MODELING HEALTH OF A LAKE: A CASE STUDY

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ABSTRACT

To improve the availability of both quality and quantity of water supply systems, it is necessary to improve the knowledge on tropical lakes and reservoirs. Modeling of lakes and reservoirs is extremely complex and is totally different from modeling of rivers. Water quality in lakes and reservoirs is subjected to the natural degradation process of eutrophication and its impacts of societal development. The major nutrients responsible for the process of eutrophication are phosphorus (P) and nitrogen (N). They are mainly reaching the water bodies through fertilizers, detergents, agricultural run off, domestic and industrial wastes. The effects of eutrophication are considered negative and often reflect human perceptions of good versus bad water quality.

A case study was carried out at Lake Porur, which is located in Chennai, Tamil Nadu, with special emphasis on eutrophication. This lake assumes great importance as most of the imported water for the city water supply has been stored in this lake. Representative samples were collected from the lake and analyzed for the horizontal and vertical variations of temperature, dissolved oxygen (DO), turbidity and phosphates. Temperatures showed a reduction of 3°C within a depth of 2.6 m. The corresponding increase in the concentration of DO was from 6.9 mg/L to 7.9 mg/L. Turbidity was found to reduce by 50% from surface to the bottom. The variation of the concentration of phosphates also showed an increasing trend towards the bottom. With an average value of 0.09 mg/L, the concentration of phosphate was found to exceed the limiting value of 0.03 mg/L, throughout the lake. A mass balance approach showed that the phosphate loading to the lake is about 847 kg per year. It is found that Lake Porur has been polluted beyond its assimilating capacity. The reasons for the pollution were analysed and some potential remedial measures are suggested in this paper.

INTRODUCTION

Water quality in lakes and reservoirs is subjected to the natural degradation process of eutrophication and the impacts of societal development. Progression from a low-productivity oligotrophic state through mesotrophic and into eutrophic conditions is a normal aging process that results from recycling and accumulation of nutrients over long period of time. Human activities increases the rate of eutrophication, often by several orders of magnitude, and a process that would take tens of thousands of years if left to nature may occur in a century or less with the aid of wastewater discharges and agricultural runoff.

For good quality of water supply to consumers, water distribution systems need to improve their knowledge on tropical lakes and reservoirs. Water quality of oligotrophic lakes is generally more suitable for a wider range of uses. Highly eutrophic lakes often are subjected to algal blooms. Modeling of lakes and reservoirs is extremely complex and is totally different from modeling of rivers. Many reports have been published concerning temperate countries lakes and reservoirs, but very few on tropical ones. This modeling study is an understanding of the behaviour of lakes in tropical climate in terms of some physico-chemical characteristics.

Modeling of lakes and reservoirs is totally different from that of rivers and extremely complex too. All these differences and complexities are attributed to the movement of water in two systems. While rivers are the running (lentic) water courses, lakes are standing (lotic) water bodies. Therefore mixing of pollutants in lakes is attributed to the perturbations by wind and temperature, unlike the thorough mixing in rivers by the natural velocity of flow. Heat transfer from surface requires careful evaluation of the wind conditions and ambient temperature variations. Thermal stratification plays a predominant role in mixing of pollutants. Unlike rivers, there is not a matter of self-purification in lakes. Pollutant accumulation and cycling are the characteristics of any static water body.

Lakes behave as non-ideal reactors with long hydraulic residence times. Even small lakes are having residence times in tens of years. Such systems are little affected by entrance and exit flow velocities. The major perturbations are caused by wind and temperature. Lakes gain and lose energy from wind, solar heating and radiant cooling. Wind causes circulatory motion, and this is enough to keep small un-stratified lake and impoundments nominally well-mixed. Deep lakes often have more than one circulatory cell in parallel, which may result in density stratification. Circulation in lower layer would be very weak, when compared to the upper cell. In warm weather, vertical convection currents are formed because of differential heating and cooling during day and night. Gradually water in the lower layer becomes significantly cooler and denser than that at the surface. The warm well-mixed surface layer which is few meter in depth is called epilimnion. The weakly mixed lower layer is called the hypolimnion. Between the epilimnion and hypolimnion is the thermocline/hypolimnion, a layer of varying depth having a sharp temperature gradient. These profiles may be shifted according to seasons.

ECOLOGY OF LAKES

Usually lakes and reservoirs contain a wide variety of living organisms, ranging from unicellular organism like bacteria to large fishes. They can be categorized into:

- Phytoplankton (bacteria, algae, and other floating plants)
- Zooplankton (protozoans, rotifers, small animals etc.)
- Crustaceans (bottom dwelling animals and plants)
- Macro organisms (small fishes and large fishes)

Phytoplanktons synthesize food for themselves, depending upon the availability of organic matter and nutrients in the case of bacteria and also on sunlight in the case of algae. Zooplanktons and small fishes fed on phytoplankton, and large fish feed on small fishes. In lakes the predominant phytoplankton species are photosynthetic algae. Since the phytoplankton concentration is a function of sunlight, temperature and turbidity, their concentration is dominant near the surface. Since zooplankton feed on phytoplankton, the concentration of the former also can be expected near the surface. Most often a first-order relationship can be assumed between them. Since temperature and nutrients are the factors involved in both models, ecological model should be coupled with hydrodynamic model.

MODELING OF LAKES

Modeling ok lakes and reservoirs is simple, if the effects of wind and temperatures are not considered. A simple mass balance can be applied according to a continuous flow stirred tank reactor (CFSTR) model. But it is extremely complex if the effects of temperature and wind are also taken into account (Tchobanoglous and Schroeder, 1987).

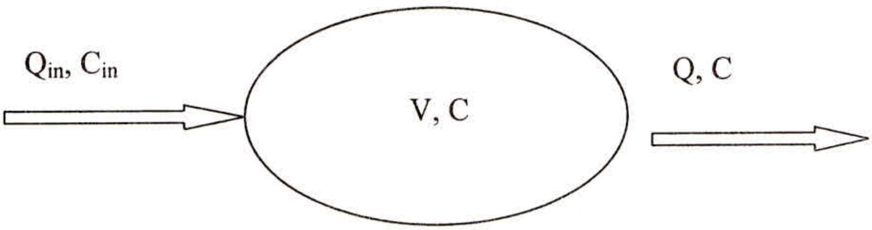

Figure 1. CFSTR Model

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

Acceleration rate = input rate – output rate – decay rate [1]

$(dC/dt) * V = (Q_{in} * C_{in}) - (Q * C) - (K*C*V)$ [2]

For steady state conditions, $Q_{in} * C_{in} = Q * C$ [3]

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 modeling 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 modeled using two or three spatial dimensions and time. Most recent modeling efforts for these utilize finite-element models for horizontal layers. Mass and energy transport between layers is described using classical hydrological approaches.

Importance of modeling, amidst all the difficulties, exists for answering three very important questions:

- Why has the current situation developed?
- What is likely to happen to lake water quality and organism populations in future?
- What will happen if the conditions are changed by a new discharge, removal of a present discharge, or a change in discharge quality?

Another importance of lake modeling is in engineering design. Facilities such as cooling ponds and impoundments can be simulated to shallow lakes.

Pollution of lakes can be attributed to different natural and cultural sources. Domestic and industrial wastewater discharges, agricultural runoff, wastewater from bathing and washing etc add organic and inorganic pollutants to the lake and most of them contain good amount of nutrients viz phosphates and nitrates. Water quality in lakes and reservoirs is more often related to eutrophication and temperatures than organic matter and BOD. Eutrophication, in the original sense, represents the natural aging process of a lake. It is known as the state of a water body, which is manifested by an intense proliferation of algae and higher aquatic plants, and their accumulation in the water body in excessive quantities.

The negative effects of eutrophication are as follows:

- Reduction in the penetration of sunlight, due to slime layer
- Natural re-aeration prevented
- Reduction in photosynthetic activity
- Depletion of Oxygen
- Aquatic organisms cannot survive
- Foul smell by rotting of algae
- Dystrophic state

CASE STUDY – LAKE PORUR

Lake Porur is located at Town Porur, about 15 km from Chennai city, at an elevation of 11.850 m from mean sea level (MSL). This small lake, with an area of 0.34 km^2 has a maximum capacity of 36Mcft (Million cubic feet) and an average depth of 3 m. Presently this lake is being used as one of the drinking water sources of Chennai city. About 33 MLD (million litres per day) is being pumped to Kilpauk Water Treatment Plant and approximately the same amount is being received from the Chambrambakkom Lake. Practically, no run-off water is reaching the lake since the surrounding lands are densely populated areas and of city nature. The lake receives a small quantity of rain water during the monsoon. The shores of the lake seem to be heavily contaminated with lot of solid wastes. The lake is being continuously used by the local people for bathing, washing clothes, bathing of cattle, even near the intake tower. The shores are being used as vast open toilets. Heaps of solid wastes can be seen along the shores. Totally unhygienic situation prevails near the lake. Most often several reports are coming in news papers, about the unsanitary conditions of the lake and the unauthorized uses of the lake by the local people.

MATERIALS AND METHODS

Sampling and Field Measurements

A reconnaissance survey was conducted to study the conditions and the present scenario of the lake and the surroundings. Samples were collected from 16 selected stations, at different horizontal distances and different depths. The sampling points were so selected that they supposed to cover the entire lake representatively (Figure. 2)

In-situ measurements were taken for Temperature and Dissolved Oxygen (DO) using Dissolved Oxygen Meter. The samples collected from various locations were analyzed for Biochemical Oxygen Demand (BOD), Chemical Oxygen demand (C Turbidity, Phosphate-P and Sulphate as per Standard Methods for Water and Waste Treatment (APHA, 1992).

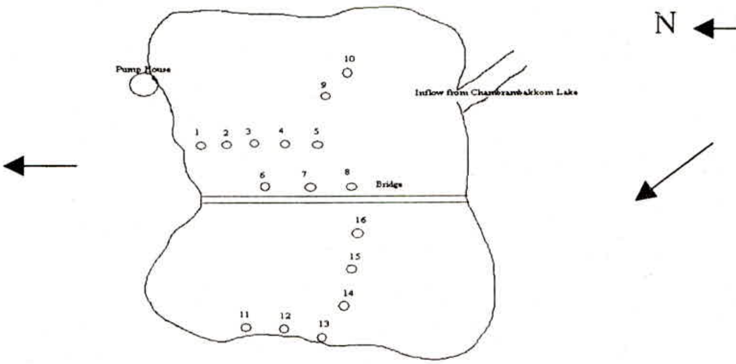

Figure 2: Sampling Locations

RESULTS AND DISCUSSION

The variations of temperature and DO with depth are shown Figure 3 and Figure 4 respectively. The temperature profile shows an epilimnion of about 1.2 m depth and a gradual thermocline from 1.2 m to 2 m depth and a shallow layer of hypolimnion.

The DO of the surface water was found to be as low as 6.5 mg/L. In spite of the direct contact with the atmosphere, this low value may be due to the higher temperature towards the surface. The thin film of oil and dirt, which is directly releasing as a result of intensive bathing and washing of clothes, enhances the reduction in DO especially near the shores. The DO concentration was found increasing towards the bottom of the epilimnion, which is obvious due to the reduction in temperature. But towards the bottom of the hypolimnion, the DO again decreases to a lower value, as low as 4 mg/L. This may be due to the excessive utilization of DO for the decomposition of dead phytoplanktons. The profile of Biochemical Oxygen Demand (BOD) also showed the corresponding trend (Figure 5).

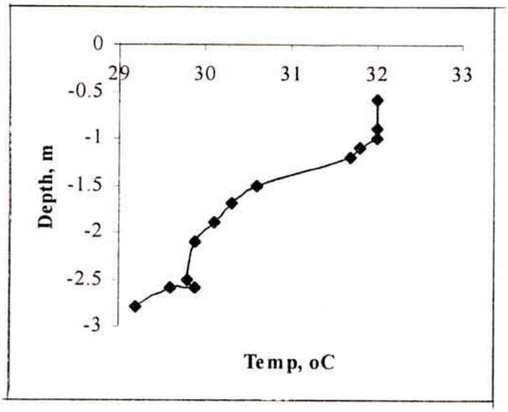

Figure 3. Temperature Profile

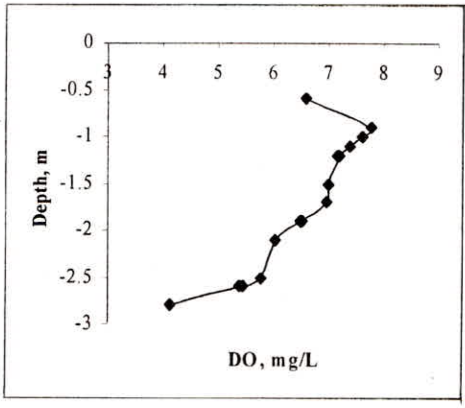

Figure 4. Profile of Dissolved Oxygen

The surface water showed a higher turbidity of about 14 NTU with a gradual reduction towards the thermocline (Figure 6). The turbidity again increased to higher values of about 16-18 NTU towards the hypolimnion, which may be due to the sediments and dead planktons.

The most important parameter which decides the health of a lake is the presence of nutrients, Phosphorus and Nitrogen. The profile of Phosphate-P with depth is shown in Figure 7. The surface water was found to have high concentrations of phosphate-P, especially near the shores. Intensive use of detergents containing good amount of phosphates is obviously one reason. Dumping of solid wastes at many points near to the shore also contributes a lot to this fact. The concentration of Phosphorus decreased from a value of 56 μg/L at the surface to 52 μg/L to the thermocline, which again increased to higher values of >60 μg/L towards the bottom of the hypolimnion. This can be explained by the settling nature of phosphates.

The Organization for Economic Co-operation and Development (OECD, 1982) has given the range of concentrations of phosphates-P for oligotrophic (4.8-13.3 μg/L), mesotrophic (14.5-49 μg/L) and eutrophic (48-489 μg/L) lakes (Ryding and Rast, 1990) . The ranges given are mean ± 1 SD. Lake Porur is proved to be slightly eutrophic by its average phosphate-P concentrations 50 – 62 μg/L. This value is about 700 % of the normal concentration of phosphate-P for an oligotrophic lake.

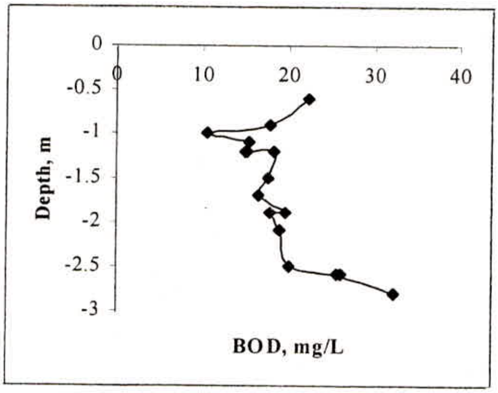

Figure 5. Profile of BOD

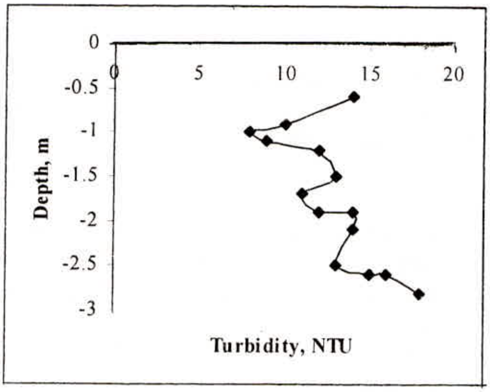

Figure 6. Profile of turbidity

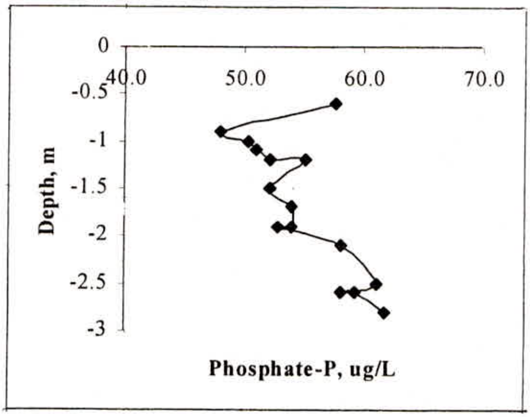

Figure 7. Profile of Phosphate-P concentration

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 8).

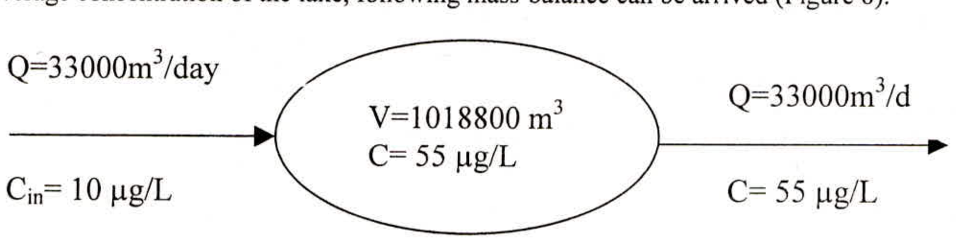

Figure 7: Mass balance for phosphate-P

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 pf 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.

RESTORATION OF THE LAKE

Even though many techniques are developed for the control of eutrophication in lakes, economical methods are only few (Mitsch and Jorgensen, 2004). Direct reduction of phosphates at the source is one practical alternative. This can be achieved only by the controlled use of detergents in the case of Lake Porur. Laws regulating the amount of phosphates in detergents do exist in some countries. For example, in Canada, a detergent phosphate limitation of 2.2 % (by weight) is in effect. Switzerland does not allow any phosphates in detergents (Ryding and Rast, 1990). India does not follow any regulations like that. Since Lake Porur is a major source of drinking water for the City of Chennai, strict rules and regulations should be implemented by the local authority for any other use of this lake which may lead to pollution. Use of detergents and bathing of animals should be totally prohibited by laws.

Even though no authorized entry of sewage into the lake is there, banks are severely polluted with solid waste dumps from shops, markets and other commercial centres. Nutrients like phosphates and other pollutants from these dumps will ultimately reach the lake, especially during the rainy season. Even though the Public Works Department of Tamil Nadu decided to construct a 'pucca wall' around the lake in 2003, which was scheduled to be constructed with in six months, still these attempts are in papers only. Since the location of this lake is amidst of city, protection of the lake by a wall all around is an immediate requirement. Implementation of laws regulating the use of the lake is possible only after the construction of this wall.

Dredging of nutrient rich sediments from the lake bottom is one option for the control of eutrophication, via the control of internal loading of nutrients and other materials. Severely affected regions can be restored by harvesting the macrophytes and the attached algae, which can provide an immediate relief. Biological control (Biomanipulation) involves the use of specific organisms to control growths of algae. But extreme caution is advised in introducing foreign or exotic species to a given water body, since they may severely upset its ecological structure. Considering the possible toxicity effects, chemical control (application of specific chemicals to water bodies to kill undesirable aquatic plants) is not advisable in the case of Lake Porur.

CONCLUSIONS

Lake Porur is being pouted beyond its assimilating capacity. The prolonged use of this small lake, in the present unhygienic manner will lead to a pathetic situation, from which a return is very difficult. This matter should be tackled by the concerned authorities. The concentration of

Phosphate-P should be brought down to one seventh of the existing value. Construction of a wall all around the lake is an urgent step to be taken to prevent further entry of phosphates by run-off and unauthorized use of the lake by local people for washing and bathing. Strict rules should be implemented to restrict the dumping of solid wastes on the banks of the lake. Harvesting of macrophytes and the attached algae can be done for immediate relief from eutrophication. Dredging of nutrient rich sediments can be done to remove or reduce the phosphates settled at the bottom.

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