Personal Computer System Supporting Water Quality Management in Eutrophicated Bay

TOHRU MORIOKA*, YOSHINOBU KIDO*, AKIRA MIICHI† and MITSURU NAKADAN‡
Osaka University, 2-1, Yamadaoka, Suita, 565 Japan
†*Kansai University, 3-3-35, Yamate-cho, Suita, 564 Japan*
‡*Mitsubishi Electric Corp., 1-1-2, Wadamisaki-cho, Hyogo-ku, Kobe, 652 Japan*

The system has been developed in terms of working on a personal computer (PC) in order to support policy-makers to formulate water quality management plan. The system consists of four subsystems furnished by a water quality model and an external loading model. The computer graphics techniques in the PC system provide some types of visual informations for decision making. This paper presents effective functions of the PC system aiding decision-makers to judge what they should do.

INTRODUCTION

A red tide frequently occurs in Osaka bay in the summer season, though the construction of the sewerage system and regulation of point source have been carried out. It has been said that the organic pollutant and nutrient loads transported from the interior of Osaka bay by tidal movement causes the eutrophication in the wide area of this bay. It is important for water quality management in such a wide area to control the pollution with collaboration of related municipals and prefectural governments. Therefore, it is necessary to validate appropriate performance and consistency of the developed model by means of analysing the sensitivity of model parameters, the material balance in receiving water and the flux balance of contaminants through boundary section. In the stage of planning for water quality improvement, the alternative regulatory or structural policies are introduced, evaluated and finally selected for the management plan. In the practice and follow-up stage of the plan, practical effects of control policies should be monitored, forecasted in near future, and evaluated in the time section of auditing, and detailed planning should be modified during the period of implementation.

SYSTEM COMPONENTS AND FUNCTIONS

This system is requested to have the function of the convenient tool for pilot study antecedent to minute simulation on a mainframe machine, which can be not easily accessed to by government officers. The structure of the developed personal computer system is shown in **Fig.1**. The functions of subsystems are described as follows.

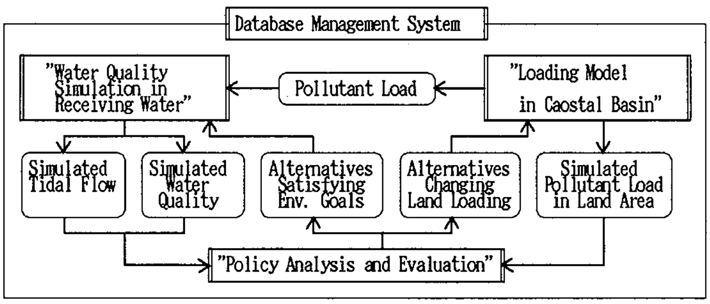

Fig 1 Structure of Management System for Eutrophication Control

The subsystem "water quality simulation in receiving water" presents water quality by model calculation in the receiving water, which are compartmentalized into boxes with an proper spatial distribution of pollutant concentration in the phenomena of diffusion and eutrophication in Osaka bay. The subsystem has display function on many types of screen supporting users to specify inputs and to recognize outputs of simulations. The hierarchical set of menu is provided to enhance interactive communications between humans and machines.

The subsystem "loading model in coastal basin" stores the data of human activities and industrial productions in the land area. It aggregates inflow loads to the receiving water from some types of sources generating pollutants in each subdivided land area. The system can show the necessary reduction ratio of

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pollutant loads in each catchment area subject to satisfy concentration of environmental goals in receiving water. Furthermore, the system shows the effectiveness of sewerage construction to environmental quality improvement.

The subsystem "policy analysis and evaluation" specifies control policies as those which give actual effects on the flux and the balance of pollutant loading or which change the values of variables/parameters of the water quality model and the loading model. The major policies are reduction of pollutant loading and dredging sediment in a harbor area. This system has user-friendly menus on the display showing changeable options for expected regulatory options, and provides variations data files corresponding to the variety of model simulations.

EUTROPHICATION MODEL SIMULATION

The water quality model represents non-conservative balance of chemical oxygen demand (COD) for examining to meet environmental standards, organic phosphorus (O-P) and inorganic phosphorus (I-P) for assessing eutrophication in Osaka Bay. This model with two level layers of water above the sediment in compartmentalized boxes are put into calculation in the following conditions.

1) Mean concentration during daytime in summer or winter season are of concern.
2) Two scale model are provided, where Model I represents behavior of pollutants in Osaka bay and determine the off-shore boundary conditions of Model II, and Model II represents two dimensional distribution of pollutants in the Kobe harbor area under consideration.
3) The plankton grow by photosynthesis in the upper layer whose depth is 8 m in Model I and 4 m in Model II. No photosynthesis occurs in the lower layer.
4) The concentration of bulk water in each box is provided for comparison between the calculated and the observed and also between the calculated and the level of environmental goals in each area.
5) The model are described with simultaneous differential equations, which are numerically solved by using 5th order Runge-Kutta-Gill method with time step of 15 minutes.

Fig.2 shows transfer, transport and transformation of nutrients and COD.

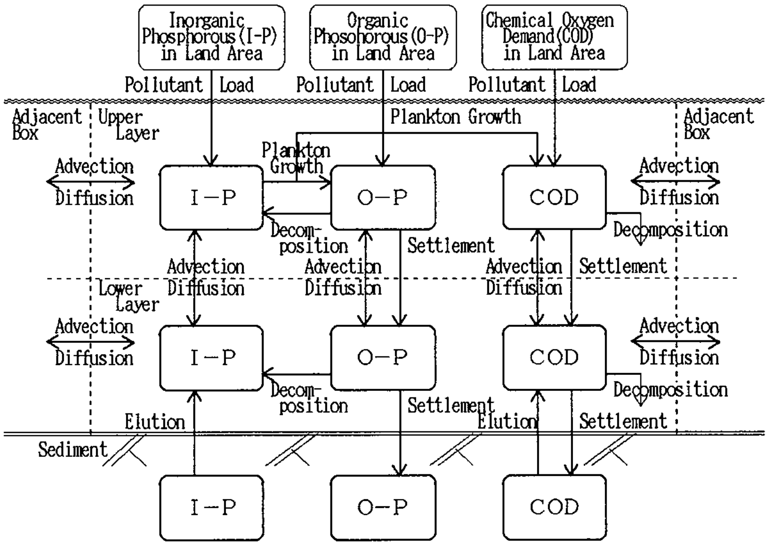

Fig. 2 Transfer, Transport and Tranformation of Nutrients and COD of Water Quality Model

The compartmentalization of receiving water has been done as follows:

1) The local receiving waters in Osaka bay are grouped into some clusters having the similarities discovered by using some means of correlation analysis of monitoring data.
2) The boundary of compartmentalized box is determined not so to get across two or more zones pertinent to environmental goals, because calculations can be compare with them for policy analysis.
3) There is at least one monitoring point in compartmentalized box as possible.
4) The compartmentalization is determined under the consideration of geographical effects in the bay, especially effects of breakwaters expanding from the Wada cape to the mouse of the Yodo river.
5) The rate of water exchange is expected to be less than 25% of box volume in a calculation time step even in the box with the minimum volume.

Therefore, Model I has 11 boxes and Model II has 14 ones. **Fig.3** shows the compartmentalization for both models, and besides spatial zoning for the environmental goals setting and observed points for water quality assessment described later.

The handling of monitoring data from 1983 to 1987 without the maximum and the minimum produces the mean concentrations as target values for comparison with simulation in summer or winter seasons. There are 48 time steps during one tidal period. The convergency is judged to be acceptable if less than 0.1% of difference between in the present iteration and in the former one in each box. The mean concentration values during one tidal period should be compared with target ones. The model parameters have been validated with respect to not only both of the consistent agreement between calculation values and target ones, and whether being inside or not of the range between the upper and lower limits of monitoring data, but also the results of the correlation analysis between calculation and target values in all boxes. Many past studies and investigations were reviewed to determine appropriate range of parameters. Furthermore, the sensitivity analysis has been done before final simulation in order to get a sufficient degree of model validation. The results of Model I are shown in **Fig.4**.

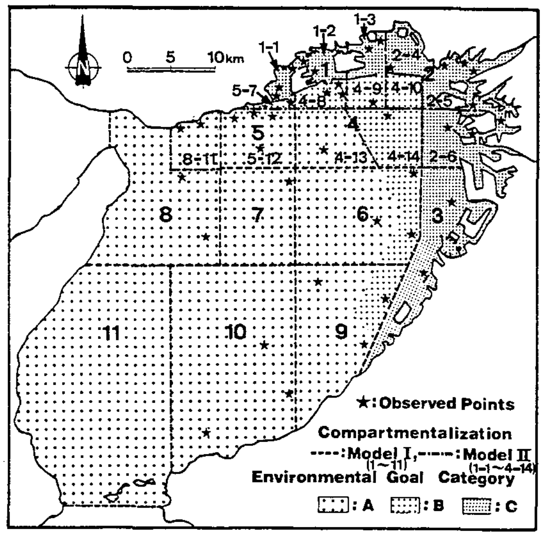

Fig. 3 Compartmentalization, Environmental Goals Zoning and Observed Points

Model I simulates the present distribution of COD in Osaka bay. The correlation coefficient in winter season is high. The calculated I-P concentration values are generally lower than target ones because of keeping parameters in the ranges to bring the high degree of agreement of COD concentration. Some O-P concentration values are a little higher than target ones. The monitoring data of I-P and O-P have wide ranges among seasons and stations because these water quality indices are subject to be much varied by rapid reaction of photosynthesis in daytime. Model I is judged to have high fidelity of simulation.

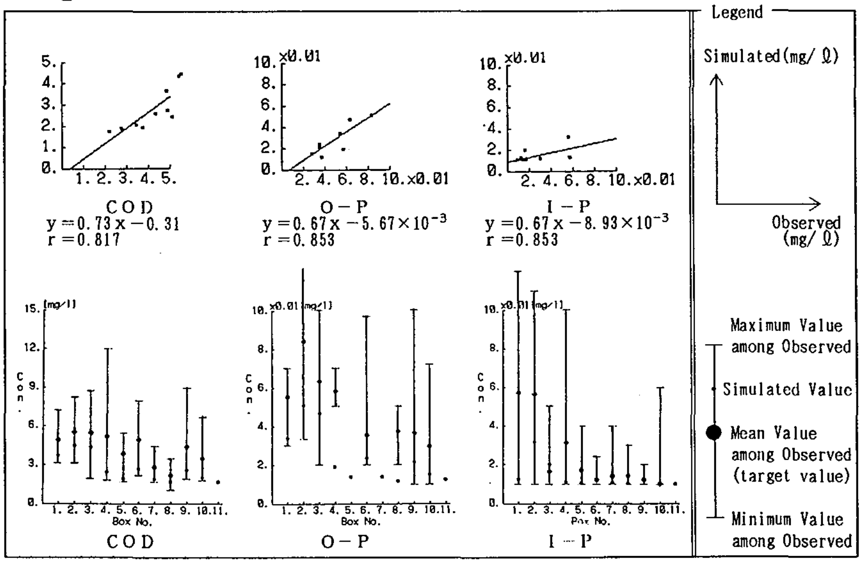

Fig.4 Comparison of Simulated and Observed Concentrations (Model I, Summer Season, Upper Layer Box)

The box 2-4 and 2-5 of Model II, which are located near the mouse of the Muko river and the Yodo river respectively, have lower calculated values of COD than the observed ones in both seasons. The monitoring data is influenced by instantaneous effects of plankton growth in great variance during a day, and the ill-mixed water in box causes the systematic deviation of values between concentration in the monitoring point and referenced mean value in the box. In winter season, the fidelity of Model II is so good and O-P concentration values are in the range between the maximum and the minimum of monitoring data. Model II is estimated to be reliable. The material balance is reasonable in each box and in the Osaka bay area by the examination program of budgeting flux of pollutant.

The multiple correlation analysis among mean values of COD monitored in summer, X_1 and winter, X_2 and 25% exceeding values Y shows Eqs. (1) and (2) about COD. It is based on the stochastic consideration of environmental standards in Japan. Simulated values are a little lower than the observation-based ones, but both model have fidelity enough to simulate 25% exceeding values of COD in Osaka bay and the Kobe harbor area.

$$(\text{Model I}): Y = 0.53 \cdot X_1 + 0.42 \cdot X_2 + 0.23, \ R = 0.950, \ \text{COD mg/l} \quad \cdots\cdots(1)$$
$$(\text{Model II}): Y = 0.37 \cdot X_1 + 0.98 \cdot X_2 + 0.25, \ R = 0.950, \ \text{COD mg/l} \quad \cdots\cdots(2)$$

The limitation of model performance are described as follows:

1) The I-P concentration values of Model II especially lower in summer season have resulted from not the calculation algorithm but the limitation of modelling itself.
2) Tidal movement is dominant to determine spatial distribution of pollutants more than diffusion does, judging from the results of pollutant budgeting in the bay.
3) The box model can represent the mean concentration values in each box. These values cannot be directly compared with the observed ones, because monitoring points are unevenly distributed.

POLICY ANALYSIS ON POLLUTANT LOAD

The subsystem "policy analysis and evaluation" has some menus representing some types of expected regulations. A policy-maker selects them and become able to simulate water quality and estimate the efficiency of regulations. It can roughly show the relative performance of reducing each pollutant load from catchments adjacent to Osaka bay. Of course, final reduction ratio should be determined in the administrative and political processes.

The uniform reduction ratio is put into calculation in order to judge how much of loads should be reduced to meet environmental goals as shown in following procedures.

1) The simulations in both summer and winter seasons are executed on condition of 20%, 30% and 50% reduction of pollutant loads from the coastal area. And then the 25% exceeding value of COD is obtained.
2) The necessary reduction ratio of pollutant loads to satisfy the environmental goal in any box is estimated by means of the liner regression analysis between 25% exceeding values of COD and the reduction ratios of pollutants.

Fig.5 shows the result of this analysis for box 6 by using Model I. **Table 1** shows the result of this analysis for all boxes by using Model II. About 33% reduction ratio of pollutant load is necessary to satisfy the environmental goal by using Model I, and in the same manner about 60% is necessary by using Model II. The box 4-10 in the case of Model II requires much more reduction ratio to satisfy its environmental goal of B category. Because water quality of this box is affected by that of the box 2-5 where high COD, caused by direct inflow of nutrient load from the Yodo river, is observed. This box is judged to be important area to control pollution in the adjacent Kobe harbor area.

The additional model simulation has been executed on condition that one unit of loading, which consists of 1 ton COD/day and 1 kg I-P/day, is added to the present load from each land area. Results of this simulation illustrate typically the impacts from the land area to the marine environment. It also specifies the dominant land area to be controlled by regulatory policies.

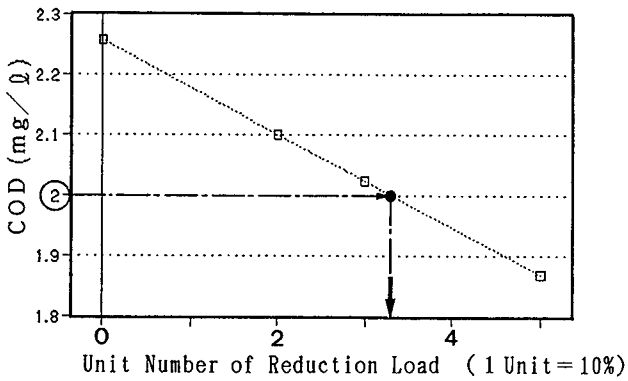

Fig. 5 Reduction Ratio of Pollutant Load to Satisfy Environmental Goals in Box 6 by Model I

Table 1 Reduction Rate of Pollutant Load to Satisfy Goals in Model II

Box Number	Environental goal (mg/ℓ)	Simulated 25% exceeding Value		Reduction Ratio of pollutants (%)	
		Upper	Lower	Upper	Lower
1−1	8.0	3.287	3.037		
1−2	8.0	3.789	3.171		
1−3	8.0	4.513	3.642		
2−4	3.0	7.010	5.887		
2−5	8.0	8.155	6.396	2.95	
2−6	8.0	4.391	2.971		
5−7	3.0	2.175	2.036		
4−8	3.0	2.618	2.337		
4−9	3.0	3.367	2.632	23.42	
4−10	3.0	4.532	3.134	59.59	
8−11	2.0	1.552	1.143	21.29	
5−12	2.0	1.720	1.247		
4−13	2.0	2.132	1.493	20.00	
4−14	3.0	2.820	1.935		

Fig.6 shows the impact of each land block to box 4 of Model I, and indicates

that the Kobe city area is land area of high performance to improve water quality in the target Box 4 in terms of volume of loading without consideration of difficulty of reducing equivalent loading effects. When the loading model is linked to this set of results, the physical efficiency of alternative regulations with spatial variations, for example promoting the sewerage construction and advanced sewer treatment in each land area, is estimated.

When using these impacts matrices, simultaneous linear equations are formulated to represent the quantified relation between water quality and land loading. Furthermore, when the objective function of maximizing pollutant loading or minimizing reduction ratio of pollutant load is provided, the linear programing technique gives a better solution for allocation of total required reduction amount. Some preliminary examinations have been executed, in which inflow loads are weighted by some social indices representing the difficulty of implementing regulations, for example sewerage served area ratio and the ratio of pollutant derived from point sources.

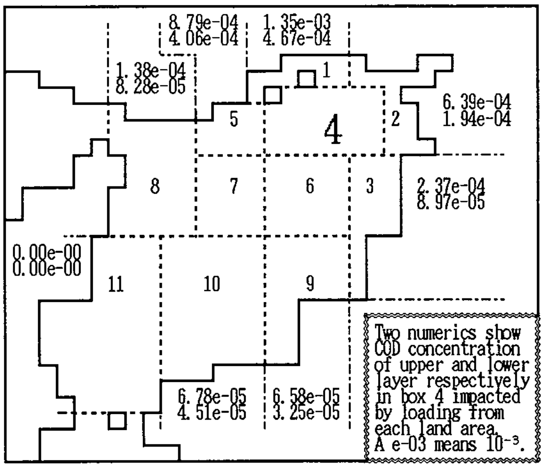

Fig.6 Impact to Receiving Water(Box 4) of Unit Loading(1ton COD/day) from Land Area

Some results of policy analysis by using the PC system are as follows:
1) The 100% reduction of external pollutant load from the Kobe city area can not obtain so much improvement of water quality not only in the wide area of Osaka bay but also in the Kobe harbor area, because pollutant load from this area accounts for about 4% of total amount in the Osaka bay area.
2) Even 80% reduction of internal loading as in recurrent of nutrient and pollutants in a harbor area by dredging sediment show relatively small improvement, too. The combination of dredging and reduction of external loading had a more effect on improvement of area-wide water quality.
3) The pollutant load from the interior of Osaka bay have greatly influenced on water quality in offshore area of Nishinomiya, which is critical for area-wide control of water quality

EXPANSION OF DEVELOPED SYSTEM

The system can support a policy-maker to evaluate alternatives with technological/engineering perspectives. It is inadequate for a policy-maker to make a holistic decision without the integral perspectives of technological issues connected to economical/political aspects. An option of subsystem, which install a module for cost-benefit analysis, multi-criteria analysis and so on, is attached to the PC system. A set of many simulations is available to determine regulatory policies in the process, where an optimum alternative is obtained by using macroscopic economic analysis such as cost-benefit analysis. Furthermore, the database for water quality control, which stores demographic, industrial and urban activities, can display these information with multiple screens by menus type operation easily to be understood. Therefore, the PC system supports decision-makers to concentrate their efforts to judge what to do, how to do, and how much to do based on excellently aggregated information provided by experts of system analysts.

CONCLUSION

The system has been developed on a personal computer in order to support policy-makers to make frame of water quality control plan. The box model which is liable enough to estimate water quality is provided. The effectiveness of actions for improving water quality is easily evaluated by using this loading-receptor model. The system provides the many types of functions as man-machine interface; for example in menus which shows a human how to operate a machine, in the message for unexpected errors and in display of the waiting time. This system enables policy-makers to solve effectively the mixed problem of technological and administrative issues such as in area-wide eutrophication control in enclosed sea.