saturated with water, so that water fills all the pores between the particles of soil and there is no air space (as in case of aquatic sediments), the soil is said to be at its maximum water holding capacity or saturation. The tension of water at saturation capacity is almost zero and it is equal to free water surface. It can be calculated using following formula:

$$WHC\ (\%) = \frac{(W_2-W_1)-(W_1-W_0)}{(W_1-W_0)} * 100$$

Where, WHC is water holding capacity; W_0 is weight of empty box (g); W_1 is weight of box with dried soil (g); W_2 is weight of box with water saturated soil (g).

(iii) Dry Bulk Density: The dry bulk density of the soil is defined as the dry weight of a unit volume of it, and is expressed as g/cm^3. Normally the bulk density ranges from 1.1 to 1.5 g/cm^3 for medium to fine textured soil and from 1.2 to 1.65 g/cm^3 for coarse textured soil, but its is slightly higher in case of alkaline saline soils. The soils with high bulk density are inhibitive to root penetration, and have low permeability and infiltration. The bulk density is inversely related to pore space of soil.

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Weight of soil (g)}}{\text{Volume of soil (g)}}$$

(iv) Moisture Content: Among most frequently determine soil characteristics is water content and is defined as the ratio of weight of water to weight of soil in a given mass of soil. The water content is generally expressed as a percentage and it may also be expressed as a fraction. In this study, the moisture content was determined using oven drying method.

The undisturbed samples were collected and weighed, w, at site and brought to soil laboratory in plastic covers, collected soil were kept in a oven (105^0-110^0 C) for about 24 hours so that it become perfectly dry. Its dry weight, wd, is then measured and water content is calculated from below equation:

$$M.C\ (\%\ db) = [(w-wd)/(wd)]*100$$

(v) Particle Size Distribution: The relative proportion of sand, silt and clay determines the soil texture. The percentage of various sizes of particles in a given dry soil sample is found by a particle size analysis or mechanical analysis. By mechanical analysis is meant the separation of a soil into its different size fractions. The mechanical analysis is performed in two stages: (a) sieve analysis, and (b) sedimentation analysis or wet mechanical analysis. The first stage is meant for coarse grained soils only, while the second stage is performed for fine grained soils. In general a soil samples may contain both coarse grained particles as well as fine particles, and hence both the stages of mechanical analysis may be necessary.

The textural analysis is performed for disturbed sample oven dried and these oven dried samples of soil is separated into two fraction by sieving it through a 4.75 mm IS sieve.

Sieving should be performed on the soil sample passing through 4.75 mm IS sieve by arranging largest aperture sieve at the top and the smallest aperture sieve at the bottom. The sieves used for fine sieve analysis are: 2 mm, 1 mm, 600, 425, 300, 212, 150 and 75 micron IS sieves. A receiver is kept at the bottom and a cover is kept at the top of the whole assembly. The proportion of the soil sample retained on each sieve is weighed and the percentage is calculated on the basis of total weight of dried soil sample taken.

The material passing through 75 micron sieve is used for sedimentation analysis using hydrometer. The results of particle size analysis using both fine sieve analysis as well as hydrometer analysis are plotted to get a particle size distribution curve with the percent finer (N %) as the ordinate and the particle diameter as the abscissa with the diameter being plotted on a log arithmetic scale. Fig.3 presents the textural classification chart for 12 main textural classes. In Fig.4, the dotted lines indicate the method of determining the textural class of a soil containing 18% clay, 36% silt and 46% sand. The three lines join at a point A which lies within the class 'loam'.

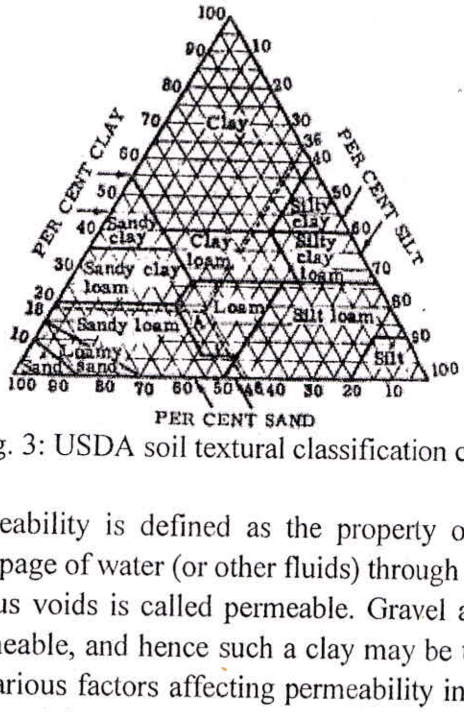


Fig. 3: USDA soil textural classification chart.

(vi) Permeability: Permeability is defined as the property of a coarse material which permits the passage or seepage of water (or other fluids) through its interconnecting voids. A material having continuous voids is called permeable. Gravel are highly permeable while stiff clay is the least permeable, and hence such a clay may be termed impermeable for all practical purposes. The various factors affecting permeability include grain size, properties of the pore fluid, void ratio of the soil structural arrangement of the soil particles, entrapped air, and foreign matters, adsorbed water in clay soils. The qualitative relation of permeability and texture of soils is given in Table 2. Darcy showed experimentally that the rate of water q flowing through soil of cross - sectional area A was proportional to the imposed gradient i or

$$q/A \sim i, \text{ then } \quad q = kiA$$

The coefficient of permeability has been called " Darcy's coefficient of permeability" or "coefficient of permeability" or permeability or even hydraulic conductivity. The study of seepage of water through soils is important for the engineering problems involving flow of water through soils such as seepage under dams, the squeezing out of water from a soil by the application of load, and drainage of sub grades, dams, and back fills. The effective strength of the soil is often controlled by its permeability. The coefficient of permeability can be determined by the following method:

(a) Laboratory methods:

(i) Constant head permeability test.
(ii) Falling head permeability test.

Permeability can be determined in the laboratory by direct measurement with the help of ICW Laboratory permeameter, by allowing water to flow through soil sample either under constant head or under variable head. Permeability can also be determined directly by field test using In-situ Guelph Permeameter. In laboratory, most common method for determining the permeability is ICW laboratory permeameter, which is constant head type equipment. For this, undisturbed soil samples are collected from field by driving a stainless steel cylinder of size 53*55 mm (content 100 cc) and collected soil samples are brought to laboratory. Top and bottom of the ring sample were checked to determine whether they have not been sealed up. Spot seals are removed by taking away tiny particles with the point of a knife, so that pores and root passage are reopened and it should be kept in a water basin for two days, the water level in the basin must remain approx. 1 cm below the top of the sample ring. K-factor can be expressed with a formula in ICW Lab Permeameter as below:

$$K=144(Q.L)/(h.F1)$$

Where,

K, coefficient of permeability in m/day
Q, quantity of through-flowing water per unit time (cm^3/min)
L, length of the sample (m)
h, level difference inside/outside the ring or ring holder (m)
F1, area of cross section of the soil sample (cm^2)

Table 2. Textural Classes of Soils and Permeability

General Texture	Textural Classes	Permeability
Clayey (Heavy)	Clay	Very Slowly
	Silty Clay	
	Sandy Clay	

Moderately Clayey	Silty Clay Loam	Slowly
	Clay Loam	
Loamy (medium)	Sandy Clay Loam	Moderately
	Silt Loam	
	Loam	
	Very Fine Sandy Loam	
Sandy (light)	Fine Sandy Loam	Rapidly
	Sandy Loam	
	Loamy Fine Sand	
Very Sandy	Loamy Sand	Very Rapidly
	Fine Sand	
	Sand	

THERMAL BEHAVIOR OF LAKES

Most aquatic organisms are cold-blooded, meaning they are unable to internally regulate their core body temperature. Therefore, temperature exerts a major influence on the biological activity and growth of aquatic organisms. To a point, the higher the water temperature, the greater the biological activity. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have preferred temperature ranges. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are few, or none. For example, we would generally not expect to find a thriving trout fishery in ponds or shallow lakes because the water is too warm throughout the ice-free season. Changes in the growth rates of cold-blooded aquatic organisms and many biochemical reaction rates can often be approximated by this rule, which predicts that growth rate will double if temperature increases by 10°C (18°F) within their "preferred" range.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen that cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures. Temperature is reported in degrees on the Celsius temperature scale (C).
The most obvious reason for temperature change in lakes is the change in seasonal air temperature. Daily variation also may occur, especially in the surface layers, which are warm during the day and cool at night. In deeper lakes (typically greater than 5 m for small lakes and 10 m for larger ones) during summer, the water separates into layers of distinctly different density caused by differences in temperature. Unlike all other fluids, however, as water approaches its freezing point and cools below 4°C, the opposite effect occurs and its density then begins to decrease until it freezes at 0°C (32°F). This is why ice floats. This process is called thermal stratification. The sun warms the surface water,

but the bottom of the lake remains cold. You can feel this difference when diving into a lake. Once the stratification develops, it tends to persist until the air temperature cools again in fall. Because the layers don't mix, they develop different physical and chemical characteristics. For example, dissolved oxygen concentration, pH, nutrient concentrations, and species of aquatic life in the upper layer can be quite different from those in the lower layer. It is almost like having two separate lakes. The most profound difference is usually seen in the oxygen profile since the bottom layer is now isolated from the major source of oxygen to the lake - the atmosphere. A typical development of stratification has been shown in Fig. 4a&b.

When the surface water cools again in the fall to about the same temperature as the lower water, the stratification is lost and the wind can turbulently mix the two water masses together because their densities are so similar (fall turnover). A similar process also may occur during the spring as colder surface waters warm to the temperature of bottom waters and the lake mixes (spring turnover). The lake mixing associated with a turnover often corresponds with changes in many other chemical parameters that in turn affect biological communities. Watch for these changes in your lake this fall and spring. Because light deceases exponentially with depth in the water column, the sun can heat a greater proportion of the water in a shallow lake than in a deep lake and so a shallow lake can warm up faster and to a higher temperature. Lake temperature also is affected by the size and temperature of inflows (e.g., a stream during snowmelt, or springs or a lowland creek) and by how quickly water flushes through the lake. Even a shallow lake may remain cool if fed by a comparatively large, cold stream. (http://lakeaccess.org/russ/temperature.htm).

Fig. 4a. Thermal Stratification

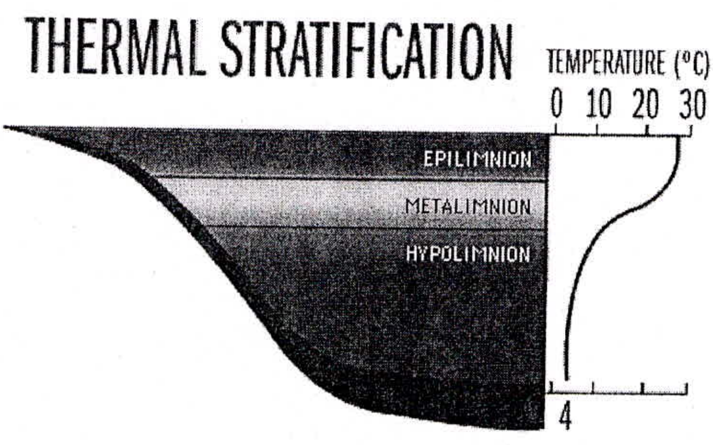
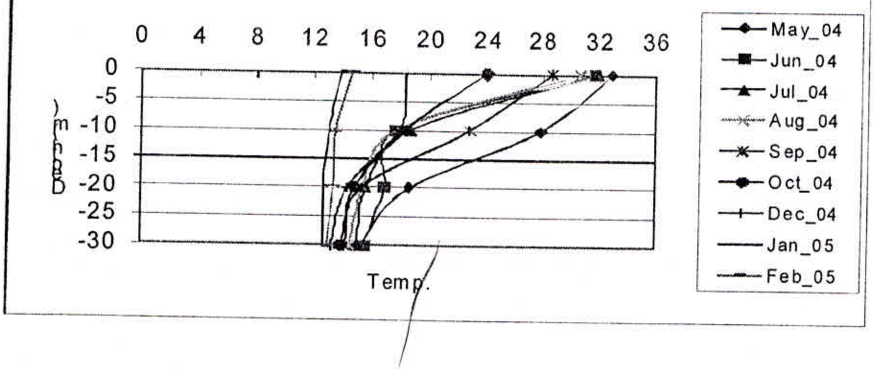


Fig. 4b: Depthwise monthly variation of Temperature in the Mansar lake (J&K)



EUTROPHICATION OF LAKES

Natural lakes are formed due to some geological process which creates a depression, which is latter filled with water to become a lake. In case of reservoirs, these depressions are artificially created by damming a river valley. At birth, all lakes are deficient in nutrients and hence, are unable to support aquatic life. However, since lakes, both manmade and natural, are bodies of standing waters, the relative lack of motion of the lake water makes their basin (the depression that is filled with water), a sediment trap. Thus, sediments and other material brought with the inflow gets accumulated in them. Sedimentation fills the lakes, slowly turning them first into ponds and swamps and then into marshy lands and ultimately into terrestrial systems causing their extinction. Thus, after their formation, with passage of time nutrients brought by sediments from the catchment and from other sources, get accumulated in them and their productivity increases. Through bacterial and other decompositions of the sediments, the water bodies become further rich in nutrients on which phytoplankton thrive. With increase in phytoplankton and food supply, the zooplankton and other forms of animals also increase. Thus, there is an overall increase in the species diversity and biological productivity. This process is called eutrophication. It, thus describes the biological effects of an increase in concentration of plant nutrients on lakes manifested through the excessive growth of aquatic plants, both attached and planktonic to levels that are considered to be an interference with desirable water uses. Three general designations of productivity are used for lakes. Lakes with low productivity are called oligotrophic, those with intermediate productivity are called mesotrophic and the ones with high productivity levels are referred to as eutrophic.

Trophic state determination is an important aspect of lake surveys. Trophic state is not the same thing as water quality, but trophic state certainly is one aspect of water quality. Trophic State is a measure of the degree of plant material in of a body of water. It is usually measured using one of several indices (TSI) of algal weight (biomass): water transparency (Secchi Depth), algal chlorophyll, and total phosphorus. The TSI values of Carlson (1977) range from less than 0 to greater than 100, where each 10 units represents a doubling in Transparency or a halving of Total Phosphorus. TSI limits to classical trophic state terminology are (Table 3a):

Table 3a: TSI Limits of Trophic Condition

Trophic Condition	TSI Limits
Ultra-Oligotrophy	0-20
Oligotrophy	20-40
Mesotrophy	40-50
Eutrophy	50-70
Hypereutrophy	>70

In accordance with the definition of trophic state given above, the trophic state index (TSI) of Carlson (1977) uses algal biomass as the basis for trophic state classification. Three variables, chlorophyll pigments, Secchi depth, and total phosphorus, independently estimate algal biomass.

Calculating the TSI: The index is relatively simple to calculate and to use. Three equations are used: Secchi disk, TSI (SD); chlorophyll pigments, TSI (CHL); and total phosphorus, TSI(TP). The simplified equations are below:

$$\mathbf{TSI\ (SD) = 60 - 14.41\ ln\ (SD)}$$

$$\mathbf{TSI\ (CHL) = 9.81\ ln\ (CHL) + 30.6}$$

$$\mathbf{TSI\ (TP) = 14.42\ ln\ (TP) + 4.15}$$

The units for chlorophyll (CHL), Secchi Depth (SD) and TP are same as given in Table-3b.

Other TSI Indices

Nitrogen: Other indices have been constructed to be used with the basic three. Since nitrogen limitation still classifies a lake along Naumann's nutrient axis, the effect of nitrogen limitation can be estimated by having a companion index to the Total Phosphorus TSI. Such an index was constructed by Kratzer and Brezonik (1981) using data from the National Eutrophication Survey on Florida lakes. This index is calculated using the formula:

$$\text{TSI (TN)} = 54.45 + 14.43 \ln (\text{TN}), \text{ Nitrogen in mg/L}$$

Macrophytes: The TSI in its present form is based solely on algal biomass. It is therefore blind to macrophyte biomass and may, therefore, underestimate the trophic state of macrophyte-dominated lakes. This is a serious drawback that needs to be addressed. The solution could be very simple. Canfield *et al.* (1983) proposed a method to measure the total phosphorus content of lakes. The total macrophyte biomass in the lake is estimated by the equation:

$$\text{TSMB} = \text{SA} \times \text{C} \times \text{B}$$

TSMB = total submersed macrophyte biomass, SA = lake surface area, C = percent cover of submersed aquatic macrophytes, and B = average biomass collected with a sampler.

Relating Trophic State to the State of the Water body

Any trophic state index gains value when it can be correlated with specific events within a water body. Below is a table of attributes that could be expected in a north temperate lake at various TSI values. Some characteristics, such as hypolimnetic oxygen or fisheries may be expected to vary with latitude and altitude and the table may not place these changes in the proper TSI category.

Table-3b: A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl (ug/L)	SD (m)	TP (ug/L)	Attributes	Water Supply	Fisheries & Recreation
<30	<0.95	>8	<6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic		Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	7.3-20	2-1	24-48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible		Warm-water fisheries only. Bass may dominate.

60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes		
>80	>155	<0.25	192-384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible

CONTROL AND MANAGEMENT OF EUTROPHICATION

The need to manage and restore the culturally eutrophic lakes has mainly arisen to avoid the untimely death of lakes. 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.

Most eutrophication control and management efforts so far have been concentrated on limiting, diverting, or treating the excessive nutrient, organic, and silt loads as the first most obvious step toward protection and restoration of a lake. In some lakes, where it is not economical to use them or where they are insufficient to produce immediate and long lasting improvements due to internal recycling of nutrients, techniques to manipulate or alter one or more internal chemical, biological, or physical processes or conditions, have been tried to restore or rehabilitate the water bodies. Thus, eutrophication control techniques can be broadly categorized as those involving the control of external phosphorous load and in-lake eutrophication control methods. Control of external phosphorous load deals with controlling the major sources of phosphorous in the drainage basin, before the nutrients reach the lakes. Various techniques to achieve this include phosphate elimination by chemical precipitation using aluminum or iron salts or lime during the sewage treatment process; restriction of detergent phosphates; and controlling land use changes. Other methods involve the treatment of influent water by techniques like construction of pre-reservoirs; physical or chemical treatment of the influent tributary before reaching the lake by flocculation; direct addition of phosphorous - precipitating chemicals such as iron salts to the influent waters; and filtration of tributary water through an aluminum oxide filter (activated alumina columns). External phosphorous can also be controlled by simply diversion of the wastewater without any treatment, in case of localized point sources. This may, however, give a temporary solution and carry the problem to some other location. Another method is the use of seepage trench.

Unlike the direct methods which control the basic cause of eutrophication, the in-lake eutrophication control methods deal with control and manipulation of the nutrients within the lakes. Although these methods are less effective compared to the direct methods and hence, may be needed to be repeatedly applied, they are however, relatively economical (Clasen et al., 1989).

The major in-lake eutrophication control methods include:

- Nutrient inactivation through direct addition of phosphorous precipitating chemicals to lakes;
- Flushing of lake water;
- Hypolimnetic aeration;
- Artificial circulation;
- Selective withdrawal of hypolimnetic water;
- Lake level drawdown;
- Covering bottom sediments;
- Dredging;
- Harvesting of macrophytes;
- Bio-manipulation and
- Use of algaecide (eg. copper sulphate) or herbicide

As has been mentioned earlier, a lake may have a considerable non point source of nutrient as well. For the control of non point source of nutrients, the suggested method is the construction of wetlands around lakes, at or near the mouth of inflowing river (Mitsch, 1994).

All these techniques of in-lake eutrophication control have been developed to treat different symptoms, although control of excess algae is more or less a common goal. For example hypolimnetic aeration and artificial circulation are done to control foul odours, fish kill and algal blooms. Algaecides is used to control toxic algae. Herbicides are used to control excessive growth of macrophytes. Bio-manipulation is used to control excess algae as well as macrophytes. Sediment covering helps in controlling foul odours, fish kills as well as algal blooms. Like dredging, it also helps in preventing nutrient release from sediment to lake waters (Khobragade, S.D., 2006).

Bibliography

1. Bindhu, B.K. & S. Mohan (2005). Modeling Health of a Lake: A Case Study (Urban Lakes In India: Conservation, Management And Rejuvenation", eds. Bhatia & Khobragade, 2005, NIH), M/S Anubhav Printers, Roorkee.
2. Carlson, R. E. (1977), A trophic state index for lakes. Limnology and Oceanography, 22:361- 369.
3. Chow, V. T. (1964), Hand Book of Applied Hydrology, Mc. Graw Hill Book Company.
4. Eijkelkamp Agrisearch Equipment (1985), ICW lab. parameters for determination of water permeability of soil samples, Brochure No. III/09.02/85/E, Eijkelkamp Agri. Equipment, Giesbeek, The Netherlands, pp.13.
5. Green, W. H. and Ampt, G. (1911), Studies of soil physics, part-1: The flow of air and water through soils, J. Agric. Sci., 4, pp.1-24.
6. Horton, R. E. (1940), An approach towards a physical interpretation of infiltration capacity, Soil Science Society, Amer. Proc. 5, pp. 399-417.
7. James, G. Lary (1988), Principals of Farm Irrigation Systems Design, John Wiley & Sons, New York.
8. Kratzer, C. R. and Brezonik, P. L. (1981), A Carlson type trophic state index for nitrogen in Florida lakes, Water. Res. Bull. 17, 713-715.
9. Kostiakov, A. N. (1932), On the dynamics of the coefficients of water percolation in soils and on necessity for studying it from a dynamic point of view for purpose of amelioration, Trans. of the 6th Commission, Intl. Soc. Soil Sci., Russian, pp.17-21.
10. Khobragade, S. D. (2006), Eutrophication in lakes and reservoirs, Lecture Notes of Training Course on "Water Quality and its Management" 22-26 May, 2006, Jointly organised by NIH & CSMRS, New Delhi.
11. Michael, A. M. (1990), Irrigation: Theory & Practice, Vikas Pubs. House Pvt. Ltd., New Delhi.
12. Philip, J. R. (1957), The theory of infiltration: 4, Sorptivity and algebraic infiltration equations, Soil Sci. 84, pp.257-264.
13. Rai, S. P., Kumar, V., Singh, O., Kumar, B. and Jain, S. K. (2001), Limnological Study of the Mansar Lake, Final Report (JK-SPCB Sponsored Project), NIH, WHRC, Jammu.

14. Reckhow, K. H. and Chapra, S. C. (1983), Engineering Approaches for Lake Management, Volume 1: Data analysis and empirical modelling, Butterworth Publ., Woburn, M A.
15. Soil Moisture Equipment Corporation (1983), 5&15 Bar Ceramic Plate extractors: Operating instructions: P.O. Box 30025, Santa Barbara, CA 93105, USA.
16. USDA (1954), Diagnosis and Improvement of Saline and Alkali Soils, Handbook No. 60, U.S., GPO, Washington, D.C., USA.
17. USDA (1996), National Handbook of Water Quality Monitoring, Part 600 National Water Quality Handbook, USDA, Washington, DC 20250, USA.
18. US EPA (1981b), Guidelines for Evaluation of Agricultural Non Point Source Water Quality Projects, NC State Univ., Raleigh, NC.
19. USGS (1977), National Handbook of Recommended Methods for Water Data Acquisition. Chapter 5, Off Water Data Coord., USGS, Reston, VA.
20. Zumberge, J. H. and Ayers, J. C. (1964), Hydrology of Lakes and Swamps, In: Ven Te Chow (eds.), Hand Book of Applied Hydrology, Mc Graw-Hill Publishing Co., New York.