Memoirs of the Faculty of Engineering, Okayama University, Vol.26, No. 1, pp.61-73, November 1991

The Model of Water Quality Management for the Hino River

Osami KAWARA*, Hideki DANNO**, Takao KUNIMATSU***

(Received October 14 , 1991)

SYNOPSIS

Lake Biwa is the largest lake in Japan, and one of the most important fresh water resources. The Hino River is the fourth largest river among the rivers which flow into Lake Biwa. The eutrophication of the lake has been warned since the 1960s. In order to improve the water quality of the lake, to decrease the loads through rivers is inevitable. Therefore, it is needed to predict the effects of measures to control pollutant loads and the influence of development in the basin on the loads from rivers before developing the basin and taking measures.

This paper deals mainly with the model of water quality management for the Hino River and the effects of the development in the basin on the water quality. The model was formulated considering loads from forests, rice paddy fields, households, housing land, industrial factories. Using this model, a calculation system by a microcomputer was developed and the influence of urbanization of the basin was discussed.

---

* Department of Civil Engineering
** Tohre Engineering, Ltd.
*** Faculty of Agriculture, Shiga Prefectural Junior College

1. INTRODUCTION

The Hino River flows into Lake Biwa, Shiga Prefecture, which is the largest lake and one of the most important fresh water resources in Japan. The eutrophication of Lake Biwa has been warned since the 1960s, and the water quality of the lake has not been improved so much. In order to improve the water quality of the lake it is inevitable to decrease the loads through the rivers.

In this paper, we studied the water quality of Hino River and identified a model which predicts the influence of pollutant sources on the water quality of the river. Then, we developed a calculation system by a microcomputer and the influence of pollutant loads was discussed.

The area of the Hino River basin is 210.9 km^2 and the average flow rate is estimated at about 6 m^3/s. The Hino River is the fourth largest river among the rivers which flow into the lake. Most of the basin consists of mountains, forests and rice paddy fields. The observation point of water quality is located at 8.5 km from the river mouth and the area of the upper basin from the point is about 175 km^2. The total area of mountains and forests in the upper basin is about 60% of the upper basin. And that of rice paddy fields is about 30%. The population in this area is about 50,000 persons. As the population of Shiga Prefecture is increasing mainly in the southern part, the population in this area is likely to increase in the near future.

2. METHOD OF OBSERVATION

Fig. 1 shows the basin of the Hino River, study area, observation point of water quality and that of the river water level. For the purpose of modeling water quality, the study area is divided into 7 blocks based on the tributaries of the Hino River. The water quality of the Hino River was observed usually two times a week from July of 1985 to June of 1986. The items picked up in this paper are chemical oxygen demand (COD), total nitrogen (T-N) and total phosphate (T-P). The flow rates were estimated from the water levels observed near the observation point of water quality. The pollution loads were calculated from the above water quality and flow rates.

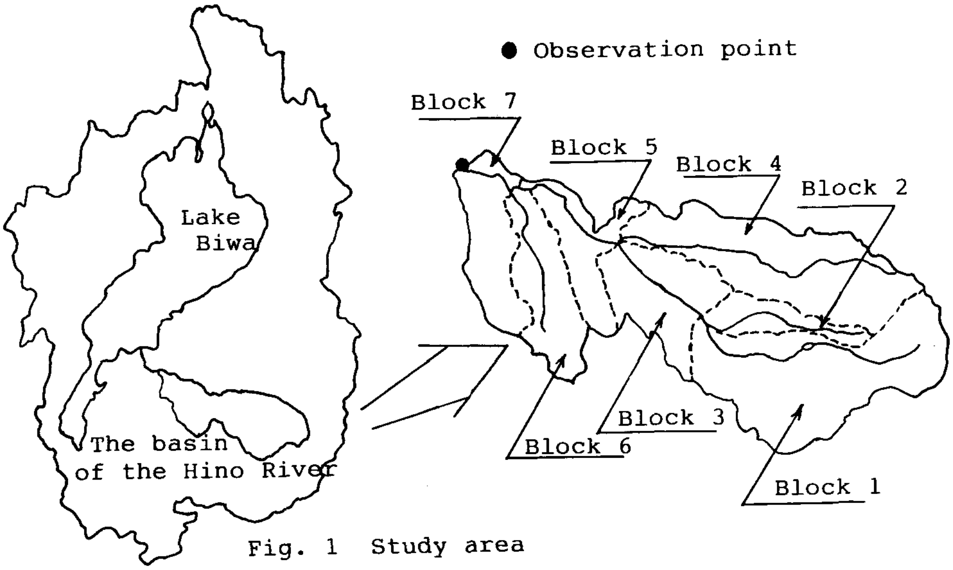

Fig. 1 Study area

3. MODELS

The model identified consists of four submodels. They are submodels of runoff, point-sources, non-point sources, and pollutant behavior in a stream.

3.1 Submodel of Runoff

The total flow rates observed are divided into flow rates of direct runoff and those of baseflow which include wastewater from point sources by using filter separation AR method(1). Fig. 2 shows the the separated flow rates by the filter separation AR method.

The lines in Fig. 2 show the total flow rates and the flow rates of base flow, respectively. The differences between the total flow rates and the flow rates of base flow represent the flow rates of direct runoff. The results obtained here are similar with those of the Asahi River and the Yodo River. The separated flow rate components are used for the estimation of pollution loads from non-point sources.

3.2 Submodel of Point-Sources

The point-sources are classified into households, industries and livestock. The whole human waste in this basin is treated by a night

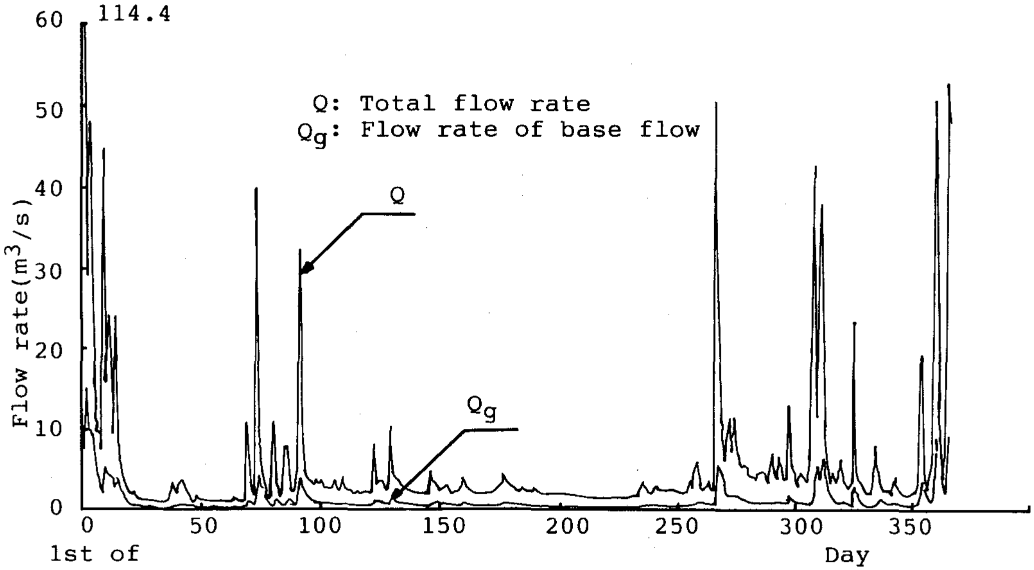

Fig. 2 Components of flow rate

soil treatment plant on the outside of this basin, private sewerage systems, or used as manure. But, most of the gray water is discharged without treatment. The pollutant loads L_h from households are expressed as follows.

$$L_h=R_f\ (1-r)\ F\ P. \tag{1}$$

Where, R_f=flow-out ratio, r=removal ratio by treatment, F=pollution loading factor and P=population. The pollutant loads from livestock are expressed the same as the above. Those from industrial factories are estimated based on observations and the total amount are used in the model.

3.3 Submodel of Non-Point Sources

The non-point sources classified into forests, rice paddy fields and housing lands. The loads of roads are included in those of housing lands. Each load function is expressed as follows.

The load function of forests L_f is expressed as follows based on previous studies(2,3).

$$L\ =a\ Q_s{}^b\ +\ c\ Q_g\ . \tag{2}$$

Where, Q_s=flow rate of direct runoff, Q_g=flow rate of baseflow, a and b=constants and c=ground water quality. Q_s and Q_g are estimated by the submodel of runoff.

The three load functions of rice paddy fields are formulated because the runoff of COD, T-N and T-P are different from each other. Those of T-P and T-N are formulated based on the observations by Kunimatsu$^{(4,5)}$ and the pattern of fertilization in the basin. The equations are not based on the mechanisms which govern the behavior of pollutants in rice paddy fields, but they reproduce the observed load patterns from rice paddy fields.

$$L_x = \underbrace{\frac{Q_x}{\sum_{x=1}^{365} (Q_x f(x))}}_{(1)} \underbrace{a}_{(2)} f(x) A . \tag{3}$$

$$f(x) = \underbrace{\frac{c_1}{\sqrt{2\pi}\,\zeta x} \exp\{- \frac{(\ln x - \mu_1)^2}{2\zeta^2}\}}_{(3)} + \underbrace{\frac{c_2}{\sqrt{2\pi}\,\sigma} \exp\{- \frac{(x - \mu_2)^2}{2\sigma^2}\}}_{(4)} + \underbrace{\frac{c_3}{365}}_{(5)} . \tag{4}$$

Where, a=pollutant load factor (T-N; 27.5kg/ha/y, T-P; 0.88kg/ha/y), Q = water supply + precipitation - evopotranspiration, A=area of rice paddy fields, Q=monthly value of Q averaged for 20 years.

Each term of the above equation represents following phenomena. Term (1) is for the correction of yearly variation of precipitation because the above pollutant load factors are averaged values and the runoff loads in a rainy year are greater than them. f(x) represents the simplified seasonal change of water quality observed by Kunimatsu. Term (3) expresses the rapid increase of water quality due to much fertilization in the middle of May and the subsequent slow decrease due to the less fertilization of three times after May. Term (4) represents slow increase and decrease of T-N or T-P concentrations by digging up the rice paddy fields in autumn or reduction of T-P in the soil in summer, respectively. Term (5) represents the base pollutant runoff.

The load function of COD from rice paddy fields is expressed as follows.

$$L_x = a\, Q_s^{\,b} \tag{5}$$

Where, a and b =constants, Q_s = flow rates of direct runoff obtained by the submodel of runoff.

The load function L_{ho} of housing lands is formulated based on the study of Wada(6).

Rainy day (p-r>0)

$$S(t)=S(t-1) - L_{ho}(t). \tag{6}$$

$$L_{ho}(t)=a\ S(t-1)\ (p-r)^b. \tag{7}$$

Dry day ($p-r \leq 0$)

$$S(t)=S(t-1)\ \exp(-k) + \alpha \tag{8}$$

$$L_{ho}(t)=0. \tag{9}$$

Where, S(t)=pollutant loads deposited, P=precipitation, r=vaporization, A=area of housing land, k=decay rate constant of pollutant, a and b=constant and α =accumulation rate of pollutant in housing lands.

3.3 Submodel of Pollutant Behavior in a Stream

Considering the pollutant balance in an incremental volume shown in Fig. 3, the following equations are derived.

$$\frac{\partial(AC)}{\partial t} = -\frac{(AvC)}{\partial x} - k_1AC + B(-k_3C + aW_bQ^b) + P. \tag{10}$$

$$\frac{\partial W_b}{\partial t} = k_3C - aW_bQ^b. \tag{11}$$

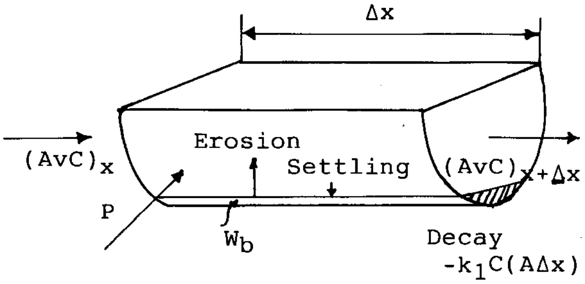

Fig. 3 Behavior of pollutant

Where, A=cross sectional area, B=width of river, k_1=decay rate constant, k_3 = removal rate constant by sedimentation and/or adsorption, Q=river discharge, W_b =pollutant loads accumulated on river bed, P=pollutant loads from sources per unit reach of river and v=flow velocity.

Assuming steady state during a day as daily mean discharges are used in this study, the above equations are solved as follows.

$$L = \exp\left\{-(k_1 + \frac{k_3}{h})T\right\}\int_0^x \left\{(P + Bf)\exp(k_1 + \frac{k_3}{h})t\right\}dx$$

$$+ L_0\exp\left\{-(k_1 + \frac{k_3}{h})T\right\} . \qquad (12)$$

$$W_b = \frac{k_3 L}{aQ^{b+1}}\left\{1-\exp(-aQ^b)\right\} + W_0\exp(-aQ^b) . \qquad (13)$$

$$f = aW_bQ^b . \qquad (14)$$

Where, T=time of flow from x=0 to x=x, L_o=pollutant inflow from upstream, W_{bo} =pollutant load accumulated on river bed at t=0 and h=water depth.

4. Method of Parameter Estimation

There are many unknown parameters in the models. These parameters are estimated to minimize the difference between calculated and observed concentrations. In this study, the Marquardt method is used for the parameter estimation. The estimated parameters are restricted within certain ranges which are known by observations or experiences.

5. RESULTS AND DISCUSSIONS

5.1 Model Identified and Calculation System by Microcomputer

Fig. 4 shows the comparisons between the observed concentrations and results simulated by the model. It seems that the results obtained by the model show relatively good agreement with observations. The loads from nonpoint sources and point sources are shown in Table 1. In this area the loads from nonpoint sources are dominant. The yearly total estimated loads of COD, T-N and T-P at the observation location during the 365 days are 840t/y, 210t/y and 42t/y, respectively.

In order to predict the effects of measures to control pollutant loads and the influences of change of pollutant sources on the water quality of the Hino River, a calculation system by a microcomputer was

Table 1 Loads from pollutant sources

	Nonpoint Sources	Point Sources		
		Household	Livestock	Industry
COD	650	210	140	31
T-N	250	34	30	3.8
T-P	46	9.4	8.3	1.9

unit; t/y

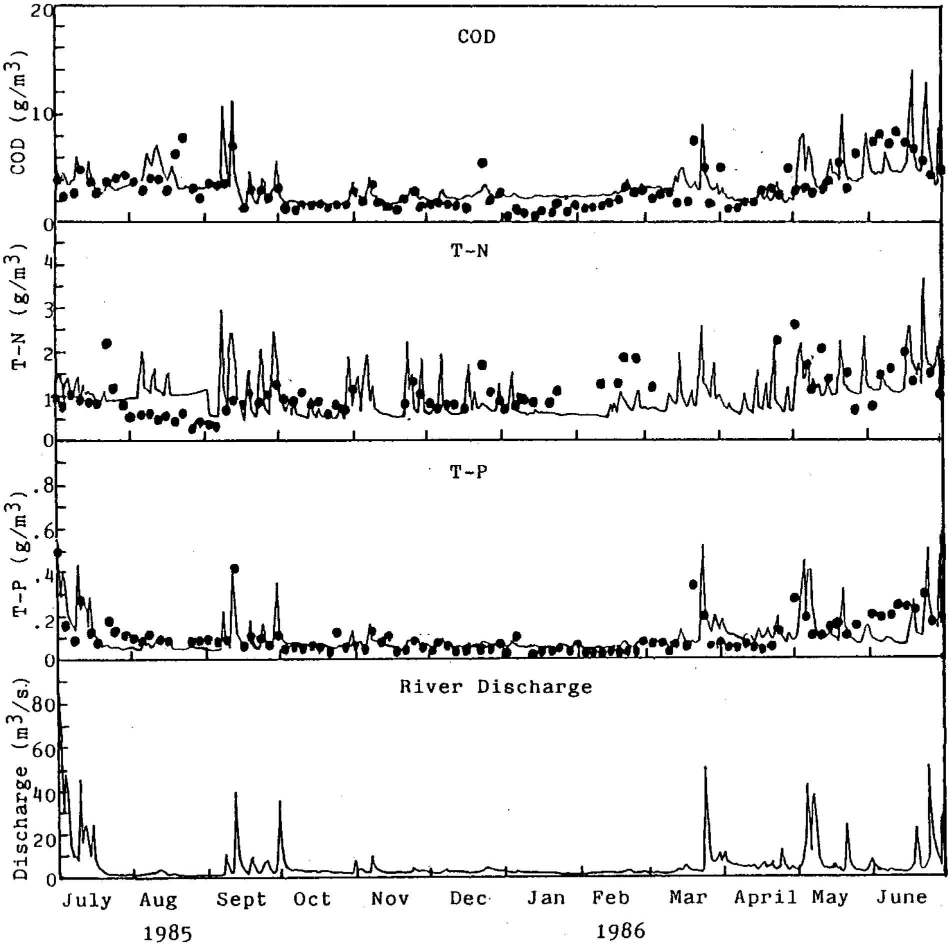

Fig. 4 Comparison between observations and simulations

developed. This system uses the water quality model identified above. The aim of this system is to support the decision making for the water quality management of the Hino River.

The flow chart of the calculation and display is shown in Fig. 5. This system is composed of a main program which includes the water quality model and "Lotus 1-2-3 " which is a famous software. The results calculated in the main program are transfered to "Lotus 1-2-3", and display is carried out by "Lotus 1-2-3". The model parameters and data of pollutant sources are stored in "Lotus 1-2-3", the data needed for the calculation of water quality are transfered from "Lotus 1-2-3" to the main program.

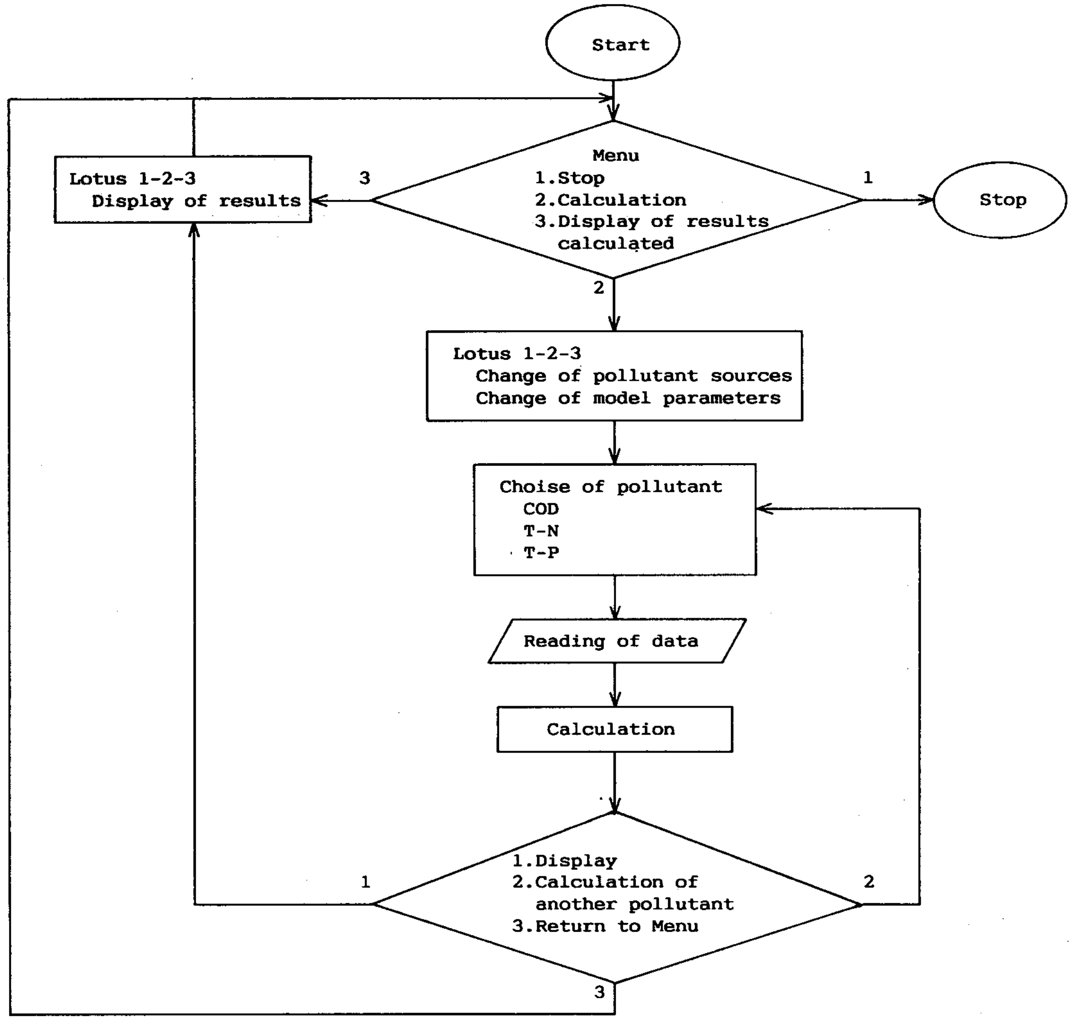

Fig. 5 Flow chart of calculation

The examples of results obtained by this calculation system are shown in Fig. 6, Fig. 7 and Fig. 8. The influences of the change of pollutant loads and the effects of measures on the water quality of the Hino River are easily predicted by this system within the conditions that the model identified here is valid.

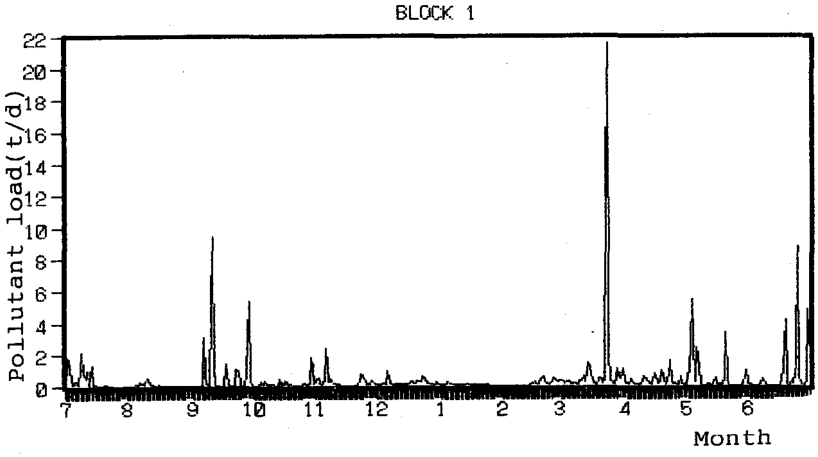

Fig. 6 Time series of pollutant loads

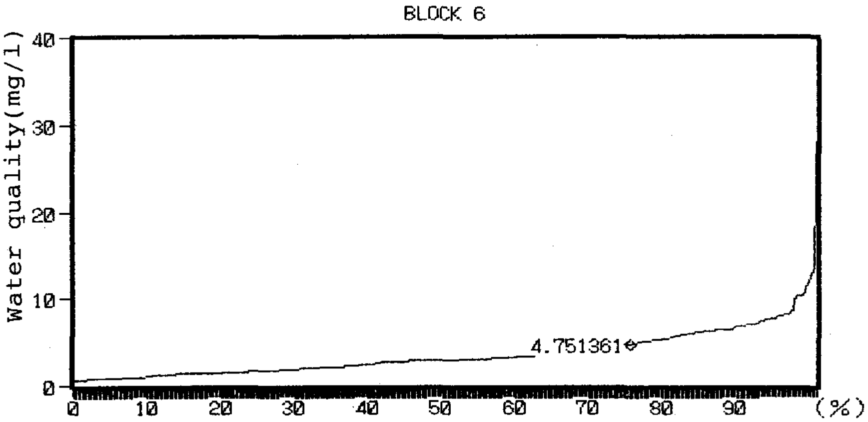

Fig. 7 Water quality corresponding to cumulative probability of 75%

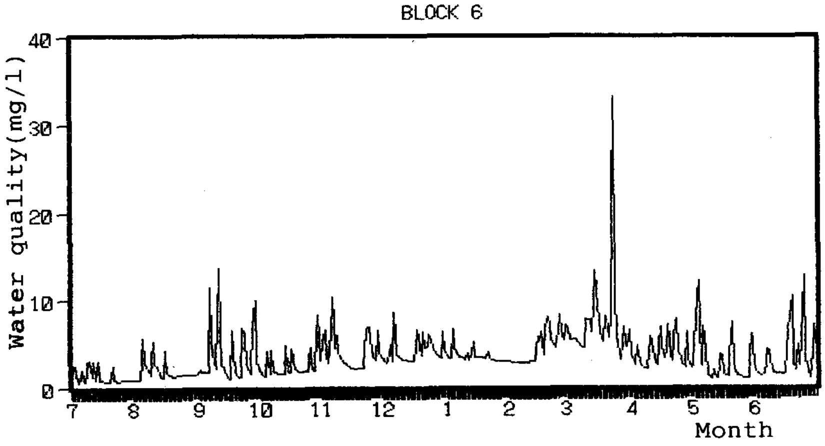

Fig. 8 Time series of water quality

5.2 Influence of Change of Pollutant Loads

Fig. 9 shows the effects of population increase and decrease in the use of human waste as manure on T-N quality of the Hino river. Here, it is assumed that the population in the basin increases by 30%, and the use of all human waste is stopped, and the loads due to these

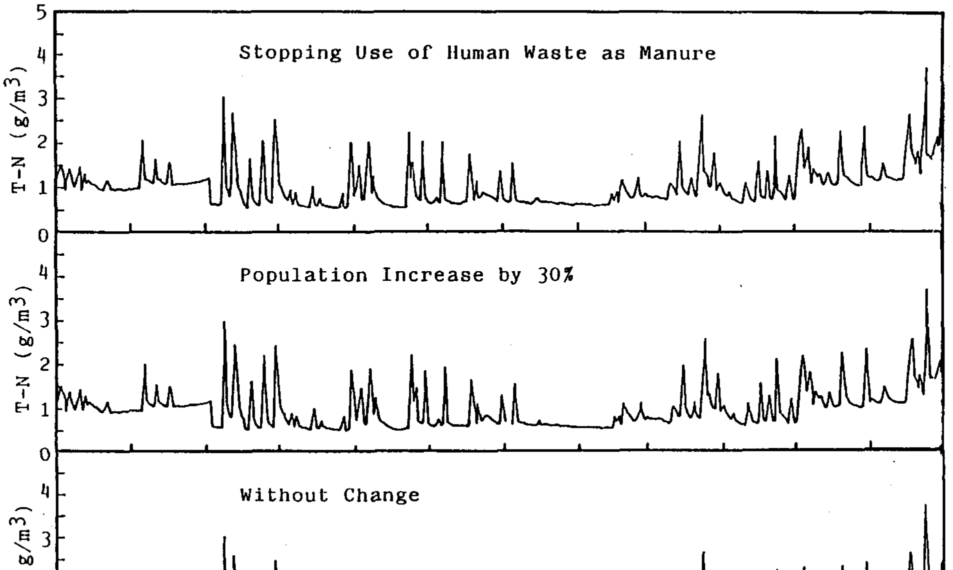

Fig. 9 Effects of urbanization on concentration of T-N

changes are treated by private sewerage systems. As seen from Fig. 9, the increase of the population and decrease in use of human waste do not affect the water quality of the Hino River so much. From these results, it is important to control the nonpoint sources in the basin.

6. CONCLUSIONS

In this paper the model of water quality management for the Hino River basin is formulated and a calculation system by a microcomputer was developed in order to predict the change of water quality and support the decision making for the water quality management.

The identified model reproduces the observed water quality relatively well. The developed calculation system is easily operated and predicts the influences and effect of developing of the basin and change of pollutant loads. Predicting the effects of the development in the basin on the water quality of the Hino River using this model, the increase of population and decrease in use of human waste as fertilizer do not affect the water quality of the Hino River because the pollutant loads from forests and rice paddy fields are much greater than from households. In the Hino River basin to control nonpoint sources is important for the water quality management.

A part of this paper was presented at the Fifth International Conference on Urban Storm Drainage held in 1990.

ACKNOWLEDGEMENT

We thank our colleagues for their assistance in observations.

REFERENCES

(1)Hino, M. and Hasebe, M. : Analysis of Hydrologic Characteristics from Runoff Data - A Hydrologic Inverse Problem, Jour. of Hydrology, 49, (1981), 287.

(2)Kunimatsu,T. and Kira, T. : Nutrients Runoff from Forests and the Countermeasure, Water Purification and Liquid Waste Treatment, 27, (1986), 721 (in Japanese).

(3)Watabe, H., Ii, S. and Tanaka, K. : Characteristics of Pollutant Flux from Forest, Jour. of Japan Sewage Works Assoc., 24, 273, (1987), 41 (in Japanese)

(4)Kunimatsu, T. : The Loads of N and P from Farmlands (I), Jour. of Environmental Technology, 14, (1985), 114 (in Japanese).

(5)Kunimatsu, T. : The Loads of N and P from Farmlands (II), Jour. of Environmental Technology, 14, (1985), 195 (in Japanese).

(6)Wada, Y. : Study on the Determination and Simulation of the Runoff Accumulated Load of the Road Surface in the Nonpoint-pollution Load, Japan Jour. of Water Pollution Research, 4, 3, (1981), 143 (in Japanese).