A Numerical Simulation of Water Quality in Tokyo Bay

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In this report, the JATWEM model is introduced. This model was developed to satisfy the need for a model that can be applied to all kinds of water bodies, and is easy to understand and use in the evaluation of primary production. The JATWEM model enables water quality to be calculated by an inductive parameter method based mainly on information obtained by field observation. A caluculation has been executed at Tokyo Bay which has successfully evaluated the water quality of the bay. This report explains the concept and caluculation process of the model.

The Diffusitive Equation of Nutrients.

Total nitrogen (TN) and total phosphorus (TP) are either in a soluble state or a particulate state. As particlulate movement is differnt than water, and since TN and TP readily change from particulate to solubel state and from soluble to partilulate state, the modeling aspect of the state of TN and TP becomes important. The JATWEM model basically consists of two equations: one for TN and TP in a soluble state or as small-sized particulates which act the same as water, and the other for large-sized particulates. Large-sized particulates were chosen to appoximate the vertical transportation in the ocean which is caused by giant-sized particulates called Marine Snow.

The settling mechanisum of giant-sized particulates are discussed by Tsunogai(1978), Nozaki(1981), et al., and many complex models to describe the reactions of various-sized particulates have been proposed based on this mechanism. In this report, however, a simple one dimentional equation model was applied for the settling of nutrients in surface water, and it was assumed that once settled a certain percent of the particulates will decompose near the sea floor.

For nutrients which act the same as water, soluble materials, and small-sized particulates, the following equation was used:

$$\frac{\partial C}{\partial t} = -U_x\frac{\partial C}{\partial x} - U_y\frac{\partial C}{\partial y} - U_z\frac{\partial C}{\partial z} + K_x\frac{\partial^2 C}{\partial x^2} + K_y\frac{\partial^2 C}{\partial y^2} + K_z\frac{\partial^2 C}{\partial z^2} - K_1 C + r\cdot\frac{\partial WM}{\partial z}$$

For the settling flux, the following equation was used:

$$\frac{\partial M}{\partial t} = (1-r)\cdot\frac{\partial WM}{\partial z} + K_1 C$$

note:
- C = concentration of materials which act the same as water
- V_x, V_y, V_z = velocity in the x,y,and z directions
- K_x, K_y, K_z = diffusion coefficients for the x,y,and z directions
- K_1 = removal coefficient with aggregation
- M = settling velocity
- r = ratio of decomposition

Parameters used inthe present model are shown in Table 1. K_1 values are obtained by sediment trap observation , and r values are calculated to

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meet mass balance of nutrients between sediment and water, on the bases of the difference between settling rate of nutrients in water and their sedimentation rate, and also the seasonal variation of N/P ratio in water.Values in Table 1 represent summer condition in Tokyo Bay.

Evaluation of COD Originated in Primry Production

In the JATWEM model, primary production is not calculated directly, but is estimated from simulated values of TN and TP. The ratio between organic nitrogen or organic phosphorus is determined from field data. Then COD originating from primary production can be estimated. Direct inflow of COD is simulated with another diffusion equation. The two simulated value, for primary production and for direct inflow of COD, are added together to give a final value for COD concentration.

Table. 1 Parameters in the model

nutrient	level	K_1	r
TP	1 , 2	0.07 day^{-1}	0.0
	3	0.00	1.1
TN	1 , 2	0.016	0.0
	3	0.00	0.95

The results of the Simulation of TN,TP, and COD

The model simulation was accomplished using a 4×4 km mesh horizontally and adopting a 3 level system (0 to 2 m, 2 to 10 m, and 10 m to bottom). The current data was modefied using the resultus of the current caluclation with the Level model reported by Nakata (unpublished). Inflow load data from the summer season of 1980 was used. The results are indicated in Figures 1 to 3. TN and TP values simulated by the JATWEM model , in general, correlated well with the observed values in the field. Correlation coefficients between simulated and observed values are fairly high, i.e., correlation coefficient for TP at level 1 was 0.87 and lelel 3 , 0.69, for TN at level 1 , 0.88 and at level 3 0.66. Concentrations of TP and TN show nearly a 1:1 agreement.

Mass balances of TN and TP show that the important fluxes for nitrogen and phosphorus are the settling flux (Figure 4 to 5). Especially for phosphorus, the role of the settling flux is important. Except by the mouth of the bay, downward fluxes to the bottom levels are almost equivalent to the upward fluxes. One condition of the simulation is that all of the settling fluxes of phosphorus are converted to a soluble state by decomposition and after being added to phosphorus from sediments by ellution, are again transported to the surface. Thus, the residual time for phosphorus gets longer than the residual time for water. Consequently, phosphorus accummulates in the bay.This is the reason that the concentration of the bottom level becames nearly equal to the surface for phosphorus.

Based on the obtained TN and TP values, the ratio between nitrogen and phosphrus can be calculated. Being affected by the difference of the removal coefficient between phosphorus and nitrogen, where phosphorus dissolves out from sediment and nitrogen is added to sediments, our investigation shows the differences of the ratio of nitrogen to phosphorus in the upper level and bottom level. That is, at the upper level all the phosphorus ratios are more than the Redfield ratio by 7.2:1. Thus, phosphorus becomes the limiting factor of primary production in Tokyo Bay.

On the other hand, at the middle and lower levels, the ratio of nitrogen to phosphorus decreases compared with the upper level. In certain waters, there appeares areas where the ratio of nitrogen to phosphorus is less than 5:1. This tendency coincides with the field observation data. It can be said that basically the theoretical framework for the actions of nitrogen and phosphorus is adequate.

Comparing simulated COD values by the JATWEM modes with observed values, results correlate well with observed data except near Tokyo Harbor (north west side of the Bay).Near Tokyo Harbor observed data is lower than model results. Correlation coefficient between simulated values by JATWEM and observed values are high, i.e., 0.85 at the level 1 and 0.71 at level 2, not including values at Tokyo Harbor.

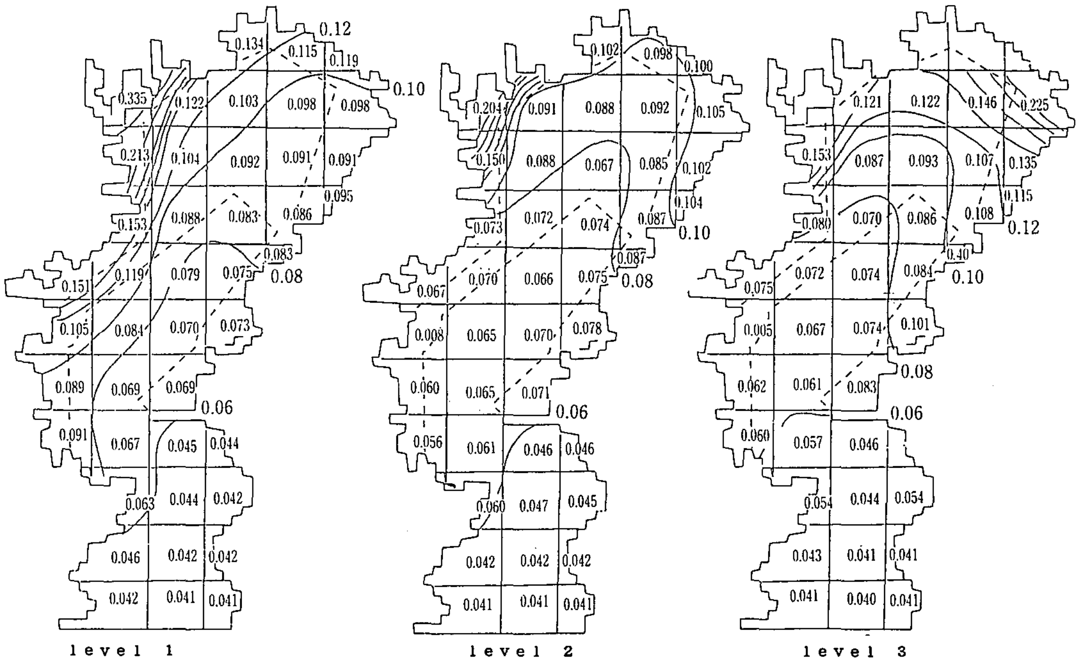


Fig. 1 Simulated Values of TP for 1980 (mg/l)

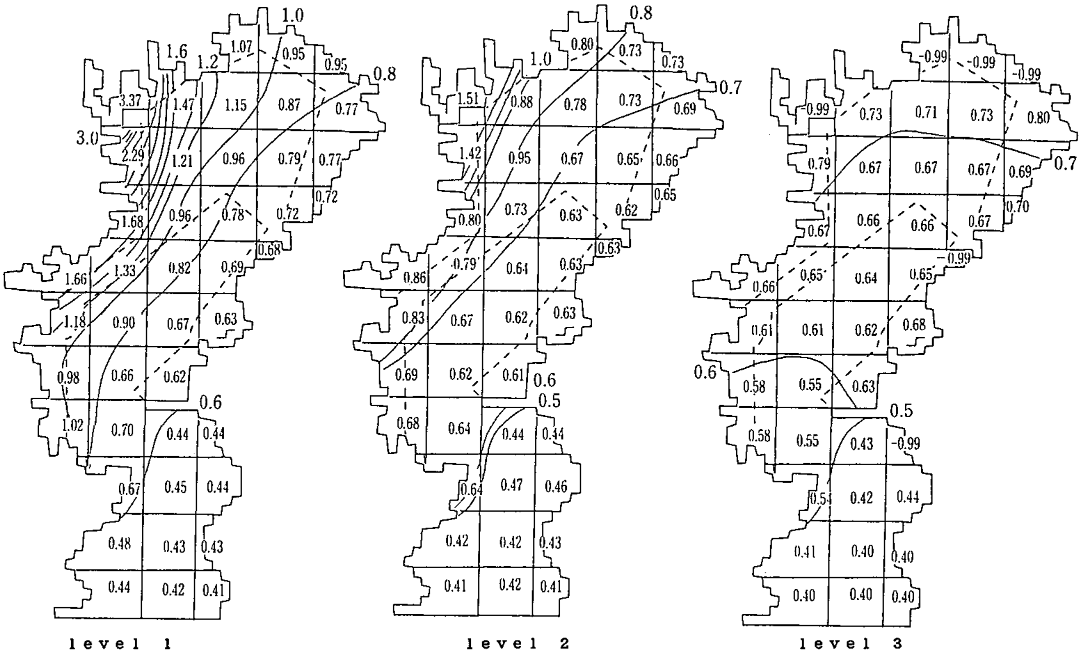


Fig. 2 Simulated Values of TN for 1980 (mg/l)

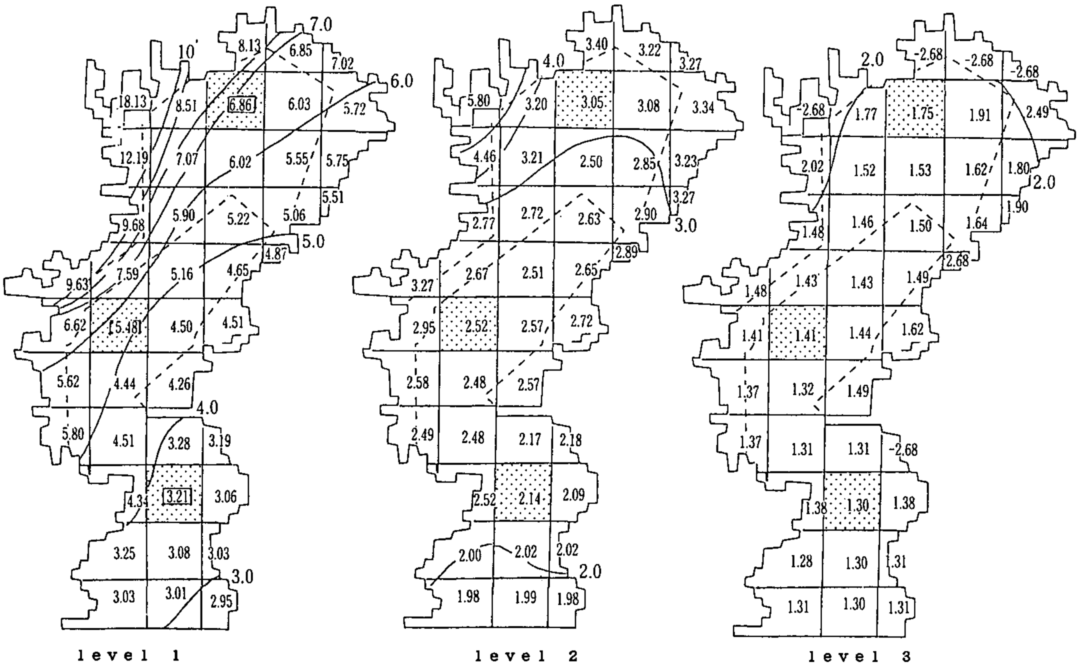
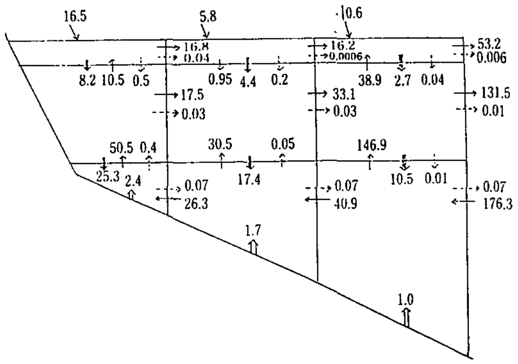
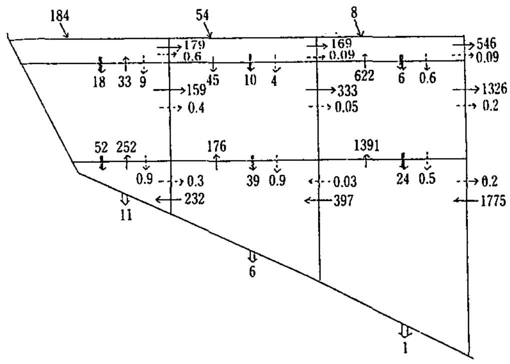


Fig. 3 Simulated Values of COD for 1980 (mg/l)





→flow flux
➡settling flux
⇨sedimentation (elusion) unit (ton/day)

Fig.4 Mass Balance of TP

Fig.5 Mass Balance of TN

Discussion

In a simulation of the water quality of Tokyo Bay, it has been found that the JATWEM model, whose parameters has been obtained through field observations, shows good results as mentiond before. It was proven that a simple structured model using easily attainable information can describe behaviers of nutrients and the phenomena of primary production of COD. There were, however several problems. In Tokyo Harbor, the calculated COD value significantly exceeded the observed value, even though the concentration of nutrients (bases of COD estimation) have been consistant with observed values. This indicates that the model considering only nitrogen and phosphorus aslimitting factors for primary production can not evaluate concisely the actual primary production near inflow load areas.

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