LAKE HYDROLOGY

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INTRODUCTION

The hydrology of lake is a subject that has not attracted the attention of Indian Hydrologists even upto the 1980's decade. In the International level, the area drew the attention of hydrologists after the symposium held at Garda in 1966. Since then, remarkable progress has been made in the developed countries, however, the progress made,if any, in our country in this field is very little and may be negligible,when compared with the development made in the developed countries. There are some piecemeal works on hydrological components of lake but the components studied had not been looked upon in the context of overall hydrological aspects of lake nor gave any thought with special reference to the importance of lake in the hydrologic balance. Though, lakes play a signifacant role in shaping the socio-cultural, socio-economic, ecological and hydrological balance of a region, however, activities of our predecessors reveal that seldom do these important facts realized by our planners and scientists even upto 1980 decades. Importance of lakes in the light of ecology and limnology had been realized even before the independence preiod and some studies had been conducted on those aspects for few lakes. Studies carried out after independence mainly dealt with the ecological as well as limnological aspects of lake. Based on the available information, studies carried out and development made in India have been reported in this chapter . Recently National Institute of Hydrology,Roorkee has established a Division on 'Lake Hydrology' to study the hydrological problems of India's Lakes, and to develop methods of solution of such problems. Since, hydrology of lake is an emerging area and so many factors are resposible in the hydrologic chain of the lake, a concise idea has been given in the subsequent paragraphs.

Lakes and Reservoirs

From hydrology point of view, lakes are considered as storage elements of a local or regional hydrologic system. They alter the quantity and quality regime of the water flowing through the system. Though, there are some differences recorded in the geometrical, hydraulic and biological characteristcs of lakes (natural) and reservoirs, but similar concepts, principles, and models are used for planning and development of lakes and reservoirs. Moreover, lakes and reservoirs are in most cases being used for similar purposes despite of the differences. The recorded significant differences between natural lakes and man made inland bodies of water (reservoirs) are :

(i) Reservoirs have both larger drainage areas and larger surface areas associated with them than natural lakes;

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(ii) Reservoirs have both larger mean and maximum depths than natural lakes;

(iii) Reservoirs have shorter hydraulic detention times than natural lakes;

(iv) Reservoirs have lower total phosphorus and chlorophyll concentrations than natural lakes despite the fact that reservoirs in general receive higher total phosphorus and nitrogen loadings;

(v) Reservoirs also exihibit longitudinal density and concentration gradients which are phenomena not usually observed in natural lakes.

In this chapter, the discussion has only been concentracted on natural lakes, unless otherwise noted.

Some Aspects of Lake

Lakes, in some respects, can be considered as "Little Ocean". Like oceans they receive inflow from rivers, exihibit vertical stratification, undergo cycling and sedimentation, lose water through evaporation and so forth. However, most lakes differ from oceans only by evaporation but in freshwater lakes, water also leaves via surface or subsurface outlet. Due to the above charactericsts, lake is considered as a portion of a drainage system where water is retained for considerably larger periods than in normal river channels.

Quantitatively, lakes constitute only about 0.01% of the total water at the earth's surface, they have received proportionately greater attention because of their importance to human. In many places, lakes are used as a source of drinking water, as a receptable for sewage and agricultural runoff, for recreation, and for industrial purposes. Because of their generally small size, they can be severely altered by the above activities. However, the evaluation of the actual or potential effects of a lake on its physical and biological environment usually start with the identification of the changes in the hydrologic regime as a first step and basis for further studies.

Lakes in general, represent additional storage capacity of hydrologic systems. Natural or artificial changes in the storage either on quantity or quality of water alter not only the streamflow regime but also the water balance in the region. These effects may be of particular significance in arid and semi-arid regions. The 'hydrologic side effect' cannot be overlooked or ignored while planning the water resources and comparing them with the other alternative solutions of development of water supply. Alteration in the flow regime and the quality of lake water, a common problem faced in every corners, arising due to the increasing demand and several development activites, will obviously hamper the activites supported by lakes and also there is a chance of ecological & hydrological imbalances in the region. Determination of positive and negative impacts is important to improve the planning and management of lake based water resources of a region. However, difficulties experinced in evaluating and interpreting of impacts are due to the large variety of problems and reasonable methods of solution.

Quality of lake water is another aspect for develpment of lake based water resources programme. All kinds of water do not satisfy human needs. Its quality has to correspond to certain criteria depending on the purposes for which the water in the lake or supplied from the lake is used. The planning of lake requires predictions not only on quantities of water filling the bed of the lake and also causing fluctuations of its level, but also on the quality regime of the water that will be stored in or supplied from the lake. The physical, chemical, biological and radiological properties of the water in the lake or leaving the lake can considerably differ from the properties of water entering the lake. Possibility to understand, predict or control this change without knowing the flow regime and the stratification processes within the lake is very remote. Seasonal temperature flucturations are the most common causes of density stratification but other agents such as dissolved or suspended solids could also be factors.

Hydromechanical analysis of the basic processes, field surveys, and physical or conceptual models are equally important and mutually interrelated tools in investigating flow regime of lakes. Hydraulic models and laboratory tests are widely used tools in studying basic and appplied problems of flow regime and stratification.

Components of Lake Hydrology

Based on the action chain takes place in a lake at different stages the hydrological aspects of lake can broadly be divided into the following categories :

(i) Physico - Geography (ii) Water balance (iii) Hydrometeorology (iv) Hydraulics (v) Sedimentation, and (vi) Biological Process.

PHYSICO - GEOGRAPHY

The determination of the age of lake water, the turnover time of the storage period, flow channels and stagnant zones by using isotope techniques or other newly - developed methods, fall in this category.

Radioisotope tracer techniques have proved to be a practical tool for studing the local distribution and dilution rate of wastewater discharged into a watercourse and the short-term and local characteristics of flow patterns in lakes and also to determine the residence times in lakes. The method was developed first at the Reactor Laboratory of Finland during 1971. The method is still to be used in our country. Tritium, the radioisotope of hydrogen which has successfully been used as a natural tracer in solving number of hydrological problems, has also been used with some success in lake studies to yield answers to the following problems :

(i) to determine the composition of water in lakes according to origin,

(ii) to examine the water balance of lakes with two unknown terms in the water balance equation,

(iii) to determine the macro-mixing processes and currents in the lake, and

(iv) to determine, in principle, the age of lake water and the turnover period of change.

Tritium measurements yield supplementary data in solving problems where other methods have proved unsuccessful, e.g. in the determination of low-velocity flow and diffusion in large water masses, identification of water for different origin.

Bathymetric mapping, is a well known technique to study the morphometric characteristics, was first applied in India by Mukherjee in 1932 for survey of the Dal Lake of Kashmir. This technique later on (1983) was applied by Khanka to analyse the morphometric characteristics of Kumaun Lakes of Himalayan region, U.P.. Singh, et.al. (1987) conducted some studies on morphometry of Renuka Lake, Himachal Pradesh with reference to Flora and Fauna, using the bathymetric technique.

The turnover time of water resources forms an important problem of lake hydrology. For shallow lakes this turnover time is of great importance as far as eutrophication research is concerned. As such, no study has been reported anywhere in this direction.

WATER BALANCE

Water balance relationships form the basis for rational deterministic hydrological forecasting models. The study of water balances of lakes is necessary in order to estimate quantitatively the water resources available and potentially available for practical use. The water balance equation for lakes for any time interval is a continuity equation. According to the law of conservation of matter, there is equilibrium between inflow components, outflow components and the change of water volume for each interval of time. This equilibrium is described by the water balance equation.

$$I_{Si} + I_{Gi} + P - E - I_{o} - I_{GO} - S = O$$

where, I_{Si} = surface inflow into the lake, I_{Gi} = groundwater inflow, P = precipitation on the surface of the lake, E = evaporation from the lake, I_{o} = surface outflow from the lake, I_{GO} = undergound outflow, S = change in the water storage in the lake.

The relative magnitudes of water balance components vary from place to place and season to season. Morphological, Geological and climatological factors which are the main components influence the magnitude of the terms in the water balance equation.

Various methods are available to predict the components of water balance euqation. For example, surface inflow into the lake is dependent upon the morphological, geological and climatological factors of the lake basin. Lake inflow is mainly related to amount of precipitation and stream flow and groundwater seepage in the lake basin. Statistical, stochastic and real time analysis are generally applied to determine the quantity of inflow into the lake. Similarly, to determine the outflow from the lake in otherway the volume of water available in any time in the lake; conventional methods like real time analysis, routing method applicable for rivers and reservoirs, are used. Conventional and the advanced equipments are used to assess the magnitude of various parameters required to determine water balance of a lake.

As such, studies concerned with lake (natural) water balance specifically with reference to Indian lakes had not been reported anywhere. Number of studies had been carried out on reservoirs to mention few important one, Rao, K.L. and Palta, B.R. (1973) on Bhakra Lake, and Kumaraswamy, P., (1973) on Budery tank in Madras state.

Methods for measuring Water balance components

Main components of input and output in lakes are as follows :

Inputs

(i) Rainfall and snowfall on lake surface, (ii) Stream and river flow, (iii) Spring discharge along lake margin, (iv) Groundwater seepage through lake floor, (v) Artificial conduits.

Outputs

(i) Evaporatioin, (ii) Outflow at surface via natural outlets such as a stream waterfall. (iii) Outflow at surface via man-made conduits, irrigation channels, dams etc. (iv) Seepage out through lake floor.

Lake inflow and outflow data are computed from the available observational data which are measured through the advanced techniques available for measuring each component. When there are no measured data available for the drainage basin surrounding the water body, or in areas where data are scarce, it may still be possible to estimate inflow to the lake through the following commonly used techniques:

(a) The analogue method, (b) The water balance method, and (c) Basin run-off isoline maps.

In the case of non-gauged or insufficiently gauged water bodies, an estimation of the water balance components can in some cases be obtained through the use of regional maps and atlases.

For large lakes, inflow may be estimated with the help of runoff isoline maps. Precipitation isoline maps can be used directly only for estimating precipitation on small water bodies less than 100 Km^2 in areas. Maps of evaporation from water surfaces are often based on insufficiently corrected data from evaporation pans or tanks and such maps provide only rough estimation of the true evaporation from lakes. If evaporation maps are not available, evaporation from the surface of a water body may be approximately determined with the help of maps of net radiation, air temperature and humidity.

HYDROMETEOROLOGY

Evaporation plays an important part in the water regime of a lake. Direct measurements of evaporation are lacking and so determination is generally carried out in indirect ways by applying different methods of calculation.

Indirect Ways of Measuring Evaporation

Following emperical methods are widely used for measuring evaporation from lakes :

(a) Energy balance (b) Penman's Formula (c) Meyer's Formula (d) Dalton's law (e) Meyer's Formula (f) Watere balance method (g) Bulk aerodynamic method.

For direct measurements of evaporation losses from lakes, pan mounted on rafts are used. These provide an optimum approximation to natural conditions.

In order to ascertain the water balance of a lake, following three indices have been identified as principal features:

1. The first is the average volume of water in the lake related to the average annual flux. The latter is the sum of input (precipitation + inflow) or output (evaporation + outflow) components of the water balance. This ratio characterizes the renewal process of water in the lake,
2. The second is the ratio of average annual prrecipitation on the lake surface to the average annual flux,
3. The third is the ratio of average annual evaporation to the average annual flux.

HYDRAULICS

The chemistry of freshwater lakes depends to a large extent upon a circulation driven by temperature changes. The density of water in lakes is primarely a function of temperature. As temperature changes, density changes, and if less dense water becomes overlain by more dense water, connection or lake-water overturn, takes place. At 4°C the water is at a maximum density and above this temperature the density then continues to decrease with temperature like a normal liquid. This unusual temperature-density behavior of fresh water provides the fundamental basis for classifying lakes and for describing their overall circulation behavior. The thermal stratification, through the density variation, has a predominant influence on the flow patterns and circulation within the reservoir. Vertical motions are inhibited. Since oxygen transfer occurs at the water surface, transport of oxygen into the lower layers of the reservoir is restricted & often leading to high oxygen deficit, or even anaerobic conditions in this region.

Wind that blows over a lake, transfers momentum to the water and causes the main flow and velocity to fluctuate. The low frequency part of this energy input together with advection eddies has a significant affect on the large-scale dispersion pattern. On a smaller scale the dispersion results entirely from turbulent eddies. Determination of vertical exchange co-efficient is the most important one in determining the wind induced circulation in a lake where the exchange of momentum is greatest.

SEDIMENTATION OF LAKES

Sediment is carried into a lake by streams and rivers or as well as by overland flow entering into lake. Sediment entering a lake may consist of a wide range of sizes, from gravel or boulders to silt and clay particles. Because of the low current velocities available to transport the sediment through a lake, the coarser particles are quickly deposited and form deltals. Seldom will any sediment larger than silt size be discharged from a lake. The appropriate way of obtaining an accurate determination of the amount of sediment being carried to a lake by streams or by overland flow is to measure the flow rate and sediment concentration of the inflowing water just upstream of the lake. For purposes of measurement, the sediment carried by a stream is usually subdivided into two parts; (a) fine; with particle diameters less than 0.062 mm, and (b) coarse with particle diameter greater than 0.062mm. That can further be divided into suspended load and bed load.

Following methods are used to estimate the rate of accumulation of sediment in a lake.

(i) Surveying Methods. (ii) Dating of Sediments. (iii) Remote Sensing (iv) Sediment Density (v) Particle size (vi) Water Currents (vii) Residence time in Reservoirs or Lakes.

Surveying Methods

The general procedure is to construct a bathometric map of the lake bottom which can be compared to a previously constructed map to determine differences in the volume of sediment deposited. The range-line method is the most widely used for medium to large reservoirs. To apply the method a number of cross sections of the lakes are to be surveyed before it is first filled or measured and than periodically resurveyed. The contour method is also used for topographic mapping procedures. To apply the method it is important to have a good contour map of the reservoir before filling. Selection of the contour interval is controlled by the same factors which are used in selecting a map contour interval, but it is suggested that interval should not exceed 1.5 m and 0.5 m for large and small reservoirs respectively. Accuracy requires in measurement of water depth. The simplest way of measuring the water depth is to use a sounding weight or a pole to obtain it directly. Sonic sounding equipment for measurement of depth is preferred on most reservoirs. The scientific depth sounding equipment can also be used to provide a continuous record or chart of the bottom profile.

Dating of Sediment

A lake receives runoff and sediment from its drainage basin and most of the sediment is trapped on its bed. Because of hydrologic processes that are interrelated to some degree the on trapped sediment contains and the physical, chemical and climatic conditions existing over the basin. Any significant change in these conditions should leave a record in the accumulated sediment. If these changes can be identified and dated in the accumulated sediment, the rate of sediment accumulation can be estimated.

Carbon-14 dating of organic sediments has widely been used to estimate sedimentation rates during past millenia. Cesium-137 also used in many cases for determination of sediment profile.

Remote Sensing

Low level remote sesning has several main applications in the assessment of reservoir sedimentation. Contour maps prepared from aerial photographs can be used to determine sediment volumes provided the water level is lowered greatly; aerial photograph can be used to trace turbidity plumes to define the distribution of sedimentation. Through remote sensing, it is possible to determine which infiows to a reservoir or lake are contributing the greatest sediment load. Colour photography has been found more useful in detecting sediment plumes than colour infrared because the exposure setting is less critical and has greater water penetration.

Sediment Density

The bulk density of a sediment deposit provides a simple and direct conversion from dry weight of sediment added to the reservoir to the volume of water displaced. Traditionally the bulk density of sediments measurement are made by use of core samples forwhich variety of types of samplers are used to obtain undisturbed samples of reservoirs deposits. Determination of bulk density by a core sampler is labouries and time consuming. Use of nuclear density probes has received wide acceptance.

Particle Size

Particle size information is useful in predicting erosion, transportation, deposition and compaction of sediments. The size distribution of incoming sediment is very important in determining the pattern of deposition in a reservoir and it is one of the most important aspects in the evaluation of the amount of space occupied or quantity of transported sediment will occupy in a reservoir or lake. Sizes of sediments are generally measured indirectly by observing their settling characteristics in water. Traditional sedimentation methods most commonly employ the pipet, the bottom-withdrawal tube, and the hydrometer. Past few years developement reveals that electronic intruments are also well accepted for measuring size distributions of the sediment.

Water Current

In case of lake fed by river water, the velocity rapidly decreases and all coarse sediment is deposited usually formaing a delta. The very fine sediment remain in suspension for a long period of time and finally carried to all parts of the lake or reservoir by internal currents. Water currents in a reservoir are caused by wind, density differences and through flow of the river. In order to predict the distribution of the deposition of incoming sediment or to estimate the trap efficiency of a reservoir, it is necessary to measure the velocity and water flux of reservoir currents. Current meters, drogues, and tracer techniques are widely used for these measurments.

BIOLOGICAL PROCESS OF LAKES

Lakes are considered to undergo a process of "aging" which has been characterized by three qualitatively defined conditions. The initial condition of a lake is termed oligotrophic and is normally associated with deep lakes, where waters at the bottom of the lake are cold and have relatively contain high level of dissolved oxygen throughout the year. Oligotrophic lakes are poorly fed; have a low concentration of nutrient elements such as nitrogen and phosphorus productivity in terms of the population levels of phytoplankton, rooted aquatic plants, and zooplankton.

On the other hand, eutrophic or "wellfed" lakes have high concentrations of plant nutrients and large concentrations of phophorous plankton due to high organic productivity. Eutrophic lakes may be either shallow or deep. They are characterized by high concentrations of suspended organic matter in the water column and by relatively large sediment depths with high organic contents particularly in the upper layers of the sediment. Biological productivity is high and the diversity of biological populational may be somewhat limited.

A third lake condition is mesotrophic which is an intermediate state between oligotrophic and eutrophic. Mesotrophic lakes have intermediate level of biological productivity and can have some reductions in bottom dissolved oxygen levels. Quality of water in this category of lakes is adequate for most beneficial uses but may be deteriorating towards the eutrophic state.

Two nutrients, nitrogen and phosphorus are of greatest concern in the growth of biological organic matters in the lake. In addition to these nutrients, phytoplankton require carbon dioxide and a host of minor elements (potassium, sodium) and trace elements (iron, manganese, cobalt, copper, zinc, boron, and molybdenum) and organic growth factor.

Of the nutrient elements needed for photosynthesis, hydrogen and oxygen are readily available and also carbon is generally available from atmospheric cárbon dioxide. The major elements that are not always available are nitrogen and phosphorus. Since phosphorus does not occur as a gas in the atmosphere, a lake has noway of compensating for phosphorus deficiencies, and thus becomes the limiting nutrient. Phosphorus input can increase during cultural eutrophication of lakes. The primary sources of phosphorus and nitrogen in lakes are direct rainfall and snowfall on the lake and runoff from the surrounding drainage area. In oligotrophic lakes most phosphorus in runoff comes from rock weathering and soil transport. However, in areas influenced by humans there are additional sources of phosphorus, including agricultural runoff and sewage, which are discharged directly into the lake or its inlet tributories. Atmospheric precipitation may be a very important source of phosphorus for oligotrophic lakes, particularly those in areas of granitic terrain with low contributions of nutrients from weathering and those lakes whose area is large compared to the drainage area.

LAKE BIOLOGICAL PROCESS MODELS

Waste load allocations rely on the concept of reducing inputs of a limiting nutrient to control growth of phytoplankton or by controlling nutrient so that it becomes limiting. Other factors also limit the rate of phytoplankton population growth and resultant population levels. Among the other factors which may be important are light limitations, hydraulic retention times, settling, and grazing by zooplankton. If the limitations on growth imposed by factors other than nutrient concentrations are large, it may not be economically feasible to control eutrophication with reductions in nutrient inputs.

Lake eutrophication models are classified as :(i) Simplified models,(ii) Time variable mass balance models,(iii) Non-linear eutrophication models,

i. Simplified Lake Nutrinet Models

The models involve two distinct steps : (a) establishing a causual relationship between nutrient loadings and lake nutrient concentration, and establishing a basis for assigning the lake a trophic state based on lake nutrient concentration which is based on the conservation of mass principle or are direct empirical correlations between pertinent lake characteristics.

ii. Time variable Mass Balance Models

The basic mass balance equations for total phosphorus in a completely mixed lake are employed with provision for flows and loaded which vary with time. The resultant formulations calculate concentrations of total phosphorus which are a function of time. The calculated time histrory of phosphorus than compared to observe phosphorus concentrations to provide calibration for the analysis framework. Following models are available to calculate the concentration of phosphorus in the lake.

	Name of Model	Developer/Year of Development
(a)	Time variable total Research Laboratory	Steven C.Chapra/ Great Lakes Environmental phosphorus model, Michigan (1974)
(b)	Phosphorus Mass Balance Environmental Protection	David P.Larsen and John Van Sickle, U.S. Model Agency, Oregon (1978)

iii. Non-linear Eutrophication Models

Non-linear eutrophication modeling primarily concern with the calculation of food chain extended for simulation to include upper portions of the food web including fish. Analysis of water quality variables such as dissolved oxygen is another part of eutrophication modelling. Non-linear eutrophication modeling frameworks employ relatively large number of co-efficients that describe the chemical, bio-chemical, and biological reactions in addtion to co-efficients which represent physical transport such as advection, dispersion and settling. Following non-linear eutrophication models applicable in one-two and three dimensional water bodies and/are widely used for determination of eutrophicatioin capacity of lakes.

Models	Developer/Year of Dev.
Water Analysis Simulation Program (WASP)	Robert V.Thomann, Dominic Di Toro, N.Y.(1975,1979)
WASP and Advanced Ecosystem Modeling Program (AESOP) Donald	**WASP** Dominic DiToro; James J. Fitzpatrick, John I. Mancini, J.O'Conner Robert V.Thomann (1970) **AESOP** Dominic DiToro, James J.Fitzpatrick, Robert V. Thomann (1975).
CLEAN,CLEANER,Ms.CLEANER,	Park,O'Neill,Blomfield, shugart et.al; Eastern Deciduous Forest
MINI-CLEANER	Biome International Biological Programme, (1973,1977,1980 & 1981).
LAKECO, ONTARIO	Carl W.Chen Tetra Tech.Inc. California (1970).
Water Quality for River	Carl W.Chen, G.T.Orlob, W.Norton,D.Smith. Water

Reservoir Systems (WQRRS)	Resources Engineers,Inc. (1970,1978,1980 & 1981)
Grand Traverse Bay Dynamic Model	R.P.Canale, S.Nachiappan, D.J.Hineman and H.E.Allen. (1973)

INDIA'S SCENARIOS OF LAKES STUDY

Study carried out sofar in India before and after independence mainly concerned with the ecological, environmental, socio-economic and limnological aspects of lakes located in various corners of the country. Many governmental, semi-governmental, voluntary organisations, universities and institutions are engaged for extending study of India's Lakes. Due to the topographic, hydrologic 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 wetlands, entitled the All-India wetland survey, established by the Govt.of India initiated a study as long as the late 1960s and could only able to give a broad assessment of wetland areas in the country in 1984.

A total of 1,193 wetlands, covering an area of 3,904,543 ha. were recorded, out of the 1,193 wetlands 572 were natural wetlands, 542 were man-made habitats. Some 938 wetlands were freshwater, 134 brackish and 19 coastal. Most of the wetlands were small; over 690 ha. an area of less than 100 ha. and only five were larger than 100,000 ha. Some 418 of the wetlands were used for irrigation purposes, fishing reported at 369 sites, fish culture at 90, grazing at 161, waste disposal at 30 and reed gathering at 19

Lakes either smaller or larger in size, depending upon their depth of water available and purpose of uses, are known in different names in different parts like, Jheels, Bheels, Marshes, and Tanks etc. They may be called in different names in the region, however, purposes for which they are being used or are being provided services, and problems faced by them are identical in nature. Various organisations are in the leading role to study the ecological and limnological aspects of lakes. They are:

1. Governmental Organisations

(a) Ministry of Environment and Forests.
(b) Planning Commission.
(c) Ministry of Water Resources.
(d) Ministry of Agriculture.
(e) Indian Board for Wildlife.
(f) Forest Research Institute.
(g) Ganga Water Authority.
(h) Institute of Wetland Management and Ecological Design.
(i) Environmental Monitoring Organisations.
(j) National Ecodevelopment Board.
(k) National Institute of Oceanography in Goa.

2. Non-Governmental Organisation

(a) Bombay Natural History Society.
(b) WWF - India.
(c) UNDP/UNESCO.
(d) French Institute (Pondicherry).
(e) Ecological Society, (Pune).
(f) Indian Society of Naturalists (Baroda).
(g) Wildlife Preservation Society of India (Dehradun).
(h) Tourism and Wildlife Society of India (Jaipur).
(i) Assam Valley Wildlife Society.

3. Universities

(a) Andhra University, Visakapatnam.
(b) Annamalai University, Tamil Nadu.
(c) Bhopal University.
(d) D.N.R.College, Bhimavaran.
(e) Gauhati University, Assam.
(f) Jawaharlal Nehru University, New Delhi.
(g) University of Jodhpur.
(h) University of Kashmir.
(i) Osmania University, Hyderabad.
(j) University of Rajasthan.
(k) University of Roorkee.
(l) Saurashtra University.

Studies undertook on different lakes of the country and nature of study conducted are summerized below :

	Name of Lake and Location	Area/ Altitude	Nature of Study conducted	Researcher/ References
	1	2	3	4
1.	Pangong Tso, Jammu & Kashmir	65000 ha 4218 m	Breeding ecology of Grusnignicollis	Khacher (1982)
2.	Chushul Marshes, Jammu & Kashmir	11000 ha 4385 m	Ecology of Grus nigricollis	Ali (1979) Gole (1981) Hussain(1987) Khacher(1982) Narayan(1987) Nurbu (1987)
3.	Hanle River Marshes, Jammu & Kashmir	7500 ha +500 m widestrip 4250-4350 m	Marsh Flora & the bredding black-necked Cranes	Gole (1981 & 1987), Khacher(1982) Nurbu (1987)
4.	Tso Morari,	12000 ha	On breeding birds	Gole (1981 & 1982),

	Jammu & Kashmir	4511 m		Hussain (1987), Khacher (1982), Narayan (1987), Nurbu(1987)
5.	Tso Kar Basin, Jammu & Kashmir	20000 ha 4530 m	On breeding birds particularly Anser indicus and Grus-Nigricollis	Gole(1987), Hussain (1987), Khacher (1982) & Nurbu (1987)
6.	Dal Lake, Jammu & Kashmir	1670 ha 1587 m	Considerable study had been carried out on the limnological,ecological, environmental, eutrophication and siltation problems of the lake. Bathymetric survey was first introduced in the lake study for Dal Lake.	Mukherjee(1921, 1925,1931,1935) Zuthi & Vass (1979,1984,1971, 1973,1978,1988), Zuthi (1968,1975), Kant & Kachroo (1971,1977).
7.	Shallabugh Lake, Jammu & Kashmir	750 ha 1580 m	On hydrology of lake and some waterfowl censuses.	
8.	Wuler Lake, Jammu & Kashmir	20000 ha 1580 m	On limnological aspects of lake	Abdulali & Savage (1970), Luther & Rzoska (1971).
9.	Haigam Rakh, Jammu & Kashmir	1400 ha 1580 m	Department of Botany of Kashmir University conducted some study on limnological and ecological aspect of the lake. Areas covered in the research were: study of mineral composition biogeochemical cycling,plankton populations,biomass productivity, trophic structure and plant community architectures. The Bombay Natural History Society had worked on avifauna of the lake. The Department of Wildlife Protection had conducted some waterfowl census and two oxford	Abdulali & Savage (1970); Deneil (1985);Fernandes (1987).Kaul (1979, 1982,&1984, Kaul et.al(1982),Kaul, v (1970 & 1977), Kaul,v.et.al (1978), Kaul, Pandit et.al. (1980), Kaul,Trisal et.al(1980), Pandit (1982),Pandit & Kaul (1982).

			University Expeditions had studied the breeding birds & passage migrants.	
10	Mirgund Lake, Jammu & Kashmir	300 ha 1580 m	Scientists from the Department of Botany at the University of Kashmir had conducted considerable amount of limnological and ecological study	Kaul,S (1979) & (1982), Kaul,S. et.al (1982), Kaul,V.(1970 & 1977), Kaul, V et.al.(1978), Pandit & Kaul, (1982).
11.	Hokarsar, Jammu & Kashmir	1300 ha 1580 m	Limnological and ecological study had been carried out by the Biologists from Department of Botany at the University of Kashmir.	Abdulali & Savage (1970); Daniel (1985), Fernandes(1987); Kaul,S.(1979 & 1982; Kaul,S.et.al. (1982); Kaul V. (1970 & 1977) Kaul,V.et.al.(1978) Pandit (1982); Pandit & Kaul (1982).
12.	Renuka Lake, Himachal Pradesh	17.70 ha 645 m.	Department of Biosciences, Himachal Pradesh University had conducted study on limnological & ecological aspects of the lake with special reference to its Flora & Fauna.	Singh,B.& Mishra S.M.et.al(1987).
13.	Khurpatal, Uttar Pradesh	10 ha 1620 m.	Considerable studies had been carried out on the limnological and ecological aspects of lakes of Kumaun Himalaya. Limnological study was conducted through bathymetric map.	Das,S.M.(1980); Hukku,B.M.,et.al. (1984); Joshi, S.C.,et.al(1983) Khanka, L.S.(1983) Kharkwal, S.C. (1971), Mathu,S.M. (1955), Pande,I.C. (1974),Rawat,J.S. (1987), Thomas, A. (1952).
14.	Naina Lake, Uttar Pradesh	45.07 ha 1937 m	- do -	- do -
15.	Bhimatal Lake,	46.26. ha 1345 m.	- do -	- do -
16.	Naukuchiyatal Lake,	37.53 ha	- do -	- do -

	Uttar Pradesh	1320 m		
17.	Punatal Lake, Uttar Pradesh	14.85 ha 1360 m	- do -	- do -
18.	Sattal Lake, Uttar Pradesh	34.02 ha 1300 m	- do -	- do -
19.	Pyagpur and Sitadwar Jheels, Uttar Pradesh	2800 ha (Pyagpur) 150 m (Sitadwar) 125 m	The Bombay Natural History Society had conducted preliminary survey and waterfowl censuses.	
20.	Chandpata Lake, Madhya Pradesh	200-300 ha 450 m.	Studies had been carried out on flora & fauna.	Karpowicz (1985)
21.	Chhata Lakes, Uttar Pradesh-Rajasthan Boarder	3000 ha 190 m	Preliminary survey work had been conducted.	
22.	Sultanpur Jheels, Haryana State	13,727 ha 220-230 m	Some waterfowl censues had been carried out and avifuana had been well documented.	Fernandes (1987), Gole (1982), Haryana Government (1956).
23.	Sambhar,Phulera and Didwana Salt Lakes, Rajasthan.	Sambhar 23,300 ha Phulera 200 ha Didwana 200 ha	Several waterfowl surveys had been conducted at the lakes and also archaeological, palaeobotanical and palaeontological research had been carried out in the surrounding areas	Abdulali & Savage (1970), Alam (1982), Ali & Ripley (1968),De Block (1981), Fernandes (1987).
24.	Khijadia Lake, Gujarat	1000 ha. 0 - 2 m.	Some ecological studies had been carried out mainly with reference to waterfowl censuses	Gole (1984), Karpowicz (1985).
25.	Nalsarovar Lake, Gujarat	11500 ha. 11.5 m.	Ecological studies were conducted specially with reference to flora and fauna.	Fernandes (1987) Gole [1984 (a)&(b)]
26.	Ajwa,Vadhwana	Ajwa	Waterfowl Survey	

and Pavagadh Lakes,Gujarat	200-300 ha Vadhwana 400 ha Pavagadh 100 ha 50-60 m.	had only been conducted	
27. Khabartal, Bihar	7400 ha. 45 m.	The state forest department had conducted a preliminary study of the lake ecosystem.	Mishra & Negi (1985)
28. Logtak Lake, Manipur	26000 ha 770 m.	Studies carried out on ecological and socio-economic importance of Logtak Lake.	Yadav and Varshney (1982)
29. Salt Lakes Swamp. West Bengal	12000 ha. 5 m	The West Bengal Department of Fisheries had conducted some research on sewage purification and fish production in the swamp. The Institute of Wetland Management and Ecological Design had conducted some studies on public health issues and ecological aspects of lakes.	Fernandes(1987) Ghosh (1983), Maltby (1986)
30. Chilka Lake, Orissa	116500 ha. 0 - 2 m.	The Bombay Natural Society had conducted some studies on bird ringing programmes	Abdulali & Savage (1970), Ahmed (1987), Anon (1984), Asthana (1979), Banerjee & Roy-Choudhery (1971).
31. Kolleru Lake, Andhra Pradesh	90000 ha 0 - 5 m	Study had been carried out on aquatic biota of the lake and on the ecology of the lake.	
32. Pulicat Lake, Andhra Pradesh	72000 ha 0 - 10 m	The Bombay Natural History Society carried out an ornithological survey and the zoological survey of India had complied species lists for many groups of flora and fauna.	Abdulali & Savage (1970),Fernandes (1987),Hussain (1987),Krishnan (1984),Neelakantan (1980).

33. Lake Mir Alam, Andhra Pradesh	16900 ha 540 m.	Some limnological & ecological studies had been carried out by different scientists.	Reddy (1984), Mohan (1985, 1986,1987), Mohan and Reddy (1986, 1987 and 1989)
34. Lake Periyar, Kerala	2500 ha 1000 m.	The State Forest Department and the Kerala Forest Research Institute had conducted some studies on ecological aspects of the lake	M. Krishnan
35. Mayem Lake, Goa.		Studies had been carried out on limnological aspects.	Desai (1991)

EXISTING GAP

Lakes in manyways contributing to socio-economy, cultural, environmental, ecological and over and above, hydrological fronts of the natural cycle. Out of the above fronts, hydrological aspect of lakes is the primary concern. Degradation or unbalance in the hydrological cycle directly or indirectly will hamper to the secondary course of action. That is what, in many cases being observed, lake based socio-economy cycle of a region is being squeezed, continuous degradation of lake water due to the point and non-point sources of pollution and other human related activities leading to the serious environmental problems. As a result, cultural, recreational,environmental and ecological problems for most of the lakes located in various corners of the country have reached in serious stage. All the above activities are linked with the hydrologic chain of the lake. Unless the hydrology of lake is looked upon in the context of overall lake based action chain and studied accordingly, the problems related to the lake based development will not achieve the required level of success but will lead to the serious hydrological and environmental problems in the region. Studies carried out so far on different lakes located in various corners of the country mainly dealt with the ecological, limnological and environmental problems of the lakes, however, all these aspects had not been looked upon in the context of hydrology of the lake. Technology for assessing and determination of various hydrological parameters have been developed considerably and are successfully being used for other water resources problems. Use of those techniques for studying the hydrological aspects of lakes are to be explored. National Institute of Hydrology stationed at Roorkee has estasblished a Lake Hydrology Division recently to look into the hydrological problems of Lake and its related matters. The Division has taken up a research programme to study hydrological aspects of Nainital Lakes in U.P.recently.

CONCLUSIONS

Lake plays a significant role in shaping the hydrology, ecology, environmental and socio-economic structure where other resources of water are limited mainly in the arid and semi-arid region. Degradation of the lake based water resources development programme will not only deteriorate the hydrology of the region but also the socio-economic and socio-cultural structure. Problems faced in many corners are the witness of such deterioration. Studies carried out so far mainly dealt with ecological, environmental and limnological aspects of the lake, however, these are to be linked with the hydrological aspect of lake alongwith other components, if lake based water resources developments are truely be achieved.

Developed countries have made considerable progress in the field of lake hydrology, however, the problems of India's Lakes are to be studied with reference to the hydrological balances of the region.

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