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Hydrological Aspects of Lakes

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ABSTRACT

In India majority of population still depends upon the natural water resources for fulfilment of most of their requirements. Lakes are the foremost in the natural resources and supplying water for variety of uses. Therefore much attention should be given first to the deteriorating quantity and quality of the lake water. For this purpose, any lake study should first concentrate on monitoring various hydrological variables of the lake and its catchment. A detailed inventory of the lakes and their hydrological problems is to be prepared in a most scientific manner. Further a proper management plan is to be prepared in order to address various problems hydrological problems related to both quality and quantity of water. This paper addresses such and various other issues in general and lakes classification, hydrology of lakes, water balance and management in particular.

INTRODUCTION

Water is a primary constituent of life and is key to a wide range of economic activities. Water resource, as an individual ecosystem, is intrinsically complex. It can have different responses with regard to the quality of its water and, more generally, the status of the system, showing different fragility to human pressure factors.

The ever increasing demand for water due to growing population, calls for proper conservation and management of all the available water resources, including lakes. Lakes and reservoirs hold about 90% of the world's surface fresh water. One billion people are at risk from over-use, water withdrawals and pollution of these water bodies (9th International Conference on Conservation and Management of Lakes, Japan 2001 and 3rd World Water Forum, Kyoto 2003). Therefore, lakes need special attention as they are quite often the catalysts in the development of the region by supplying water for variety of uses such as drinking, industrial, irrigation, aqua-culture, recreation and tourism etc. However, many lakes are reported to have undergone quantitative and qualitative degradation in the last few decades. Since behaviour of the lake ecosystem depends to a large extent on its hydrological regime, understanding the hydrological regime of the lakes is very significant to develop strategies for their conservation, management and rejuvenation. The aim of the paper is to describe the broader view of lakes and their classification, hydrology of lakes, water balance and management.

WHAT IS LAKE?

Definitions that precisely distinguish lakes, ponds, swamps, and even rivers and other bodies of non-oceanic water are not well established. It may be said, however, that rivers and streams are relatively fast moving; marshes and swamps contain relatively large quantities of grasses, trees, or shrubs; and ponds are relatively small in comparison to lakes. In literature, various definitions of lake are available some of them are given below:

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).

A lake (from Latin lacus) is a terrain feature (or physical feature) that is a considerable inland body of water, not part of the ocean, that is larger and deeper than a pond, and may or may not be moving slowly, and is localized to the bottom of basin (another type of landform or terrain feature) and is fed by a river.(http://en.wikipedia.org/)

A Lake is defined as any relatively large body of slowly moving or standing water that occupies an inland basin of appreciable size. Geologically defined, lakes are temporary bodies of water. (Brittanica online)

Lake is a body of fresh or salt water of considerable size, surrounded by land. (http://dictionary.reference.com/browse/lake)

A lake is an ephemeral feature of the landscape and is a dynamic system.

Natural lakes are generally found in mountainous areas, rift zones, and areas with ongoing or recent glaciation. Other lakes are found in endorheic basins or along the courses of mature rivers. In some parts of the world, there are many lakes because of chaotic drainage patterns left over from the last Ice Age. All lakes are temporary over geologic time scales, as they will slowly fill in with sediments or spill out of the basin containing them.

There are about 3 million lakes in the world and most of them are located in the Northern Hemisphere. 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 hydro electric 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. As a summary, a water body should fill the following requirements to be a lake (Table 1) :

Table 1: Requirements of a water body to be classified as a lake

Requirements of a water body to be defined as 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^2 at mean sea level.*

CLASSIFICATION OF LAKES

Lakes are generally classified under five major groups:

I. Classification based on region of lakes
II. Classification based on biological properties of lakes
III. Classification based on chemical nature of lake water
IV. Classification based on carbon dioxide content of lake water
V. Classification based on calcium content in the lake water

I. Classification based on region of lakes

The regional classification of lakes is given as:

i. ***Tropical Lakes:*** Tropical lakes have summer temperature of 25 to 30 ^{0}C and a winter temperature of 16 to 20 ^{0}C.

ii. ***Temperate Lakes:*** Temperate lakes have summer temperature of 16 to 20 ^{0}C and winter temperature of 4 to 8 ^{0}C.

iii. ***Cold Climate Lakes:*** Cold climate lakes have a summer temperature of 4 to 8 ^{0}C and winter temperature of 0 to 4 ^{0}C.

II. Classification based on biological properties of lakes

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

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

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

iii. Mesotrophic Lake - These lakes have intermediate properties between those of oligotrophic and eutrophic lakes. Their major properties are moderate fertility, adequate aquatic plant population, greenish water and moderate production of phytoplankton. The dissolved oxygen content of such lakes varies in the range of 2 to 4 mg/liter.

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

III. Classification based on chemical nature of lake water

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

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

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

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

IV. Classification based on carbon dioxide content of lake water

i. Soft Water Lakes - These lakes have pH in the range of 4 to 6. These lakes are

common in the region of low lands. Their water have a low carbon dioxide content; nearly about 200 ppm.

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

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

V. Classification based on calcium content in the lake water

Reid & Wood (1976) have reported the classification of lakes on the basis of their calcium content:

(i) Poor Lakes – Having calcium content less than 10 mg/liter.
(ii) Medium Lakes – Having calcium content from 10 to 25 mg/liter.
(iii) Rich Lakes – Having calcium content more than 25 mg/liter.

CLASSIFICATION OF LAKES IN INDIA

In our country numerous natural lakes of varying sizes are present either in high altitude Himalayan region or in low altitude region. Many of the lakes of Himalaya are fresh water with or without inflow and out flow. These lakes region show varying chemistry in terms of solutes, bio-geochemistry, mineralogy vis-à-vis ecohydrology of the water body. These are primarily related to enormous altitude variation governing the climate, vegetation, agriculture, lithology, tectonics and type and intensity of erosion/ weathering at source. The high altitude lakes are mostly oligotrophic and are fed from snow-melt, precipitation and springs whereas lakes of low altitudes receive water from local rains, through streams, Nalas and springs and some of them approach advance stage of trophic state due to strong impact of anthropogenic influence such as tourist influx, unplanned settlements, land-use and development activities in the catchment area, and disposal of municipal and domestic wastes. In general the Indian lakes are either fresh water or salt water lakes. Some of them are sacred lakes. A major classification of the Indian lakes is represented as:

A. Urban lakes
B. Non-Urban Lakes
   a) Inland Fresh Water
   b) Inland Brackish/salt water
   c) Sacred lakes & Tanks

C. Coastal Estuarine Lakes of brackish water (Salt and Fresh Water Mix)
D. Ephemeral Lakes (Beels, Jheels & Tals) of the Ganga - Brahmaputra Basins

Lakes falling under the above classification are given in Table 2 to 7.

HYDROLOGY OF LAKES

Lakes in the same or different regions have different hydrologic characteristics due

Table 2: Urban lakes in India

STATE	URBAN LAKES
Andhra Pradesh	Hussain Sagar (3,300 ha) & Saroornagar (400 ha), Osmansagar (4,016 ha) and Himayatsagar (3,584ha) and other lakes.
Chandigarh UT	Sukhna lake, -188 ha
Jammu and Kashmir	Dal & Nagin Lakes,–1720 ha., Wular Lake, 17,300 ha - Called flood-lung of the Jhelum River.
Karnataka	257 lakes Mysore city's five lakes- Kukkarahalli, Lingambudhi, Karanji, Devanoor, and Dalavai, - 363.5 ha.
Kerala	Sastamkotta Lake , -373 ha.
Madhya Pradesh	Bhopal's Upper and Lower Lakes - also named Bhoj Wetland, - 3201 ha.
Maharashtra	Mumbai city's lakes, - Powai, Tulsi, Vihar lakes -2200 ha.
Punjab	Nangal Lake and Hussainiwala lakes, – 1088 ha.
Rajasthan	Jalmahal Lake also called Mansagar lake, Jaipur city, - 110 ha (after restoration), Jaisamand lake or Dhebar lake -7224 ha., Udaipur city's five Lakes - Fatehsagar (400Ha), Rangsagar, Pichola, Swaroopsagar and Dudh Talai (1480 ha). Tamil Nadu - Kodaikanal Lake & the Ooty lake,
Tamil Nadu	Kodaikanal Lake & the Ooty lake
Uttarakhand	Lakes of Kumaon hills - Nainital, Bhimtal, Sat-Tal, & Naukuchiatal
West Bengal	Howrah's urban water bodies, Mirik Lake called 'Sumendu Lake', Darjeeling District, - 47 ha., Rabindra Sarovar (lake) or Dhakuria Lake, - 31 ha.

Table 3: Inland Fresh Water - Non-Urban Lakes

STATE	NON-URBAN LAKES- INLAND FRESH WATER
Gujarat	Nalsarovar Lake, - 12, 000 ha.
Himachal Pradesh	Pong Dam lake, - 15,662 ha. Renuka lake, Himachal Pradesh - 75 ha.
Manipur	Loktak Lake - 31,200 ha.
Punjab	Harike Lake, - 2850 ha., Kanjli Lake -490 ha Ropar lake, -1365 ha.
Rajasthan	Keoladeo National Park or Bharatpur lake -2873 ha.
West Bengal	Mirik Lake or 'Sumendu Lake'– 47 ha.

Table 4: Inland Brackish/salt water - Non-Urban Lakes

STATE	NON-URBAN LAKES- INLAND BRACKISH/SALT WATER
Jammu and Kashmir	Tsokar lake at 4,485 m - Leh, -'Lake of salt'. Tsomoriri lake or "Mountain Lake" at 4,595m - 12,000 ha -Highest cultivated land in the world.
Maharashtra	Lunar Lake - 1.8 km in diameter, largest and oldest meteoric crater in the world.
Rajasthan	Sambhar Lake - India's largest salt lake - 24,300 ha.

Table 5: Sacred lakes - Non-Urban Lakes

STATE	NON-URBAN LAKES- SACRED LAKES
Maharashtra	Shambhu Lake – 16 ha
Rajasthan	Pushkar lake, Rajasthan

Table 6: Coastal Estuarine Lakes of brackish water (Salt and Fresh Water Mix)

STATE	SALT AND FRESH WATER MIX LAKES
Andhra Pradesh & Tamil Nadu	Pulicat Lake, , - 77,000ha - Second largest brackish water lagoon in India - Unique for its multi-ecosystem.
Kerala	Ashtamudi Lake - 61400 ha. Kuttanad lagoon, Kerala, Five major rivers drain - Most area consists of freshwater - 'kayal' or backwaters - 'One of the few places below sea level with farming' Vembanad-Kol Lake system - 151,250 ha - Fed by 10 rivers -Two distinct segments of fresh water & salt water.
Orissa	Chilika Lake, - 1,16,500 ha - Largest brackish water lagoon in Asia.

Table 7: Ephemeral Lakes (Beels, Jheels & Tals) of the Ganga - Brahmaputra Basins

STATE	EPHEMERAL LAKES
Andhra Pradesh	Kolleru Lake - 90,100 ha - Hemmed between Godavari and the Krishna river basins.
Assam	Deepor beel or lake, Guwahati city -4,000 ha. (R)
Bihar	Kawar (Kabar) Lake - 6737 ha. Mokama Tal -106,2 00 ha.

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

Lakes also exhibit interesting thermal stratification like reservoirs. For evaluating the lake problems and developing a realistic approach for their management, heat budget, nutrient budget and water budget of lakes are needed. Lakes also exist in all sizes and it is obvious that a small pond of 0.01 km^2 is totally different in most ways than lake of 50 km^2. Climate, geology and anthropogenic influences are other factors that make each lake unique. This has to be realized while studying lake hydrology and describing the behaviour and characteristics of lakes.

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

The lake processes include sediment release, biochemical recycling, mixing etc. The importance of sedimentation for lake ecology can be seen from two angles. On the one hand there is plenty of life in the bottom sediments of a lake, because biological life is better in sediment than in water. On the other hand because of abundance of life in sediments, there is a great contribution to the lake system from the benthic community.

Siltation rates of a lake are essentially dependent on the conditions of the drainage area. There are also other factors, mainly morphological and hydrodynamics that are influential. Steep areas with large relief tend to have stronger time variations in their sediment load and they also carry coarse particles. Man's influence is mainly due to varying land use. While sediment transport in channel/rivers is totally dependent on the gravity driven flow and its characteristics, the situation in lakes is different and like that of coastal sediment transport. In lakes, wave is normally much more important than periodic wind driven currents. Another special feature of lake sediment problem is the large content of organic materials due to large portion of cohesive sediment in the water.

WATER BALANCES OF LAKES

Water balance relationships form the basis for rational, deterministic hydrological forecasting models and are necessary for forecast of lake levels, design, operation, predicting environmental impacts, valuable information base for effective management, global studies of climate variability etc. The water exchange in lakes is much slower than in rivers. On a global basis and in terms of the total water of the earth, the lake water is ten times more than the river water. Incidentally, the average residences time for rivers and lakes are 2.1 years and 21 years respectively and these indicate the slower water exchange process in a lake than a river. Water quantity and quality considerations are directly linked. The water balance study of lake provides very useful information about the availability of water in lakes at any time. The water balance equation of a lake for any time interval is basically a continuity equation expressed as:

$$D_s = I_s + I_u + P_i - Q_s - Q_u - E_i \qquad (1)$$

Where,

D_s = Change in water storage
I_s = Surface Inflow
I_u = Subsurface Inflow
P_i = Lake precipitation
Q_s = Surface outflow
Q_u = Subsurface outflow
E_i = Lake evaporation

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

Lakes can be divided into two main categories :

Open (exorheic) lakes with outflow and
Closed (endorheic) lakes without out flow.

Water balances for open lakes

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

$$I_s + P_i + I_u = Q_s + E_i + Q_u \qquad (2)$$

This equation can be applied to short period of time over which the measured storage change is zero, to a long period over which D_s is negligible in comparison to other terms in the equation, or to long term mean annual water balances. The water balances equation for an open lake when storage changes and subsurface flows are negligible can be expressed as

$$I_s + P_i = E_i \qquad (3)$$

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

$$I = O + D_s \qquad (4)$$

Where,

I = sum of input components of the water balance equation

O = sum of output components of the water balance equation

Equation (4) is suitable for small lakes with large inflow and outflow i.e. when there is a high rate of water exchange. Equation (4) becomes less reliable for larger (area) water bodies and shorter time periods, when the error in estimates of D_s may exceed the total inflow.

Water balances for closed lakes

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

INDIAN LAKES: *PROBLEMS AND* PRIORITIES

During recent years, due to alteration of landscape by denuding forests, urbanization

including tourist's traffic and waste discharge in the lakes, sedimentation eutrophication of have increased in Indian lakes. It has been reported that many high altitude lakes in Kashmir and in Garhwal Himalayas, which have remained clean and without eutrophication for centuries, are showing signs of deterioration. The famous Dal Lake of Kashmir, which was about 40 km^2 in the beginning of nineteenth century is presently at about 20 km^2. About almost half of the Lake Renuka (Water spread of 670 Ha), the biggest lake of Himachal Pradesh in the lesser altitude of Siwaliks of Himalayan region is filled up with sedimentation. The situation is much worst in the plains or in peninsular India. Osmansagar in Hyderabad, Upper Lake in Bhopal and Poondi, Red Hills in Chennai, sources of drinking water for their cities have shrunk considerably in the recent past causing great hardship to the city dwellers. Due to mismanagement and various other reasons in many cases lakes of smaller sizes located in the urban areas are used as a dumping spot of wastes, both solid and liquid, due to which the temperature structure of the lake changes. As a result, many lakes in India are experiencing the problem of eutrophication. Very precisely, occurrence of inorganic nutrients in water and the resulting increase in plant productivity has become a serious water quality consideration all over the country.

In our country, natural and/or manmade changes in storage of lakes, both in quality and quantity of water, have altered not only the stream flow regime but also the water balance of the region and thus directly hampering the availability of freshwater for various purposes. Alteration of flow regime and quality of lake water, a common problem faced everywhere, arising from increase in demand and developmental activities. There are also side effects of ecological imbalances in the region. Impact of degradation is less in the initial stage but the cumulative impact in longer period proves to be deleterious. In order to save the lakes and therefore, the adjoining area from economical, hydrological, and environmental disasters it is important to look on the state of the problems and implement the proper remedial measures. In national perspective, the most important ecological problems connected with lakes are presented in Table 8.

GAPS IN LAKES STUDIES

These days, many problems of lakes are being solved with the help of models in which the analytical solutions involving several parameters and their combinations are put into algorithms. The basic reason for applying the modelling approach is to simplify the analytical work though a variety of alternatives based on variable inputs of all types. Therefore, the choice of suitable model should correspond with the available information for bringing out required solutions to the various problems related to planning and management of lakes. In various parts of the world, numerous models have been developed for lake management and are today available to solve all spheres of lake hydrology problems. Due to setting-up of increasingly sophisticated models for identifying complicated processes of lakes and facilitating the amount of data requirement for any particular solution is rapidly increasing. In India due to lack of detailed hydrological investigations of any lake, model

Table 8: Important ecological problems connected with lakes

Sl. No.	Problem	Solution
1	Lowering of level due to over use of water as a result of decreasing rainfall in the catchment.	Manage the water use in order keep in view the total water inflow and available storages.
2	Rapid siltation caused by accelerated soil erosion.	Apply soil conservation measures in the lake catchment
3	Pesticides and toxic chemicals being brought through surface inflow flow.	Restrict overuse of the pesticides and chemical
4	Eutrophication	Between 1950 and 1995, 600,000,000 tones of phosphorus were applied to Earth's surface, primarily on croplands. (Carpenter et al. 1998) Control of point sources of phosphorus have resulted in rapid control of eutrophication, mainly due to policy changes.
5	Disintegration of aquatic system	Take necessary and immediate actions

for any lake has not been developed, though development of model for some of the lakes mentioned in the earlier sections is in progress.

In India, since long time attention is being paid only on research studies on limnology. Study on hydrological and/or thermal aspects of lakes is started very recently. A need is felt wherein different aspects of lake processes such as general hydrological description including water balance, sedimentation, hydrodynamics, thermodynamics, interaction with the environment, influence due to stream flow, lake water interaction with the ground water and seepage etc. should be given due importance in the research studies. This will support the planning and management of the lake water resources and will also assist in providing answers to various local problems the lakes are facing these days.

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