

THE INFLUENCE OF ARTIFICIAL DESTRATIFICATION ON CHEMICAL  
PROCESSES IN UPPER LAYANG RESERVOIR

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## ABSTRACT

Upper Layang Reservoir located 40 km from Johor Bahru is an impounded reservoir for water supply. The reservoir suffered serious water quality problems in 1995 due to algal bloom which dramatically impacted the water treatment process. An extensive study of the reservoir was conducted in order to understand the behavior of a tropical reservoir. This study comprises of three major components which focused on physical and chemical water quality properties of Upper Layang Reservoir. The first component involves investigation of long term processes affecting water quality in the reservoir. The second component addresses a trial study of an artificial destratification system designed to improve the water quality at the reservoir. The third component involves reservoir modeling with HEC-5Q in terms of temperature and dissolved oxygen simulations. In the first component, weekly observation was conducted for the duration of fourteen months at four selected sites at the Upper Layang Reservoir. The observation includes *in-situ* and water quality parameters measurements for nutrients and metals. *In-situ* parameters include temperature, dissolved oxygen, redox and pH. Nutrient analysis involves nitrate, nitrite, ammonia, total Kjeldahl nitrogen, dissolved phosphorus and total phosphorus whereas metal analysis involves dissolved iron, total iron, dissolved manganese and total manganese. The data obtained showed that Upper Layang Reservoir underwent thermal stratification for the majority of the year. Brief periods of natural mixing were also observed due to heavy downpour in the monsoon season. In the second component, a destratification process was effected using bubble plume perforated line diffuser at the reservoir. During destratification, the number of sampling sites was increased to twenty seven sampling sites. Intensive study was conducted for a period of two months on a daily basis for the first three weeks and three days a week until aeration completed. The result obtained showed that thermal stratification was successfully eliminated after seven days of continuous aeration. Dissolved oxygen concentration at the bottom of the reservoir was also increased to more than 4.50 mg/L which facilitates the reduction of iron and manganese concentrations at the bottom waters and also reduced the concentration of ammonia and phosphorus.

## ABSTRAK

Empangan Layang Atas yang terletak 40 km dari Johor Bahru merupakan takungan bagi bekalan air. Pada tahun 1995, empangan tersebut mengalami masalah kualiti air yang serius disebabkan oleh kembangan alga yang memberi kesan kepada proses olahan air. Kajian terperinci telah dilakukan di empangan tersebut untuk memahami kelakuan empangan di kawasan tropika. Kajian ini melibatkan tiga komponen utama berkaitan kualiti air dari segi fizikal dan kimia di Empangan Layang Atas. Komponen pertama melibatkan penyelidikan kesan jangka panjang ke atas kualiti air di empangan tersebut. Komponen kedua melibatkan percubaan sistem pengudaraan tiruan yang direka bentuk untuk meningkatkan kualiti air di empangan tersebut. Komponen ketiga melibatkan pemodelan empangan menggunakan perisian HEC-5Q dari segi simulasi suhu dan oksigen terlarut. Dalam komponen pertama pemantauan mingguan dilakukan selama empat belas bulan di empat stesen di Empangan Layang Atas. Pemantauan tersebut melibatkan parameter *in-situ* dan kualiti air bagi nutrien dan logam. Parameter *in-situ* yang diukur adalah suhu, oksigen terlarut, redoks dan pH. Analisis nutrien melibatkan nitrat, nitrit, ammonia, nitrogen Kjeldahl jumlah, fosforus terlarut dan fosforus jumlah manakala analisis logam melibatkan ferum terlarut, ferum jumlah, mangan terlarut dan mangan jumlah. Data yang diperolehi menunjukkan bahawa Empangan Layang Atas mengalami proses pelintapan suhu pada kebanyakan masa sepanjang tahun. Pengudaraan semula jadi dalam tempoh yang singkat juga berlaku di empangan tersebut disebabkan oleh hujan lebat pada musim monsun. Komponen kedua melibatkan pengudaraan tiruan yang direka bentuk untuk meningkatkan kualiti air di empangan tersebut menggunakan sistem udara peresap. Semasa proses nyahlintapan tersebut, stesen persampelan ditambah menjadi dua puluh tujuh stesen. Kajian intensif untuk jangka masa dua bulan dilakukan setiap hari selama tiga minggu dan kemudiannya dilakukan tiga kali seminggu sehingga selesai pengudaraan. Keputusan yang diperolehi menunjukkan bahawa pelintapan suhu di empangan tersebut berjaya dihapuskan selepas pengudaraan berterusan selama tujuh hari. Kepekatan oksigen terlarut di dasar empangan pula meningkat melebihi 4.50 mg/L yang seterusnya membantu mengurangkan kepekatan ferum dan mangan di bahagian dasar empangan dan membawa kepada penurunan kepekatan ammonia dan fosforus.

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**LIST OF SYMBOLS/ ABBREVIATIONS**

°C	degree Celsius
BOD	biochemical oxygen demand
chl-a	chlorophyll-a
CBOD	carbonaceous biological oxygen demand
DO	dissolved oxygen
HDPE	high density polyethylene
km <sup>2</sup>	kilometer square
m	meter
mg/L	milligram per liter
mm	millimeter
Mm <sup>3</sup>	million cubic meter
SOD	sediment oxygen demand
SRP	soluble reactive phosphorus
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TP	total phosphorus

## CHAPTER 1

### INTRODUCTION

Environmental problems in tropical regions are becoming the focus of increasing international attention. By the end of the century one third of the population of the world, i.e. about two billion people will be living in humid tropics (Sagastume, 1996). This presents a major challenge for the sustainable development of these countries and a potential threat to environmental quality, particularly water resources. The vast majority of environmental studies have been conducted in industrialized temperate regions. Therefore, the study of tropical aquatic systems deserves special attention because tropical aquatic environments cannot be understood using the same principles that have been applied to temperate systems (Lewis, 1987).

Malaysia is not a lake land country; the aquatic environment is dominated mainly by lotic environment. Very few lakes are formed naturally in Malaysia; there are only two principal lentic environments in Malaysia i.e. Tasik Chini and Tasik Bera (Furtado & Mori, 1982). Both of these lakes are located in Pahang and are relatively small in size. Tasik Bera is more of a freshwater swamp than a true lake, covered with stands of littoral, floating, emergent and submerged vegetation, such as *Lepironia articulata* and *Pandanus helicopus*, and very few truly open water spaces. Tasik Chini consists primarily of water bodies joined together to form a string of

small lakes (Ali, 1988). Other small bodies of water, either permanent or semi-permanent, such as the Paya Bungur and Tasik Beringin, are shallower wetland ecosystems than lakes (Yusoff *et al.*, 1984).

Man-made lakes or reservoir dominates the Malaysian lentic environment. In Malaysia, there are 63 large impoundments with a total storage of 25 billion m<sup>3</sup> ranging in size from 10 ha (Mahang Dam) to 37 000 ha (Kenyir Dam) and 150 major river systems (100 in Peninsular Malaysia, more than 50 in Sabah and Sarawak (Mohd. Azhar, 2000). These large impoundments were constructed either for irrigation, hydroelectric power generation or flood mitigation. The rest of the man-made lentic environment comprises small reservoirs whose main functions are flood mitigation, irrigation, domestic and industrial water supplies. The current estimate of the total Malaysian lentic environment is about 1000 km<sup>2</sup>, with another 1000 km<sup>2</sup> in the planning or implementing stages. The number of lakes and reservoir in Malaysia classified by their respective state is shown in Table 1.1 (Zulkifli, 2005).

**Table 1.1:** Number of lakes and reservoirs in Malaysia (Zulkifli, 2005).

<b>State -</b>	<b>Lake</b>	<b>Reservoir</b>
Perak	2	9
Selangor	5	10
Pahang	2	8
Kelantan	-	3
Johor	-	13
Kedah	1	6
Labuan	-	3
Melaka	-	3
Negeri Sembilan	-	5
Pulau Pinang	-	4
Perlis	2	-
Sabah	-	5
Sarawak	2	3
Terengganu	1	1

The Public Works Department (1999) reported that there are 33 reservoirs supplying 328.5 million cubic meters of water for domestic and industrial usage in



Malaysia. These reservoirs are operated by the State Water Authorities and administered by the Federal Public Works Department. The paradox of water supply shortage problem in Malaysia with an abundant amount of rainfall has certainly affected the country's dignity (Supiah, 2003). The water supply shortage problem, particularly in 1997 to 1998 was not predicted and totally unprepared for. The problem that has affected the country's development and human health needs harborage. The onset of the water scarcity is due to the raw water supply pollution. The tremendous pressure on water supply system could be solved either through immediate measures or long term planning. Reservoir pollution and eutrophication must be given attention to ensure sufficient water supply for the public.

The detrimental effects of an impoundment on water quality have long been recognized (Churchill, 1977; Love, 1961; Wang and Evans, 1971). Many of the problems are exacerbated by vertical density variations of a reservoir water body induced by differences in temperature i.e. thermal stratification. This natural phenomenon triggers substantial hydrodynamic and chemical alterations in the water body. The consequences include:

- Reduced dissolved oxygen in hypolimnion
- Increased concentration of anaerobic decomposition products, resulting in taste and odor problems.
- Increased concentration of iron, manganese, nitrogen and phosphorus in the hypolimnion
- Elevated epilimnion temperatures
- Accelerated evaporation
- Accelerated eutrophication associated with the dissolution of ions
- Restricted mobility of biota
- Fish kills associated with an anoxic hypolimnion
- Increased used of water treatment chemicals
- Increased concentration of diffusing substances from the sediments into bottom layers

The use of artificial destratification strategies to control certain water quality parameters in reservoir is becoming more prevalent in a world with limited resources yet increasing anthropogenic stresses (Cooke *et al.*, 1993). Reservoir managers are facing the decisions as to which control strategy to select in controlling the problems. Consequently, current remediation efforts are based primarily on experience (Burns and Powling, 1981). The optimal strategy, however, depends on which parameters are of importance, what the forcing conditions dictate and which technologies are economically feasible. Since the main cause of these problems are related to lack of dissolved oxygen due to thermal stratification, the best method to deal with the matter would be to enrich the oxygen depleted region (North America Lake Management Society, 1990). This can be achieved by breaking the thermal layer thus inducing a complex mixing of the stratified water and also by aerating the hypolimnion. Artificial mixing devices have been used to prevent water quality problems associated with thermal stratification in many western countries. The technique has also been adopted in Singapore (Tay and Chui, 1990) and at Sungai Terip Reservoir in Negeri Sembilan, Malaysia (Kassim *et al.*, 1997)

### **1.1 Background to Research Problem**

Reservoirs in Malaysia are in the process of being seriously threatened by appalling water quality conditions. Sungai Terip reservoir in Seremban for instance, encountered permanent stratification and high concentration of iron and manganese. Meanwhile, Pansoon Reservoir in Hulu Langat experienced frequent occurrence of dinoflagellate (algae) blooms (Anton, 1994) where as the Durian Tunggal Reservoir in Melaka is well known nationwide for its obvious water level problem. Upper Layang reservoir in Johor, suffered an algal bloom in 1995, which dramatically impacted the treatment process. Significant increases in coagulant were required which in turn resulted in elevated residual aluminium and turbidity levels in the treated water. It has been estimated that this event cost the operator in excess of US\$400,000. Pertaining to this matter, the well publicized New Strait Times: Joint

Research Water Development Project, May 1999, water quality and eutrophication related Sungai Layang reservoir enigma are obliged to be studied.

Sungai Layang Water Treatment Plant at Masai, Johor is served by two reservoirs i.e. Upper and Lower Layang reservoirs. Raw water from Upper Layang is piped directly to the plant for processing into drinking water. The Upper Layang reservoir has a surface area of 6 km<sup>2</sup>, with a maximum depth 16 m. It receives inflow from Lower Layang reservoir, as well as runoff from the catchment area. Lower Layang reservoir is a much smaller reservoir compared to Upper Layang, however it has a much larger surface area, approximately 32 km<sup>2</sup> with a maximum depth of 6 m. It only receives input from runoff from its catchment area. Both the reservoirs are not managed with respect to quality hence the incidents of poor water quality (algal bloom in 1995) have not been clearly linked to a specific cause(s). Therefore the likelihood of reoccurrence of such an event is unknown. This has led to the importance of developing a certain level of understanding to quantify seasonal variability of water quality in a relatively shallow tropical reservoir.

Nutrient concentration is widely recognized as a major factor regulating algae succession in lakes and reservoirs (Wang and Evans, 1971). Evidently the episode of algae bloom at Upper Layang has to be related to high nutrient content in the water column. Prior to the event, Wan Azam (1994) carried out monthly environmental monitoring at Upper Layang reservoir for a year. However his approach was focused to the presence of high concentration of iron and manganese in the water column. Hence the more likely high nutrient contents in the reservoir went unnoticed and triggered the algae bloom in 1995. Nutrients in waterway sediments will maintain algal blooms for many years and will not completely disappear (Verhoeven, 1995).

The unpredictable nature of tropical climate with intermittent wet and dry season requires aggressive reservoir monitoring in order to understand its behavior. Reservoir behavior explicitly means the response of a reservoir to all external influences, manifested as physical, chemical and biological variability within the

reservoir. To date monitoring in Malaysian reservoirs are mostly carried out on monthly basis due to financial or manpower constraint. This could miss out possible inputs and outputs of a reservoir. Therefore comprehension of a shallow reservoir behavior is an imperative element in this study.

A number of actions could then be utilized to improve the raw water quality based on the reservoir behavior in the context of economic viability. Various treatment systems have been adopted in both temperate and tropical countries. One of the most favorable methods in combating water quality problems in reservoirs is artificial destratification via diffused air aeration technique. Thus a destratification trial using this method will be carried out as one of the Upper Layang reservoir management contingency plan.

## **1.2 Objectives of Study**

This study comprised of two major components. The first component is focused on medium to long term processes affecting water quality in a shallow tropical reservoir i.e. Upper Layang reservoir situated in Masai, Johor. The second component addressed the trial of a destratification system designed to improve the water quality of Upper Layang reservoir.

The purpose of the first component of this research is to develop an understanding of the reservoir behavior and process affecting the water quality of the raw water sources. The objectives can be summarized as follows:

1. To obtain information from the reservoir (both water quality and quantity) on a routine basis over a significant period (12 months).
2. To establish some basic cause effect relationships for water quality problems occurring within the reservoir.

3. To develop recommendations for the collection of key information from the reservoirs for the purpose of improved management

The purpose of the secondary component of this research project is to develop recommendations for the implementation of a water quality improvement device (artificial destratification system) at Upper Layang reservoir in terms of

1. Reducing an existing problem i.e. thermal stratification
2. Preventing the development of a problem
3. Feasibility of a long term use of the destratification system

### **1.3 Scope of Work**

The scope of the study are summarized as follows:

1. The chemical characteristics mainly involving nutrients (phosphorus and nitrogen) in the raw water. Metals (iron and manganese) would serve as secondary parameters since their correlation with nutrients have been reported.
2. *In-situ* measurement (temperature, dissolved oxygen, pH, redox potential, conductivity, turbidity and salinity) would be carried out at selected sampling station.
3. Physical characteristics only include inter-basin transfers; rainfall over the catchment's area and evaporation.
4. Biological characteristic only covering dominant algae types and algae counting.
5. Study on the destratification trial which will only be correlated with the above selected physical, chemical and biological parameters.
6. Application of HEC-5Q model in monitoring thermal stratification and dissolved oxygen in the reservoir.