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Forecasting the trophic status of Tolo Harbour, Hong Kong

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ABSTRACT

It is feasible to develop, verify and calibrate a two-layer tidally averaged model which can represent the stratification in the vertical water column during the summer season and can provide reliable estimation of the pollutant concentration in the Tolo Harbour. Eleven systems of water quality parameters are modelled, including three organic parameters, six inorganic systems and two biological parameters. The mathematical model can predict the tidally-averaged results in each layer during the summer season when the coastal waters are stratified. In addition, extensive field and laboratory experiments are required to be carried out in order to determine suitable values for the relevant model parameters. These include the phytoplankton growth kinetics due to temperature, solar radiation and nutrient effects; phytoplankton death kinetics due to endogenous respiration and zooplankton grazing; sediment interactions and eutrophication; phytoplankton settling rate; phytoplankton and dissolved oxygen relationship. Some of the rate coefficients can then be obtained by tuning the parameters with the field data. A sensitivity analysis is then entailed to investigate the relative importance of the pollutant sources and other model parameters on the water quality of the coastal waters. The model can finally be used to forecast the trophic status of the Tolo Harbour, a valuable practical application.

INTRODUCTION

In Hong Kong, many areas of coastal waters receive sewage directly from the urbanized catchments, as well as waste discharges from domestic, livestock and industrial sources via streams and stormwater runoffs. All these waste discharges carry a heavy loading of the nutrients, nitrogen and phosphorus, which are required for the growth of phytoplankton (micro-algae). The enrichment of nutrients in the coastal waters will encourage the development of algal blooms (eutrophication).

Tolo Harbour is an almost land-locked waterbody with only one narrow exit to the open sea at Mirs Bay in the Eastern Waters (Figure 1). Due to its enclosed nature, the general water circulation in Tolo Harbour is very weak, and the water in this marine zone has only limited capacity to assimilate pollutants [1]. It was noticed that the red tide occurrences have been increased significantly in this coastal waters in the 1980s. Hence, this coastal waters are susceptible to eutrophication if waste discharges are not controlled at source.

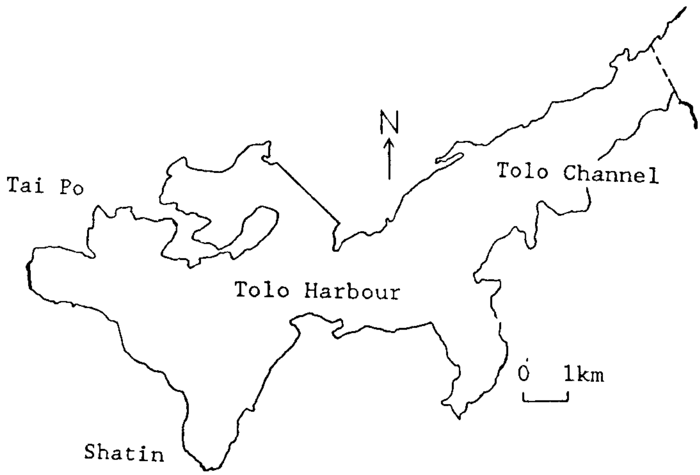

Figure 1. General layout of Tolo Harbour

Flow and pollutant transport models using powerful computer have been developed by many researchers and it can be applied in predicting the pollutant concentration. However, the accuracy of the prediction is to a great extent dependent on the accuracy of the open boundary conditions, model parameters used, and the numerical scheme adopted [2]-[5]. The rapidly varying model parameters such as solar radiation, pollutant sources, etc will inevitably add the complexity of this type of model used. Besides, the computer execution time requirements will be impracticable if the model is used for predicting the water quality due to seasonal variations.

Hence, there is a need to develop a tidally averaged model which is more simple in the model formulation, but can still provide reliable estimation of the pollutant concentration in the Tolo Harbour which will be useful for the planning purpose. This model needs less resources for computational costs and

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a higher percentage of resources can be orientated towards data collection.

For existing tidally averaged models such as [6] developed by Binnie & Partners (Hong Kong) for the Hong Kong Government, the area of interest is usually divided into segments within each of which the water quality is assumed to be well-mixed. Across each segment boundary, the model allows for a net advective flow as well as a tidal exchange flow which circulates mass exchange between adjacent segments over a tidal cycle. For small pollution loading, the iterative solution of the average pollutant concentration such as biochemical oxygen demand and dissolved oxygen level will converge in a few iterations. However, the iterative solution may rapidly convert to oscillating behaviour for heavy pollution loading. The failure to reach a unique steady state is caused by the discontinuity in the model parameters balance formulation, and the large amount of the pollutants consumed/replenished per tide. Hence, the existing model is only applicable for small pollution loading not causing oscillatory behaviour of the iterative solution. An equivalent time-dependent model [7] had been used to tackle the oscillation problem in a one-dimensional estuary. A numerical method using an explicit scheme was used to solve the time-dependent equations. However, the model parameters determined are limited to biochemical oxygen demand and oxygen levels only. More complicated interaction relationships are expected in the Tolo Harbour because more water quality parameters need to be modelled. Besides, numerical experimentation has shown that a very small computational time step has to be used in order to ensure the stability and accuracy condition.

The differences in surface and bottom water temperature distributions during the summer have resulted in temperature stratification in the vertical water column over the marine waters in the Tolo Harbour. The stratification profiles in this area are found to be non-linear, showing an obvious warmer upper water layer and a definite thermocline. The assumptions of a homogeneous mixing in the existing tidally averaged segment model will be invalid in the summer season. During winter, the strong northeast monsoon caused good turbulent mixing within the water column and fairly homogeneous water is found over the vertical water column of this coastal areas. A one layer tidally averaged model seems to be only applicable in the winter seasons.

PROJECT OBJECTIVES AND LONG-TERM SIGNIFICANCE

There are four major objectives:

(a) To develop a two-layer tidally averaged model which can quantitatively predict the trophic status of the Tolo Harbour both in the summer and winter conditions. The differences in surface and bottom water temperature distributions during the summer have resulted in temperature stratification in the vertical water column over the marine waters in the Tolo Harbour.

(b) To improve the stability and accuracy condition in the solution of the equivalent time-dependent model by using an implicit scheme method.

(c) To determine the magnitude of the parameters used in the proposed eutrophication model of the Tolo Harbour.

(d) To determine the relative influence of the various pollutant sources on the water quality of the ambient coastal waters which will be useful for future planning purposes.

The model can finally be used to forecast the trophic status of the Tolo Harbour, thus finding its practical application. The model developed can also be quite general, and will be applied in studying the average water quality of other coastal waters as well.

RESEARCH PLAN AND METHODOLOGY

A two-layer tidally averaged model is to be developed which is similar to the method used for a two-dimensional box model of estuary [8]&[9]. It is based on the application of conservation law for pollutant mass over a typical control volume of the flow domain . Each volume is considered to be homogeneous along the third dimension, i.e. the depth in the layer. The pollutant transport due to convection and tidal dispersion; loss of mass due to decay, and; any external sources or sinks are considered in the modelling. Besides the numerical advantages, control volume formulations have the advantage of easy interpretation of the physical meaning of each term in the derived equations.

Eleven systems of water quality parameters are modelled [10], including three organic parameters (carbon, nitrogen, and phosphorus), six inorganic systems (chlorides, dissolved oxygen, ammonia nitrogen, nitrite + nitrate nitrogen, orthophosphate phosphorus, and silica) and two biological parameters (phytoplankton and zooplankton).

An equivalent time-dependent method are adopted by computing the pollutant concentrations at a smaller time step instead of a whole tidal cycle. An implicit scheme is adopted for modelling the time-dependent model parameters equations. Gauss elimination and back substitution technique are used in solving the implicit equations. The quasi steady-state conditions of the water quality are arrived by the usual iteration procedure. The improved stability and the accuracy of the scheme are then compared with the explicit scheme used by others.

The model can predict the tidally-averaged results in each layer if the coastal waters is stratified. This is a numerical solution of the two-dimensional tidally averaged dispersion of pollutants. This may be a steady state model,

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meaning that the coefficients are constant in time, or the dispersion coefficient and flow parameters may vary between tidal cycle.

In order to find the real application of the model in Tolo Harbour, extensive field and laboratory experiments are required to be carried out in order to determine the suitable values of the relevant model parameters. These include the phytoplankton growth kinetics due to temperature, solar radiation and nutrients effects; phytoplankton death kinetics due to endogenous respiration and zooplankton grazing; sediment interactions and eutrophication; phytoplankton settling rate; phytoplankton and dissolved oxygen relationship. Some of the rate coefficients are then obtained by tuning the parameters with the field data.

Existing field monitoring results of Environmental Protection Department are only determined bi-weekly which is considered to be not close enough for an accurate verification of the model. Hence, it is intended that additional field measurements are conducted in about ten consecutive tidal cycles. Water quality parameters are determined in both the upper and bottom water layers especially in the summer seasons. Water samples are taken from the site and water quality parameters are determined from the existing spectrophotometer and ion analyzer equipment in the laboratory. A sensitivity analysis can then be carried out for investigating the relative importance of the pollutant sources and other model parameters on the water quality of the coastal waters.

CONCLUSIONS

In Hong Kong, many areas of coastal waters receive sewage directly from the urbanized catchments, as well as waste discharges from domestic, livestock and industrial sources via streams and stormwater runoffs. The enrichment of nutrients in the coastal waters encourage eutrophication. As such, needs arise for studies capable of relating the pollutant discharge with changes in the water quality. Tolo Harbour, which is an almost land-locked waterbody with only one narrow exit to the open sea at Mirs Bay in the Eastern Waters, is particularly vulnerable to this effect. Due to its enclosed nature, the general water circulation in Tolo Harbour is very weak, and the water in this marine zone has only limited capacity to assimilate pollutants.

The project on the development and calibration of a numerical model to simulate the eutrophication status in a harbour comes at a time where the awareness of our society concerning the environmental impact of wastewater outflows is increasing. It appears that the application of a two-layer tidally averaged model, which can represent the stratification in the vertical water column during the summer season and provide reliable estimation of the pollutant concentration, is feasible in Tolo Harbour. In addition, extensive field and laboratory experiments are required to be carried out in order to determine suitable values for the relevant model parameters. Sensitivity analysis is also entailed to investigate the relative importance of the pollutant sources and other model parameters on the water quality of the coastal waters. Through the rigorous calibration stage, the model can then be used to forecast the trophic status of the Tolo Harbour.

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