PHOSPHORUS LOADINGS ESTIMATION AND EUTROPHICATION STATUS OF SUNGAI LAYANG RESERVOIR USING VOLLENWEIDER MODEL

by

Supiah Shamsudin
Department of Hydraulics and Hydrology
Faculty of Civil Engineering

ABSTRACT

The study dealt with Phosphorus loadings estimation and lake eutrophication status using Vollenweider Steady-State Empirical Model. The phosphorus loadings predicted by Vollenweider's Model indicated that Sungai Layang Reservoir is an *eutrophic* lake. The mean hydraulics residence time obtained was 0.86 year and phosphorus loadings estimated was about 2.02 tons/year. Alternative methods of controlling phosphorus loading is briefly discussed.

INTRODUCTION

Phosphorus (P) and sediment inflows into lakes and reservoirs could accelerate the process of eutrophication or lake aging. Eutrophication is no longer regarded as a natural phenomenon since the process is accelerated through watershed disturbance by humans. This artificial acceleration is causing concern throughout the world.

Phosphorus should be controlled at sources, either point sources or non-point sources. Emphasis on phosphorus loading from non-point sources should be given because it has a significant influence over the water quality as much as the point sources. This estimate of phosphorus loading is necessary in order to forecast and control the state of eutrophication in lakes and reservoirs.

Phosphorus as Limiting Factor

The nutrient inputs results in productivity which is characterized by algal growth or dense microphyte. The algae will eventually form a layer of mats or scums on the surface which will prevent light penetration and oxygen circulation to the bottom of the lake. Photosynthesis will be reduced,

consequently reducing the amount of oxygen in the lake. The decomposition of dead algae may exhaust the oxygen, there by resulting in fish kills. Algae add taste and color to the water. Some species of algae release toxic substances, and they can be responsible for the clogging of filters at withdrawal points. Metals will become more soluble due to oxygen depletion (Olem 1990). Soluble metals are unhealthy for human beings. Therefore rapid reproduction of algae results in undesirable conditions in the lake water quality and quantity. As little as 5-10 kg/m^3 (0.01 mg/litre) of phosphorus can trigger such a bloom (Henderson 1989).

Recent investigations seem to favor phosphorus as the *limiting factor* for reservoir productivity (Henderson, 1989). If addition of more nutrient than is already in the water results in a markedly higher algal growth, that nutrient is limiting. Phosphorus is apt to be limiting because plant ceases to grow during shortage or missing of the nutrient. In most cases, the only permanent way to control eutrophication, is by reducing the amount of the limiting nutrient, preferably phosphorus.

The two main sources of P are point source and non-point sources. Point sources come from one specific location such as waste treatment plant, landfill, industry etc. while non-point sources pollutant comes from the watershed such as from developing areas, agricultural areas, animal feed lots and through process of erosion. It has to be controlled either at the above sources, in the transport phases or in the lake itself. The two different components of P in the transport phase which need to be controlled are Dissolved-P and Sediment Sorbed-P.

The continued uncontrolled loading of nutrients into lakes will sooner or later render them eutrophic. Especially for the shallow lakes, they reach eutrophic stage relatively easily. However, the very large and deep ones will take time to be changed by pollution loadings. The effect of P loading has economic implications; however, the losses due to eutrophication are troublesome to evaluate.

Objective and Scope of Study

The purpose of this study is to estimate the rate of phosphorus loading from the drainage area into Sungai Layang Reservoir using Vollenweider Steady-State Empirical Model. The eutrophication status of the Sungai Layang Reservoir is determined using the Vollenweider phosphorus loading diagram. Rainfall-runoff simulation results using MIKE 11 NAM model is used as input parameters for the above model.

Materials And Method

Site Description
There are two reservoirs within the Layang catchment area : Hulu Layang reservoir and Hilir Layang reservoir. Upper Layang reservoir is in Masai, 40km north east of Johor Bahru City. The reservoir is situated among hilly and undulating area. The maximum altitude is 160m and minimum altitude is 30m above mean sea level. The Upper Layang catchment is located approximately within the coordinates of 1°30' N and 1°36' N latitudes and 103°50' E and 104°00' E longitudes with an average catchment slope of 1.6%. It constitutes the south-western part of the State of Johor. Upper Layang catchment is one of the major hydrological sources that produce runoff for the reservoir . Sungai Layang is the main river that drains into the reservoir.

Hilir Layang Reservoir is on the eastern part of the Hulu Layang Reservoir. The drainage basin for Hilir Layang Reservoir is 20.5 km^2 The total drainage basins for both reservoirs is 50.0 km^2. Water outflow from both catchment is about 40 MGD. At the present time, the outflow rate of water from the intake tower to the water treatment plant is 28.5 MGD. These areas are shown in Figure 1.

The surrounding tributaries and their activities around the catchment area are summarized in Table 1.

Table 1: Summary of Activities Within Sungai Layang Watershed

	Tributaries	Activities around the area
Hulu Layang Reservoir	Kampung Penorogo	50 houses, human waste and chicken breeding
	Felcra Ban Foo	Agriculture, chicken and pig breeding
	Ladang Plentong	Fish farming, illegal houses
Hilir Layang Reservoir	Ladang Keck Seng	Commercialized palm tree plantation
	Ladang Bukit Layang	Palm tree estate, domestic wastes
	Ladang Sungai Tiram	Palm tree estate, domestic wastes

Phosphorus Loading Model
In view of the complexity of the transport and eutrophication processes, as well as the cycle of various nutrients in the water bodies , the model choice problem is considerably broader than purely hydrologic problems (Everett, 1972). For purely scientific purposes as reported by Bogardi (1978), it is a very worthwhile pursuit to choose no model at all (the null choice). The behaviour of one species of plankton or one predator-prey relationship can be observed and the result can be described scientifically. However, if a decision is to be
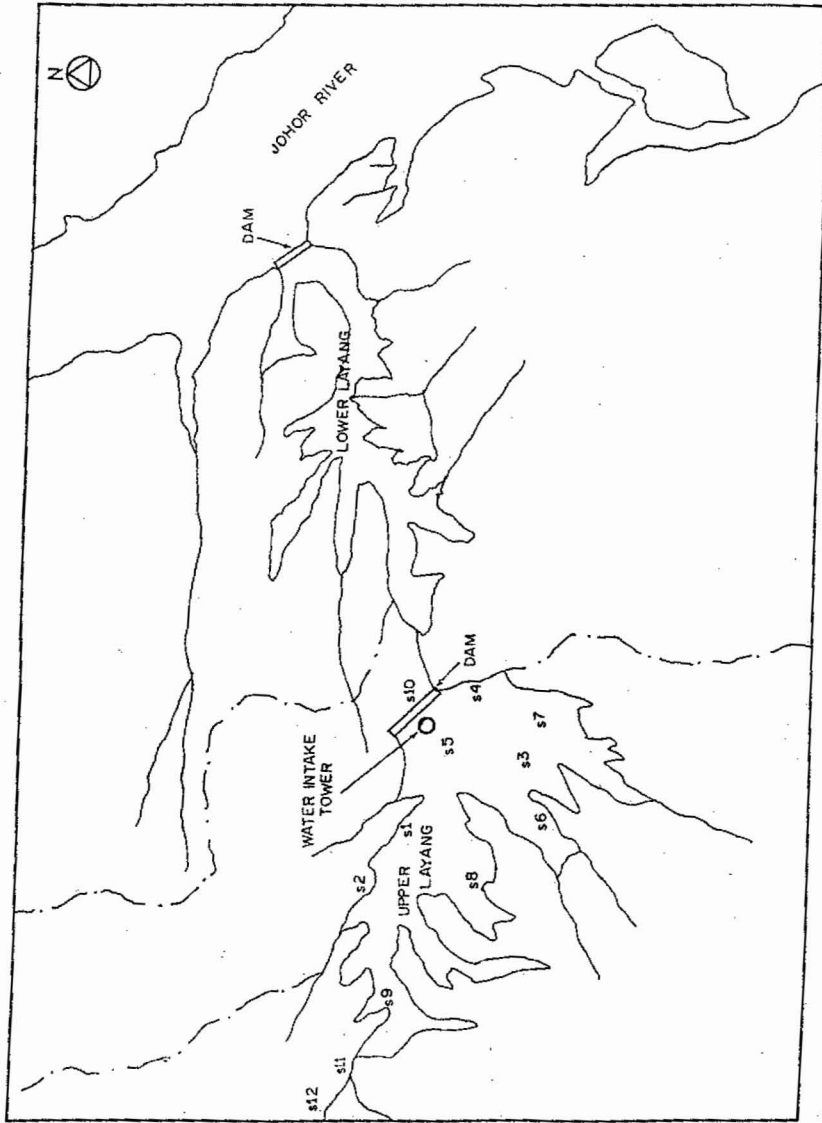
Figure 1 : Map Showing Location of Layang River Reservoirs and Station
of Phosphorus Samples.

made on the basis of the observation, then a system model is in order (Casti *et al.,1977*). Not all descriptive models are usable for decision-making: only those models capable of predicting new situations can be used. In other words, the decision to be made determines, or at least guides, the choice of a model (Bogardi et al., 1978).

For this purpose , one may envisage adapting the model developed by Imboden and Gachter (1975). Unfortunately, it would take many years to gather sufficient data to adapt and calibrate such models. The use of models such as proposed by Riley et al. (1949), Steel(1965), Chen(1968), Orlob(1968), Di Toro *et al.* (1970),Park(1959), Wilkinson(1971) and Jorgensen(1976) are based on a set of differential equations expressing the conservation of mass in the lake body.

Vollenweider (1968, 1976) has developed a series of predictive relationships between phosphorus and hydrologic loading rates using data from European and North American lakes as described by Connell and Miller (1984). The model developed by Vollenweider had been used in this study because of its proper definition of lake eutrophication processes.
In general, lake eutrophication are associated with two distinct lake process: external and internal loadings. The water quality variations are related to two distinct time scales: seasonal or annual variations and long-term variations (French,1974). For a nutrient relationship study, French (1984) points out that seasonal or annual variations are effectively treated by dynamic models, while at long-term variations in water quality are best addressed by steady-state empirical models in association with the hydraulic residence time of the water body.

Minns (1986) continued Vollenweider's model by producing a simple whole-lake phosphorus two compartment model. The model takes into account the role of sediments as sources and sinks of internal phosphorus loadings. Williams and Hann (1977) started considering uncertainties in an explicit manner in their investigation. Very few attempts had been made to model uncertainties in the eutrophication process so far as described by Bogardi (1990). In the latest development, Duckstein and Bogardi (1990) encoded uncertainty in the form of probability density function (pdf). Uncertainty study is very important as it would reveal the degree of accuracy of the result.

Vollenweider Model
The general steady-state equation for P loading by Vollenweider and Dillon (1974) can be written as :

$$Lp = \sum_{C=1}^{n} Qi \, [P]i + L_{INT} \qquad (1)$$

where
Lp is the loading of P per unit area per year; (mg m^{-2} yr^{-1})
Qi represents the amount of water supplied by each input,
Pi the mean P concentration of dissolved and sediment-bound
phosphorus (external loading)
L_{INT}, the loading from the lake sediments to the water column
(internal loading)

External P inputs are normally derived from catchment runoff, groundwater
input and rainfall. Internal loadings of P from lake sediments to the water
column are difficult to measure . They are assumed to be relatively unimportant
in many lakes as described by Connell and Miller (1984) although in certain
cases, it may exceed external loadings.

P loading to a lake can be predicted from its mean P concentration in the water
body, lake hydraulic characteristics and sedimentation rate. Using the
Vollenweider (1976) one-compartment model (assuming negligible L_{INT})

$$Lp = P . qs. (1 + \sqrt{Tw}) \qquad (2)$$

where
P is the mean total concentration of dissolved and sediment P in the
water body.
qs is hydraulic loading (m yr^{-1}).
Tw is the mean residence time of water in the lake

As a general rule, the critical P values that will convert the oligotrophic state
to the mesotrophic state is 10 µg/l (Vollenweider, 1976). Thus, equation (2)
can be transformed into:

$$Lc = 10 . qs (1 + \sqrt{z/qs}) \qquad (3)$$

where
z the lake mean depth (m)

The phosphorus loading Y tons year^{-1} is obtained by multiplying the loading L
tons m^{-2} yr^{-2} with the surface area of the reservoir.

Hydrologic Input

Results from the indirect method of simulating runoff for ungauged catchment
using the MIKE 11 NAM model (Tarmizi et al., 1997) was applied. Tarmizi et
al., (1997) had calibrated two bigger nearby catchments, Sungai Tebrau and
Sungai Sayong with respect to their observed daily discharges data. They had
simulated the runoff of an intermediate smaller subcatchment, Upper Sungai
Layang, by using the average and proportionate values of calibrated parameters
of Sungai Sayong and Sungai Tebrau. This was done by considering the same

catchment characteristics. They had obtained a relationship between the area and runoff coefficient that can be used to estimate the runoff volume. However, these data will need to be validated in the future. The calibration results and the simulation accuracy will be improved by installing more rainfall stations throughout the catchments.

The annually and yearly simulated discharges obtained from Mike 11 NAM model are tabulated in Table 2. These data are used for the hydraulic loading estimation in the Vollenweider model.

Table 2 : Average Flow For 7 Year Period (1987-1994)

Precipitation	2231.2
Overland flow	590.6
Baseflow	309.6
Simulated Discharge	941.4

Results and Discussion

Phosphorus Content of the Reservoir
Water samples were taken from 10 stations randomly selected all over the reservoir as shown in Fig. 1 : The water sample were taken at 3 different depths, that is at the water surface, middle and bottom layers. The water samples collected from the water body were tested with reagent phosVer 3 phosphate using DR 3000 Spectrophotometer (Hach Co. CO 80539-9987, USA). DR 3000 indicates the phosphorus content in the sample in mg/l. Table 3 in the Appendix shows the phosphorus content in the sample . The average *dissolved-P* concentration obtained from the study is *0.0410 mg/l @ 41.0 ug/l*. Che Yan et. al. (1993) reported that the concentration of total phosphorous was estimated to range from 0.06mg/l to 1.1 mg/l . The concentration level was lower in this study because only the dissolved-P component is taken into consideration. Other aspects of water quality observed from the site investigation are the average pH value and average dissolved oxygen (DO) content. The average pH value recorded was 6.95 while the average DO was 7.19 mg/l.

Eutrophication Status of Reservoir Sg. Layang
The eutrophication status obtained from this study was based on Vollenweider's P-loading model. The P-Loading diagram shown in Fig. 2 indicates that Sg. Layang reservoir is an *eutrophic* lake. The small dot 'A' indicates the current condition of Sg. Layang reservoir's eutrophication status. The phosphorus loading is critical and it needs to be controlled.

Table 3 : Phosphorus Content in mg/l with DR-3000

	Base (mg/l)	Middle (mg/l)	Surface (mg/l)	Vertical Average
Sample 1 (ST1)	0.043	0.025	0.052	0.040
Sample 2 (ST2)	0.060	0.025	0.056	0.047
Sample 3	0.024	0.012	0.029	0.022
Sample 4	0.044	0.059	0.070	0.058
Sample 5 (ST3)	0.023	0.054	0.030	0.036
Sample 6	0.015	0.031	0.047	0.031
Sample 7 (ST4)	0.079	0.024	0.031	0.045
Sample 8	0.025	0.042	0.033	0.033
Sample 9 (ST5)	0.043	0.055	0.066	0.055
Sample 10 (ST6)	0.039	0.032	0.033	0.035
Horizontal Average	0.0359	0.0359	0.0477	0.041

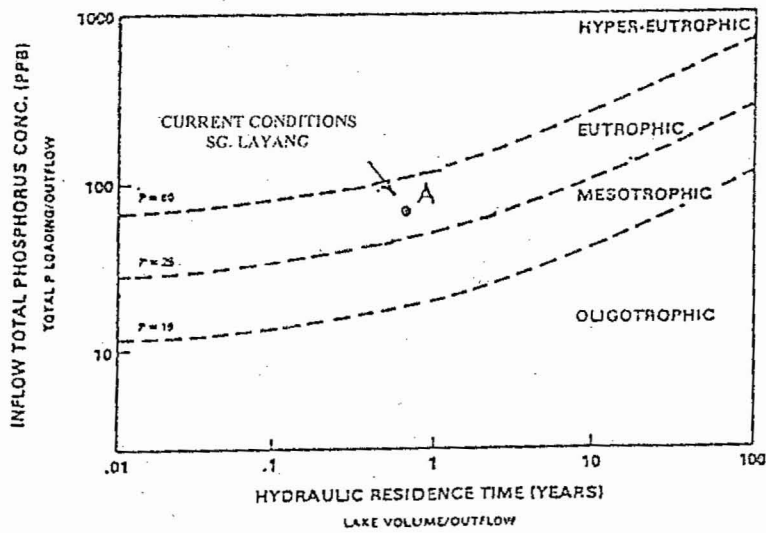*Average Concentration 0.041 mg/l (Sek, 1993)*

Figure 2 : Vollenweider's P- Loading Curve Showing Current
Condition for Reservoir Sungai Layang

Estimated Phosphorus Loadings

The dissolved-P loading estimation and its budget parameters are described in Table 4.

Table 4 : Phosphorus Loadings and Estimation Parameters for Reservoir Layang.

Flow	qs ml/yy	Area a x10 (m²)	vol 10⁵ (n³)	(m)	(yr)	Lc ... yr	Ls ...	Y...	...
Overland	3.13	652	22	3.37	0.86	0.075	0.31	0.49	2.02
Simulated Discharge	4.09	652	22	3.37	0.82	0.078	0.32	0.51	2.08

The mean dissolved-P concentration, obtained from site investigations, 0.041 mg/l, is used in the Vollenweider model as indicated earlier on. The loading can easily be recalculated if there are new concentration values in the future. The mean depth (z) obtained from the study is 3.37m while the residence time (Tw) is 0.86 year, as shown in Table 4.

An annual dissolve phosphorus loadings based on overall simulated discharges was about 0.32 g/m^2 yr. This value was higher than the critical value of $0.078 \text{ g/m}^2\text{yr}$. Overall dissolve P-loading (Yp) calculated was 2.08 ton/year. The Vollenweider's equation above was an approximation, although the values of its parameters were based on actual field measurements.

The total phosphorus concentration in Sg. Layang reservoir is expected to increase in the near future due to the present land clearing activities around the catchment area. Seri Alam Sdn Bhd, a developer, has agreed to develop residential areas within the catchment boundaries. First approximations of a phosphoros budget presented here is a step towards understanding the nutrient dynamics of these systems. It is hoped that the implications for their management will serve as a reminder to the relevant authorities to take some form of action before it is too late.

Discussion on Control Methods

There are various control methods to minimize the phosphorus content in the lake. Chemical controls such as treatment by alum or copper sulphate are approved methods. The use of selected virus to eliminate blue-green algae can be done, but research has shown that the genetic flexibility of the obnoxious blue-greens can outflank the viral attack in a very short time by developing resistant strains. This occurs so rapidly that this viral approach does not appear

promising. Deepening a lake can solve the problem of rooted aquatics, at least until the lake silts up again, and it should help solve the algal problem.

In most cases, the only permanent way of controlling eutrophication is by limiting the input, preferably phosphorous compounds. Cutting off direct pollution can be very successful in controlling algal blooms, although normally this may be difficult to accomplish. Waste treatment plants can treat wastewater to remove phosphorous, but at a considerable expense. Improper functioning of septic tanks near any water body usually contribute to its eutrophication. Bubbling air through anaerobic layers of stratified lakes has been recommended as a means of reducing the solubilization of phosphates contained in bottom sediments.

The quantity of dissolved P is controlled by the amount of runoff, which is generally impossible to change on agricultural lands unless water control structures are built, or watershed management practices are instituted. Sediment P, for example, depends on erosion, which can be controlled by proper soil conservation practices, such as terracing, contour farming, establishing grassed waterways, etc. Proper technique of fertilizer utilization such as the timing, amount or method of the application will be a contributing factor in P loading reduction. Besides that, coordination between fertilizer utilization and timing of irrigation will minimize P loading available for polluting the lake.

Hence the principal means of reducing phosphorus content is by control of soil erosion and limiting usage of fertilizers and other phosphorus sources. It is generally considered, that the best basic approach to avoiding eutrophic conditions in lakes is the control of the supply of nutrients.

CONCLUSION

The P-loadings predicted by Vollenweider one-compartment model, indicated that the Sg. Layang reservoir is an *eutrophic* lake . At the present time , reducing the amount of P-loading is always warranted. This is because P is the limiting factor for the overall lake water quality. Development and overall activities within the watershed boundary should be managed and planned properly and systematically in order to protect the overall lake water quality.

ACKNOWLEDGEMENT

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