Statistical Modeling of Pollutant Load in Subbasins of the Fuji River Basin, Japan

S. Shrestha[1] F. Kazama[2] Y. Sakamoto[3] and S. Bastola[1]

[1] Ph.D. Student. Center of Excellence, Integrated River Basin Management for Asian Monsoon Region, Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, 4-3-11, Takeda, Kofu, Yamanashi, 400-8511, Japan.

[2,3] Associate Professor and Professor. Center of Excellence, Integrated River Basin Management for Asian Monsoon Region, Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, 4-3-11, Takeda, Kofu, Yamanashi, 400-8511, Japan.

ABSTRACT

A statistical modeling approach was used to estimate the pollution loads in different river system of Fuji River Basin. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS) and Orthophosphate Phosphorus (PO_4-P) were taken as indicator of pollution. Loadings of BOD, COD, SS and PO_4-P were estimated in Kikkobashi, Hikawabashi and Omogawabashi sub basins, using a Seven Parameter Log Linear Model (ESTIMATOR) developed by United States of Geological Survey. ESTIMATOR computes nutrient and other constituent loads in rivers based on a daily values for discharge and unit value water quality samples. The fortnightly (semi-monthly) measured values of the water quality parameters of more than 10 years were used to build the concentration and load models for each water quality parameter for each sub basins to predict the daily concentrations and loadings. Of these three stations, the daily discharge in Hikawabashi and Omogawabashi subbasins was not available. Therefore, a TANK model which was calibrated and validated with very good results was used to estimate the daily discharge for those stations. The statistical summaries of concentration and load models show it is capable of predicting the loadings from each sub basin. The higher loadings of BOD, COD, SS and PO_4-P are estimated from Hikawabashi and Omogawabashi than the upstream area of Kikkobashi. These results are tied to basin cover characteristics. The higher loadings of BOD, COD, SS and PO_4-P from Hikawabashi and Omogawabashi are attributed to higher percentage of orchard, agriculture and urbanized area. The seasonality in loadings from all basins are also observed and attributed to plant growth cycles and anthropogenic influences like cultivation practices, fertilizer applications in the orchard plantation and agriculture areas. After the investigation of waste water treatment systems of the basin and pollutant loading behavior, it can be concluded that the non-point sources are the major contributors in pollutant loading in the study basin.

Keywords: Nonpoint source pollution, Tank Model, ESTIMATOR, BOD, COD, SS, PO_4-P

S. Shrestha, F. Kazama, Y. Sakamoto and S. Bastola. “Statistical Modeling of Pollutant Load in Subbasins of the Fuji River Basin, Japan”. Agricultural Engineering International: the CIGR Ejournal. Vol. VII. Manuscript LW 05 001. March, 2005.

1. INTRODUCTION

The identification and quantification of source of quality impairment is essential for the water quality management program in river basins. Water quality in estuaries, lakes and reservoirs depends upon the quantity and quality of inflows from the upstream catchment, cycling within the water body and, in case of estuaries, exchanges with the ocean. Of these processes, inflows are usually the most significant source of pollutants. Stream flow is therefore of primary importance to the health of receiving waters and its quantification is crucial to our ability to manage those ecosystems in an environmentally healthy manner. Two general sources, point and nonpoint sources of pollution are taken into consideration while studying water quality management. Typically, attempts are initially made to quantify and reduce the impact of point source pollution because this source is readily collectable and treatable by well known processes. In contrast, the role and impact of nonpoint source pollution has not been understood properly due to its diffusive nature and high variability both in time and space. In fact, the nonpoint source is the major contributor to pollutant loads into most receiving water bodies. The pollutant load runoff into receiving water may differ with the nature of a river basin and the flow regime (Yamada et al., 1991, 1993). Therefore, it is necessary to study the site-specific relationship between the basin cover characteristics and pollutant load into the water bodies.

Several water quality models have been developed to predict the nutrient loadings into the water bodies. These models ranges from simple export coefficient models (Beaulac and Reckhow, 1982; Johnes, 1990); log-linear models such as SPARROW (Alexander et al., 2002; McMahon et al., 2003), ESTIMATOR (Cohn et al., 1989 and 1992) to complex mechanistic models such as CREAMS (Knisel, 1980), ANSWERS (Beasley et al., 1980), EPIC (Williams et al., 1982), SWRB (Williams et al., 1985), GLEAMS (Leonard et al., 1987), WEPP (Nearing et al., 1989), AGNPS (Young et al., 1989 and 1994), HSPF (Donigian et al., 1995), SWAT (Arnold and Allen, 1996), etc. But the most accurate approach includes continuous recording of streamflow and frequent collection of water quality samples from both low flows and high flows. Loadings are estimated by multiplying the concentration values by stream discharge (volumetric rate) for the given time period between samples. Concentration for time periods not accounted for can be estimated using integration techniques (mass accumulation) or regression models. The regression method uses the relation between concentration or load and daily average flow to estimate daily concentration or loads of constituents (Cohn et al., 1989; Cohn et al., 1992; Cohn, 1995). The regression approach has come into widespread use because it requires less data and can be used to produce estimates for period beyond when concentration data were collected, and enables confidence limits to be placed on the estimates as a measure of the regression model error.

This study mainly focuses on estimation of pollutant loads using available rainfall runoff and regression models and identification of the major source of pollution in the river system having different type of basin cover (land use) characteristics.

2. MATERIALS AND METHODS

2.1 Study Area

The study area, Ukaibashi basin, is located in the central part of Japan (Fig 1). The Ukaibashi basin having an area of 498 km^2 is considered as a subbasin of the Fuji River basin. Fuefuki River, Hi River and Omo River are the major tributaries of the Fuji River and drain the Ukaibashi basin. The geology of this basin contains fragile rocks and produces a large amount of sedimentation. Land use in Ukaibashi basin includes 75% forest land, 13% orchard plantations, 4% agriculture area, 4% grassland and 3.5% urban areas. The forest land is located mostly in mountainous area. Agriculture and grassland areas are sparsely distributed throughout the basin especially on the west side. Orchard plantations and urban areas are situated along the water bodies. The major fruits grown in this area are table grapes, peaches and cherries, and wine grape and wine production is ranked tops in Japan. The basin lies in an inland region, and therefore has extreme variation in temperature between summer and winter seasons. The summers are hot and humid and winters are cold. The basin receives a mean annual precipitation of approximately 2,100 mm.

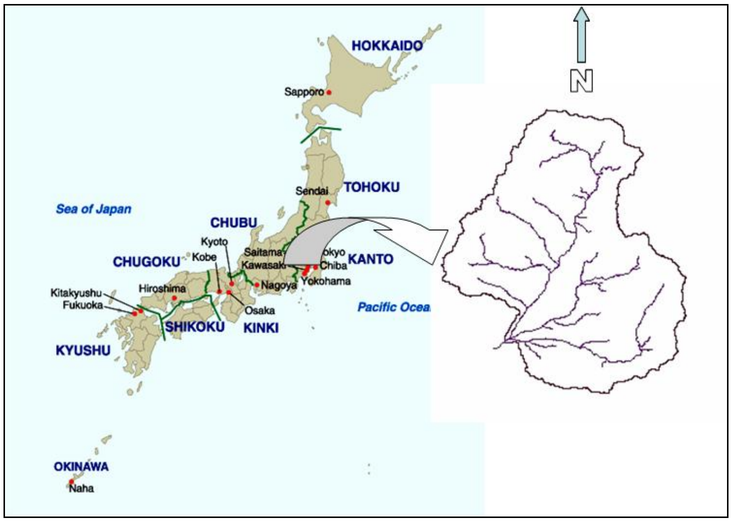


Figure1. General location map of the study basin in central Japan

2.2 Data Analysis

2.2.1 Water Quality

In order to estimate the pollution loading, fortnightly (semi-monthly) data of the four water quality parameters are obtained from The Environment Division of Yamanashi Prefecture (EDYP), Japan (Table 1). EDYP has been monitoring the hydrology and water quality of the major rivers and its tributaries at various points since 1976 (Fig 2).

Table 1. Water quality parameters (1993-2002) taken for modeling purpose

Water Quality Parameter	Analysis Method
Biological Oxygen Demand (BOD)	BOD_5
Chemical Oxygen Demand (COD)	$COD_{(Mn)}$
Suspended Solids (SS)	Dried at 105-110^{0}C
Orthophosphate Phosphorus (PO_4-P)	Mo Blue

Source: EDYP, 2004

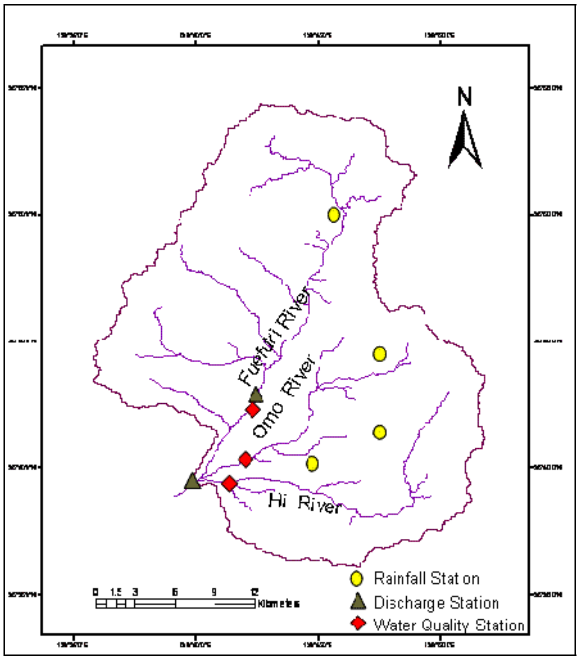
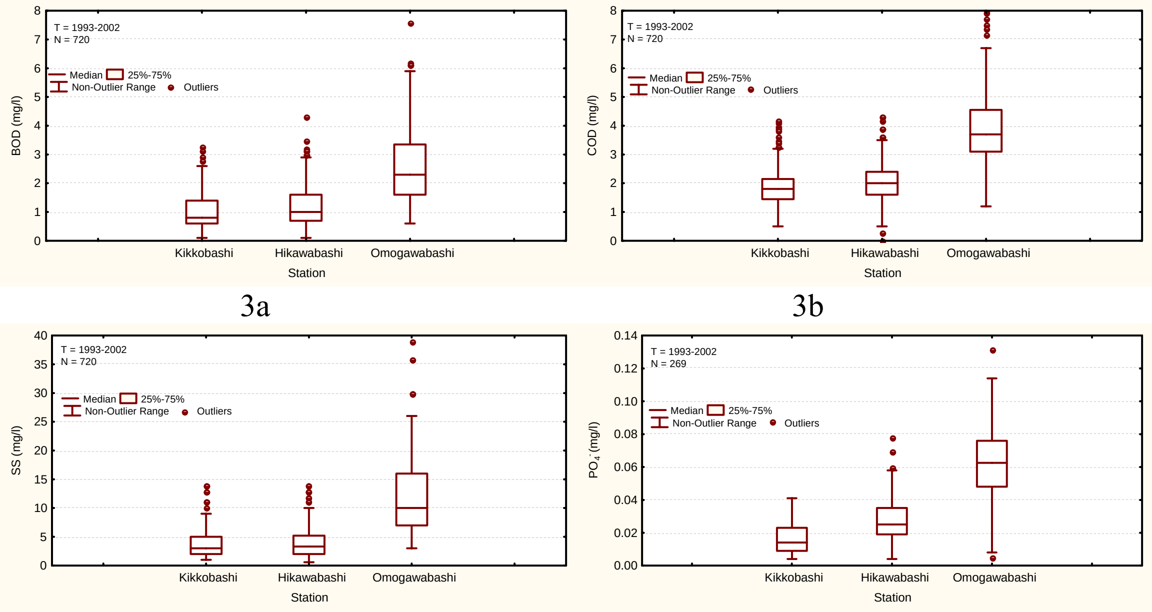


Figure 2. River network and rainfall, discharge and water quality measurement stations in the Ukaibashi basin

Biological oxygen demand (BOD_5) refers to the amount of oxygen consumed by the microorganism for the decomposition of carbonaceous organic matter and chemical oxygen demand (COD_{Mn}) is the oxygen required to oxidize all reduced compounds, both organic and inorganic in the water. BOD and COD are chosen to characterize the level of organic pollution in the water bodies. Suspended solids (SS) consists of an inorganic fraction (silt, clays etc.) and an organic fraction (algae, zooplankton, bacteria and detritus) that are carried along by water as it runs off the landscape. The inorganic portion is usually considerably higher than the organic. Orthophosphate phosphorus (PO_4-P) comes from fertilizers, pesticides, industry and cleaning compounds. Natural sources include dissolution of phosphate containing rocks and minerals as well as solid or liquid anthropogenic wastes. SS and PO_4-P are chosen to characterize the level of inorganic pollution in the basin. Water quality data from three sampling stations for Kikkobashi, Hikawabashi and Omogawabashi River are used for this modeling purpose.

BOD, COD, SS and PO_4^-P concentrations from 1993 through 2002 that were used to calculate loads and yields in the Ukaibashi basin are shown in Fig 3a-3d as box plots. The extreme outliers are the result of typhoon events in the basin. However, these extreme values are included during the construction of concentrations and load models. Box plots visually indicate the magnitude of the data set, the variation of the data and the presence of outlier values. T represents the period of observations for each site (the range in years for which data was available), and N represents the number of observations.

The box plot shows that the magnitudes of constituent concentrations vary with locations. The concentrations of all constituents are highest at the Omogawabashi River station and lowest at Kikkobashi River station. The Environmental Agency, Japan (1999) has set the standard values 1 for BOD, COD and 5 for SS for different classes of rivers. It can be observed that the constituent concentration of the river has exceeded the level of the water quality standard set by Environmental Agency, Japan.



3a 3b

3c 3d

Figure 3a-3d. Constituent concentrations in the Ukaibashi basin: available BOD, COD, SS and PO_4-P for three stations in the basin during 1993-2002.

2.3 Basin Division

A Digital Elevation Model (DEM) of 50m resolution was used to generate stream network and basin generation. With the help of ArcGIS and Archydro tools, the basin was divided into three sub basins according to the water quality sampling locations. The land cover map published by Ministry of Environment, Japan was used for this study. Land cover was reclassified from 15 to 8 classes according to the similarity in land cover and land use (Fig.4). The sub basin topographic map was overlaid on to the land cover map and the area of each land cover was calculated (Table 2). The Kikkobashi River sub basin has the highest proportion (85%) of land covered by forest and Omogawabashi River sub basin has the highest proportion of land covered by orchard (30%) and urban (6%).

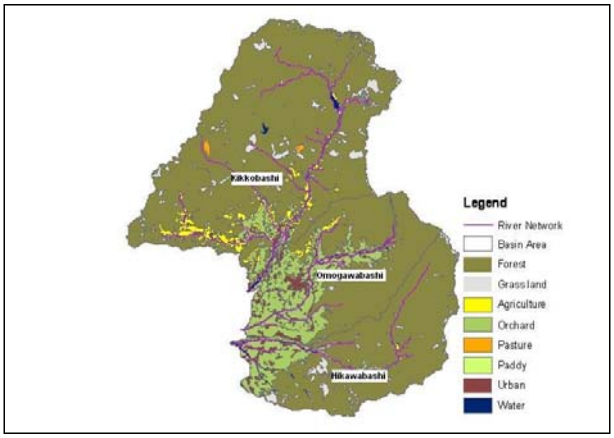


Figure 4. Land cover map of the Ukaibashi basin in central Japan

Table 2. Location and basin cover characteristics

Sub basin/Basin	Location	Area	Land cover (Km^2)					
		Km^2	Forest	Grassland	Agriculture	Orchard	Paddy	Urban
Kikkobashi	138.688^0	241.8	204.27	11.22	12.11	8.31	0.68	0.74
	35.693^0		(84.46)	(4.64)	(5.01)	(3.44)	(0.28)	(0.31)
Hikawabashi	138.680^0	111.1	87.03	5.10	0.30	13.72	0.12	3.17
	35.657^0		(78.27)	(4.59)	(0.27)	(12.34)	(0.11)	(2.85)
Omogawabashi	138.685^0	109.0	64.25	1.72	2.28	32.98	0.27	6.83
	35.667^0		(58.90)	(1.56)	(2.09)	(30.23)	(0.24)	(6.26)
Ukaibashi	138.645^0	497.5	370.26	19.30	17.46	65.13	1.53	17.54
	35.644^0		(74.41)	(3.88)	(3.51)	(13.09)	(0.30)	(3.52)

( ): percentage of total area

2.4 Modeling Approach

Several rainfall-runoff models have been developed to predict the discharge. These vary from simple lumped models to complex distributed models. However, for this study a simple TANK model was used for simulation of discharge at those basins where the continuous discharge data are not available.

2.4.1 TANK Model

The TANK model (Sugawara, 1974) is a continuous, lumped, deterministic model and comprises four vertical tanks with the provision of primary and secondary storage (Fig 5). Rainfall, the input to the hydrologic system, is transformed as output as the stream discharge. The net stream discharge is the sum of the discharges from the side outlets of the tank, which are obtained after deducting evaporation from rainfall. TANK model represents a zonal structure of groundwater. The intensity of rainfall governs the behavior of the model. The top and middle tank contributes to the surface runoff, third and fourth contributes to the base flow. The soil moisture storage of the tank model comprises of primary storage and secondary storage. First the input, the rainfall, increases the primary soil moisture storage and in gradual process the continued input is utilized in increasing the secondary soil moisture. The storage level and the capacity of these two storages govern the provision of exchange of water between these two storages. The transfer of water from the primary tank to secondary tank and vice-versa is governed by equation (1).

$$T_2 = \left[\frac{XP}{PS} - \frac{X_s}{SS}\right] \tag{1}$$

SS is the height of secondary storage tank, and X_S is the depth of secondary storage. *XP* is the depth of primary storage. T_2 is the transfer of water form lower free water to primary soil moisture. When the moisture deficit is higher in the primary soil moisture storage, then the transfer of water form the second tank to the primary storage occurs, and this transfer rate depends upon the moisture deficit of the tank i.e. XP/PS. And this transfer rate is governed by equation (2).

$$\mathrm{T}_1 = K_1 = \left[1 - \frac{XP}{PS}\right] \tag{2}$$

T_1 is the transfer rate from primary to secondary soil moisture. Evapotranspiration loss demands are at first attempted to meet at the potential rate from the top tank, when the primary storage is fully saturated. If the moisture content in the surface storage is less than these requirements, the remaining fraction is withdrawn by from the primary storage at an actual rate. The actual Evapotranspiration *Ea* is assumed equal to the potential Evapotranspiration *Ep* multiplied by the relative moisture content *PS*/*Xs*. The equation (3) describes the relation between the actual evaporation and potential evaporation.

$$E_a = E_p * \frac{PS}{XP} \tag{3}$$

The Runoff from each tank is controlled by the runoff coefficient of the side outlet provided in each tank and the amount of infiltration is controlled by the outlet coefficient of the bottom outlet.

A_1, A_2, B_1, C_1 and D_1 are the runoff coefficient of each tank, and A_0, B_0, C_0 are the infiltration coefficient of the tank. *PS*, HA_1, HA_2, HB_1, HC_1 are the height of the side outlets of each tank and X_A, *Xs*, X_B, X_C, X_D are the initial storage value of different tank included for the simulation of rainfall and runoff. *Xp* and *Xs* are the initial storage value of primary and secondary storage tank. The detailed are shown in the structure of the model (Fig. 5).

In this study, the tank model coupled with genetic algorithm (Bastola et al., 2002) was used to optimize the parameters of the tank model.

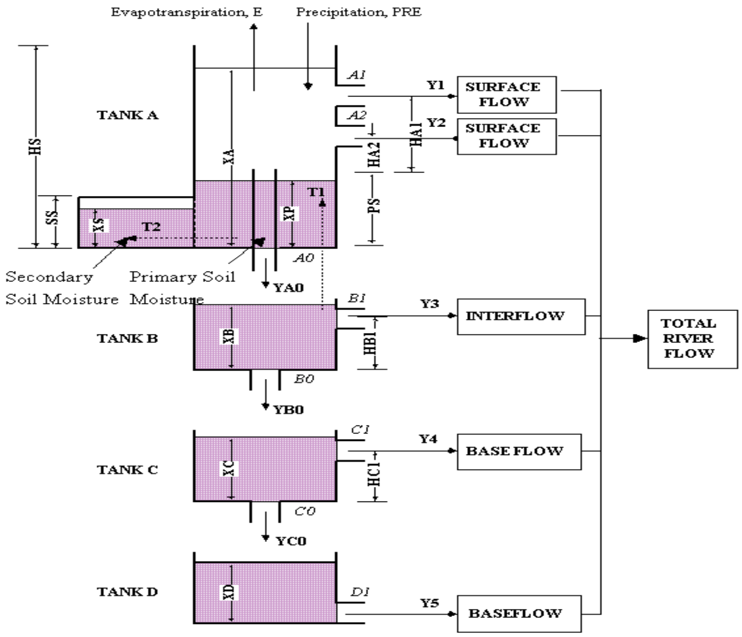


Figure 5. Structure of the TANK Model

2.5 ESTIMATOR

The ESTIMATOR program was developed to assist U.S. Geological Survey personal in estimating stream nutrient loads entering Chesapeake Bay through its major tributaries. ESTIMATOR has since been used to estimate loads of toxic organics and trace metals. It calculates loads of nutrients (and other constituents) carried by rivers by employing a statistical regression model, where the constituent concentrations are estimated based on stream flow and time/season. The application requires daily value of stream flow records and unit values of constituent concentrations. This program implements the Minimum Variance Unbiased Estimator (MVUE) (Cohn et al., 1989; Gilroy et al., 1990; Cohn et al., 1992a; Cohn et al., 1992b) to estimate the loading of constituents into the river. It requires a total of k=7 parameters: a constant; a quadratic fit to the logarithm of discharge (two parameters); a quadratic fit to time (two parameters); and a sinusoidal (first-order Fourier) function to remove the effects of annual seasonality (two parameters). The model can be written in the following form:

$$\ln[CorL] = \beta_o + \beta_1 \ln\left[\frac{Q}{Q'}\right] + \beta_2 \left\{\ln\left[\frac{Q}{Q'}\right]\right\}^2 + \beta_3[T - T'] + \beta_4[T - T']^2 + \beta_5 Sin[2\pi T] + \beta_6 Cos[2\pi T] + \varepsilon \tag{4}$$

Where ln [] denotes the natural logarithm function; C is the estimated daily concentration (mg/l); L is the estimated daily load (kg/day); Q is the daily discharge (ft^3/s); T is time measured in years; β_0 is a constant; β_1 and β_2 describe the relation between concentration and discharge; β_3 and β_4 describe the trend in concentration data; β_5 and β_6 describe the seasonal variation in concentration data; Q' is a centering variable defined so that β_1 and β_2 are statistically independent; T' is a centering variable defined so that β_3 and β_4 are statistically independent; and ϵ is the combined independent random error, assumed to be normally distributed with zero mean and variance σ_ϵ^2.

Equation (4) represents concentrations as a function of three factors: a flow factor *(Q/Q')*, a time factor *(T − T')*, and a seasonal factor *[sin (2πT) + cos (2πT)]*, which applies the effect of the four seasons to the data. Quadratic terms were included to account for curvature that remained after transformation. ESTIMATOR produces daily, monthly, and annual loads for each water year. To determine the total load of a constituent for a given month, the estimated daily mean load was multiplied by the number of days in the month. The precision of this estimate can be described in terms of the confidence interval, which is based on the estimated daily mean load and the standard error of prediction.

3. RESULTS AND DISCUSSIONS

3.1 Discharge Simulation

The TANK model was calibrated using the continuous discharge of 1999-2000 at the outlet of Ukaibashi basin. The rainfall data of four stations and evapotranspiration data of one station are used as model inputs. The statistical performance of the model was evaluated by Nash efficiency criteria and found to be 78%. Qualitative performance of the model was evaluated by comparing the daily hydrographs, flow duration curves and cumulative water balance curve of observed and simulated values (Fig. 6-8). No major discrepancies/deviations were observed in the curves .The optimized parameters of the model for the basin are presented in Table 3.

Table 3. The optimized parameters of the TANK model for Ukaibashi basin.

Parameters			
Outflow	Value	Outflow level	Value
A_0	0.41150	PS	4.990
A_1	0.00950	HA_1	11.870
A_2	0.11090	HA_2	18.780
B_0	0.88200	HB_1	3.880
B_1	0.15519	HC_1	2.110
C_0	0.07431	K_1	0.269
C_1	0.13312	K_2	0.413
D_1	0.01874		

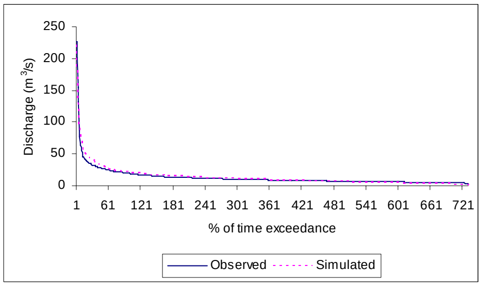


Figure 6. Comparison between flow duration curves of observed and simulated discharge

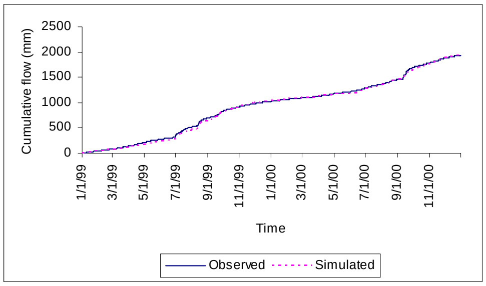


Figure 7. Comparison between cumulative flow of observed and simulated discharge

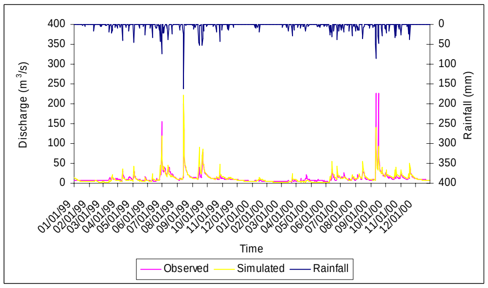


Figure 8. Comparison between observed and predicted discharge at the outlet of Ukaibashi basin

The calibrated model was validated using the discharge data of 2001 and the efficiency was found to be 85% (Fig. 9). This result shows that the model can be confidently applied to simulate the discharge in the Ukaibashi basin using the values of optimized parameters. The model was used to simulate the discharge of Hikawabashi and Omogawabashi basins from 1993 to 2002 (Fig. 10 and Fig.11).

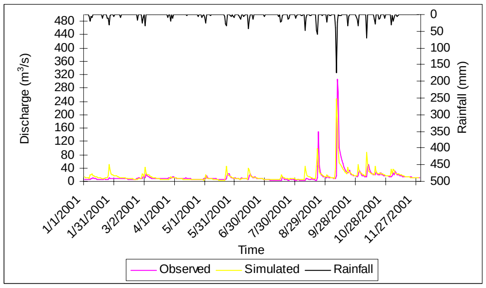


Figure 9. Observed and simulated discharge during model validation

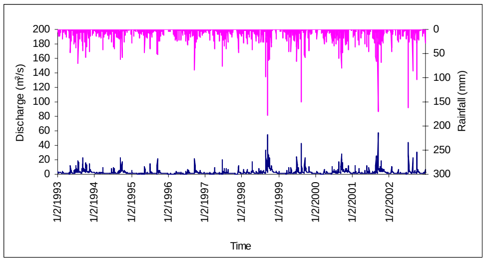


Figure 10. Predicted discharge at Hikawabashi basin during 1993-2002

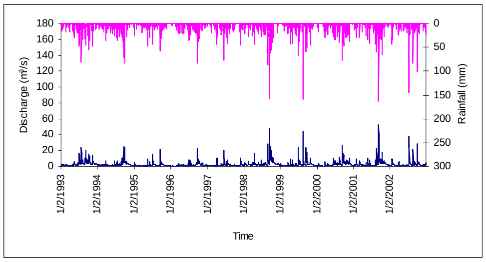


Figure 11. Predicted discharge at Omogawabashi basin during 1993-2002

3.2 Load Estimation

The observed daily discharge at Kikkobashi and simulated discharge at Hikawabashi and Omogawabashi and fortnightly measured water quality parameters (1993-2002) were used for the construction of concentration and load models using ESTIMATOR program. Before construction of the concentration and load models, Kolmogorov-Smirnov normality test was applied for all variables. The statistical summaries of the concentration and load models show their good predictive capabilities to estimate pollutant loading. The models are evaluated by standard deviation (s) of residuals, the variability (R^2) explained by the models for logarithm of concentration and load (Fig 12, a typical case) and standard error (SE) of prediction. The statistical significance (p-level) at 5% was also described for all coefficients (Appendix 1).

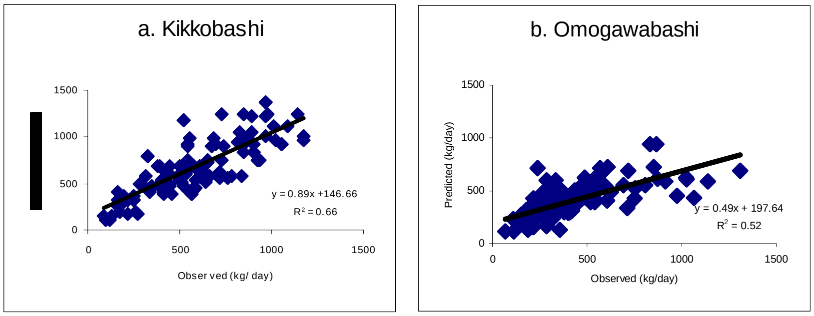


Figure 12. Comparison between observed and predicted load of BOD at a) Kikkobashi and b) Omogawabashi

The daily loadings of biological oxygen demand, chemical oxygen demand, suspended solids and orthophosphate phosphorus from each basin were estimated by the constructed models for 2000-2002 (Fig. 13-16).

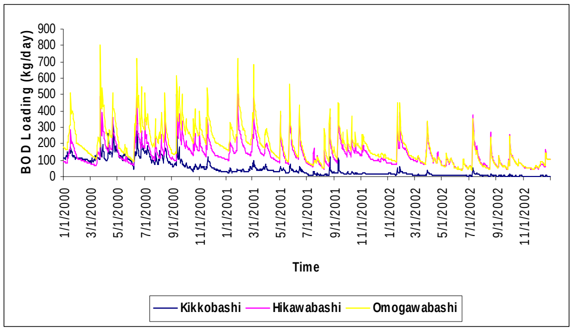


Figure 13. Daily loadings of BOD

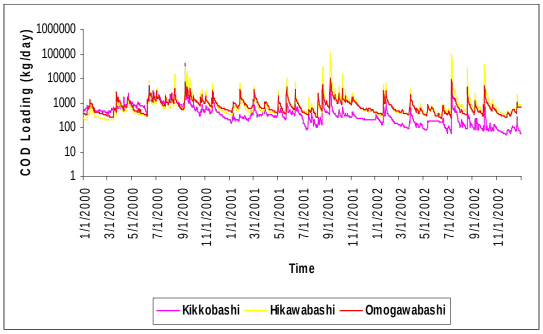


Figure14. Daily loadings of COD

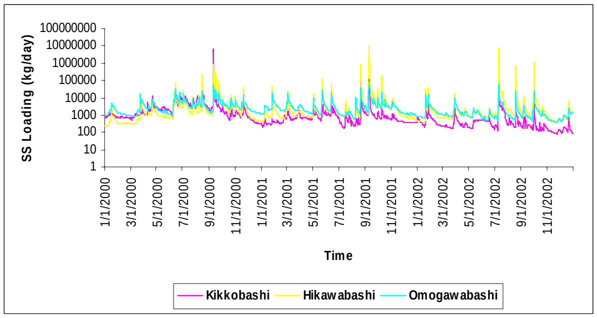


Figure15. Daily loadings of SS

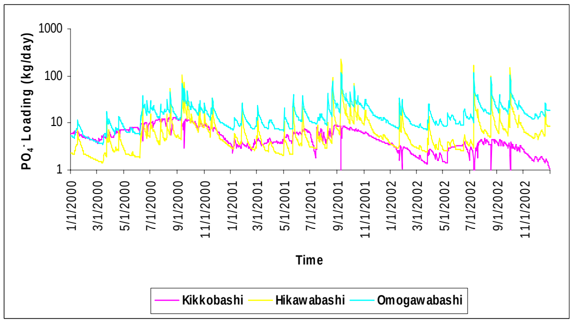


Figure16. Daily loadings of PO_4-P

The mean annual pollutant loads (Kg/yr) for each water quality parameters were divided by the area of the sub basins (km^2) to give mean annual pollutant yields (kg/km^2). This normalized the loads so that comparisons could be made among basins of varying sizes. The yields were then compared and ranked for constituent at each site in the basin. For a given constituent, the rank 1 was assigned to the sites with highest mean annual yield and 3 were assigned to sites with the lowest mean annual yield. The Kikkobashi basin ranks 3 for BOD, COD, PO_4^-P and 2 for SS. The Hikawabashi basin ranks 1 for COD and SS and 2 for BOD and PO_4^-P. The Omogawabashi basin ranks 1 for BOD and PO_4^- , 2 for COD and 3 for SS (Table 5).

The Omogawabashi has the highest yields of biological oxygen demand and orthophosphate phosphorus when compared to other basins. This result can be related to land cover of the basin. Omogawabashi basin has the higher percentage of orchard plantations, agriculture and urban areas when compared with other basins. Therefore it receives stream flow primarily from orchard, agriculture and urban runoff. However, the Hikawabashi has unexpectedly highest yield of suspended solids compared to other basins. The other important issue in dealing with the loadings of contaminants is the distance of sampling point and the source area of contaminants. The land area located at a distance from the surface drainage network may be less important in exporting contaminants to the surface drainage network than areas of land adjacent to the water course. If there is no direct hydrological connectivity between the source area and stream the contaminant uptake mechanisms of land lying along the hydrological pathway will be bypassed and the load will be diminished (Johnes, 1996). The unexpected highest loading of SS loadings from the Hikawabashi is attributed to the vulnerability of geology to the erosion and mass wasting or landslides from the riparian areas of the basin during the study period.

Table 5. Mean annual yield of water quality parameter from different sub basins

		Mean Annual Yield (kg/km^2)			
Basin	Area (km^2)	BOD	COD	SS	PO$_4^-$P
Kikkobashi	241.87	215^3	2207^3	37812^2	23^3
Hikawabashi	111.19	1335^2	14022^1	297726^1	77^2
Omogawabashi	109.09	1849^1	8595^2	32301^3	159^1

^{1,2,3}: Ranks

A correlation between BOD, COD, SS and PO$_4$-P loading was also performed in each basin (Table 6). The strongest correlation is observed between the loadings of SS and COD in all basins. The suspend solids consists of an inorganic fraction (silt, clays etc.) and an organic fraction (algae, zooplankton, bacteria and detritus). These organic fraction always demands more oxygen for degradation when compared to easily degradable organic compounds such as tender vegetations. The strong correlation between COD and PO$_4^-$P and SS and PO$_4^-$P loadings are also observed in Hikawabashi and Omogawabashi. But, very weak correlation was observed between SS and PO$_4$-P in Kikkobashi. Since the Kikkobashi basin has very small fraction of agriculture and urban area, the concentration of orthophosphate phosphorus was very less as compared with other basins. Therefore, the negligible correlation was found between the loadings of suspended solids and orthophosphate phosphorus in Kikkobashi basin.

Table 6. Correlation between BOD, COD, SS and PO$_4$-P for each sub basin

Kikkobashi					Hikawabashi					Omogawabashi				
	BOD	COD	SS	PO$_4^-$P		BOD	COD	SS	PO$_4^-$		BOD	COD	SS	PO$_4^-$P
BOD	1.00				BOD	1.00				BOD	1.00			
COD	0.51	1.00			COD	0.37	1.00			COD	0.69	1.00		
SS	0.27	0.94	1.00		SS	0.20	0.94	1.00		SS	0.62	0.97	1.00	
PO$_4^-$P	0.51	0.12	-0.05	1.00	PO$_4^-$P	0.47	0.92	0.75	1.00	PO$_4^-$P	0.32	0.85	0.78	1.00

The seasonality in the loadings was also examined in all basins (Fig 17-20). Four seasons, winter (December-February), spring (March-May), summer (June-August) and autumn (September-November) are described for study. The seasonality in the loadings of BOD has not been observed in Omogawabashi and Hikawabashi. This shows the constant discharge of wastes from residential area and limited contribution of nonpoint source pollution on BOD loading. However, the loading is larger in spring season at Kikkobashi. The forest is the major (85%) land cover in this basin. Therefore the non-decomposed or partially-decomposed vegetation are washed off by the storm into the water bodies and activity of microorganism increased which led to the increase in oxygen demand.

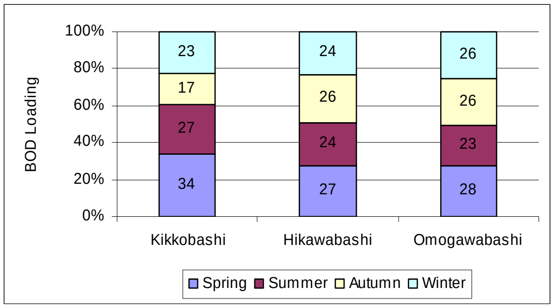


Figure17. Seasonal loading of BOD

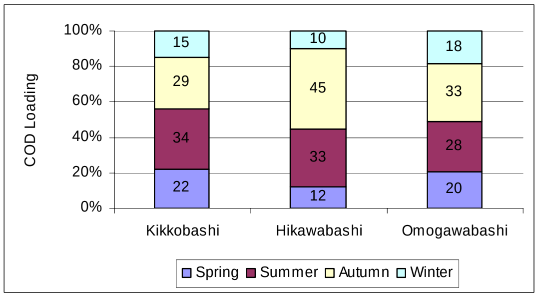


Figure 18. Seasonal loading of COD

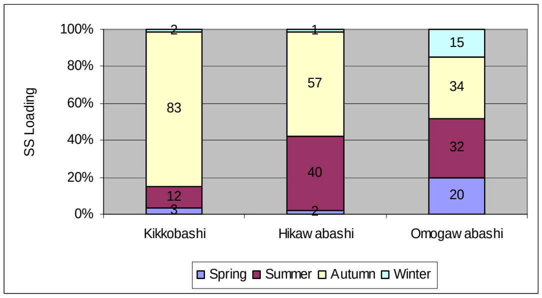


Figure19. Seasonal loading of SS

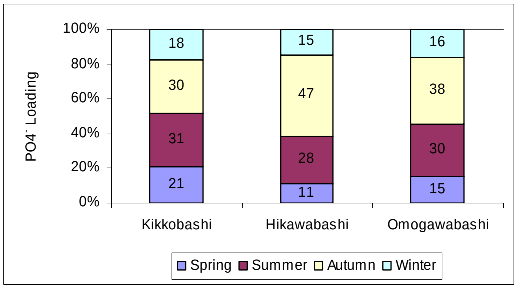


Figure 20. Seasonal loading of PO_4-P

The comparatively higher loadings of chemical oxygen demand, suspended solids and orthophosphate phosphorus are observed during summer and autumn seasons for all basins. These seasons also receives more than 37% of total rainfall in the basin. Therefore, it can be said that the major source of the pollution is nonpoint sources. The farmers usually harvest the fruits during the Summer and Autumn season and apply the fertilizer during the end of Autumn and beginning of the Winter season. The harvesting activities during the Summer and Autumn season led to the disturbances in landcover which ultimately increased the loadings of COD, SS and PO_4-P with the onset of rainfall from all basins. Nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-caused pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even underground sources of drinking water. A strong correlation was identified among the loadings of suspended solids, chemical oxygen demand and orthophosphate in all basins except in Kikkobashi. In Kikkobashi very weak correlation between suspended solids and orthophosphate phosphorus was observed. We can also see that the very less mean yield of orthophosphate phosphorus from Kikkobashi. These scenarios suggest that forest is not the major contributor source to orthophosphate phosphorus pollution.

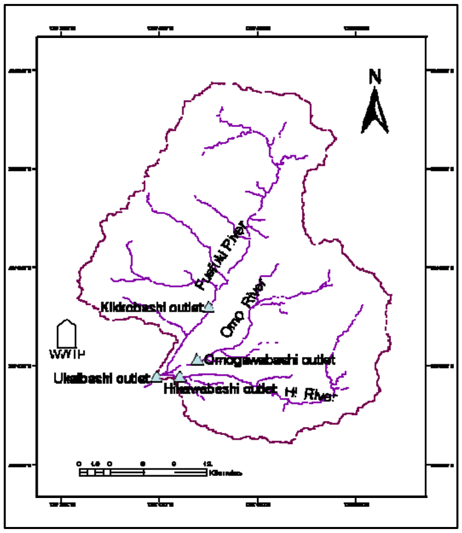


Figure 21. Location of the waste water treatment plant (WWTP) and natural drainage channels that drains the three sub basins

The basin has a very good sewerage system and the waste water treatment plant (WWTP) is also located outside the basin (Fig.21). Although the small percentage of residential area has their own septic tank and discharges wastes into water bodies, the majority of the residents, industries and factories use the sewerage system. Therefore it can be said that point source loading should have a minor effect in pollutant loading.

3.3 Best Management Practices (BMPs)

According to the loading estimation and correlation analysis, it was observed that reducing suspended solids from agricultural and orchard areas can reduce the loading of COD, BOD and PO_4-P from the study basins. Therefore, the BMPs which can reduce the suspended solid movement associated with runoff i.e. water erosion, are described in this section.

3.3.1 BMPs for Detachment

The most effective stage to implement BMPs is during detachment, when soil particle is being detached and taken up by runoff water. BMPs that target detachment include the use of crop residues or vegetative cover to protect the soil from erosion. One of the most successful BMPs for protecting crop fields from erosion has been conservation tillage and no-tillage systems, which leave residue from the previous crop on the surface soil.

3.3.2 BMPs for Transport

Conservation practices can be used to reduce the amount and velocity of water runoff and reduce suspended solids erosion from fields. A successful example of this is the use of terraces on sloping lands. Terraces reduce the distance water moves downslope and divert water at reduced slope to grassed waterways or an underground outlet system.

3.3.3 BMPs for Deposition

This is the practices to control the erosion by allowing for deposition or settling out of the soil particles. Anything that slows the water will cause soil particles to settle out. The filter stripes or buffer areas next to rivers, lakes, and streams have proven effective in removing soil particles from storm water runoff.

4. CONCLUSIONS

Four water quality parameters (Biological Oxygen Demand, Chemical Oxygen Demand, Suspended Solids and Orthophosphate Phosphorus) were used to study the major sources and level of pollution by sub-basin basis in the different river system of Fuji River Basin. The TANK model was used to simulate the discharge in the basin where discharge was not available. The model was calibrated and validated with very good efficiency. During calibration and validation, the efficiency was found to be 78% and 85% respectively. This discharge and fortnightly (semi-monthly) measured values of water quality parameters were used to construct the concentration and load models. The statistical summaries of the models show very good predictive capabilities. These models were used to estimate loadings from each basin.

Although the basin area is smaller, the mean annual yields of BOD, COD, SS and PO_4-P are higher in Hikawabashi and Omogawabashi than Kikkobashi. The mean annual yield of BOD and PO_4-P are higher in Omogawabashi whereas mean annual yield of COD and SS are higher in Hikawabashi. The organic and inorganic pollution level is highest in these two basins where the percentage of orchard, agriculture and urban area are higher than the Kikkobashi.These results show that the basin cover characteristics and anthropogenic activities are important factors that influence water quality. The need for investigation about the distance of source area and sampling point is realized as it affects the contaminant transport mechanism in the basins. Similarly, higher loadings were estimated in summer and autumn season from all basins. Since the basin has very good sewerage system and waste water treatment plant is located outside the basin, the major source of pollution is attributed to the nonpoint sources. These seasons also receives more amount of rainfall in the basin. However, some best management practices were described, careful need of management and planning of basin with respect to agricultural and urban activities especially during summer and autumn season are emphasized to reduce the loadings of organic and inorganic pollution into the water bodies.

5. ACKNOWLEDGEMENTS

The author would like to acknowledge the help from The Environment Division of Yamanashi Prefecture, Japan for providing the water quality data; the members of Kazama Lab, Department of Ecosocial System Engineering, University of Yamanashi for their help in translating the language from Japanese to English. The author would also like extend sincere thanks to the reviewers for their critical comments and suggestions to improve the quality of the paper.

6. REFERENCES

Alexander, R.B., A.H., Elliott, U Shankar, and G.B. Mcbride. 2002. Estimating the source and transport of nutrients in the Waikato River Basin, New Zealand. *Wat. Resour. Res.,* 38, 1268-1290.

Arnold, J.G. and Allen, P.M. 1996. Estimating hydrologic budgets for three Illinois watersheds. *J. Hydrol*. 176, 57-77.

Bastola, S., M. Sugawara, N.M. Shakya, and T. Hamasaki, 2002. A continuous, lumped TANK hydrological model with optimization capability using genetic algorithm. Department of Human and Environment, Osaka Sangyo University, Japan.

Beasley, D.B., Huggins, L.F. and Monke, E.J. 1980. “ANSWERS: A model for watershed planning.” *Transaction of the ASAE* 23 (4): 938-944.

Beaulac, M.N. and K.H. Reckhow. 1982. An examination of landuse-nutrient export relationships. *Wat. Res. Bull*., 18, 1013-1024.

Cohn, T., DeLong, L. L., Gilroy, E. J., Hirsch, R. M.., and Wells, D. K. 1989. "Estimating Constituent Loads," *Wat. Resour. Res.,* 25(5), 937-942.

Cohn, T., D. Caulder, L., Gilroy, E. J. Zynjuk, L. D., and Summers, R. M. 1992a. "The Validity of a Simple Statistical Model for Estimating Fluvial Constituent Loads: An Empirical Study Involving Nutrient Loads Entering Chesapeake Bay, " *Wat. Resour. Res.,* 28(9), 2353-2364.

Cohn, T., Gilroy, E. J. and . Baier, W. G.1992b. Estimating Fluvial Transport of Trace Constituents Using a Regression Model with Data Subject to Censoring. pp142-151, *Proceedings of the Joint Statistical Meeting*, Boston, August 9-13,

Donigian, A.S., Bicknell, B.R., and Imhoff, J.C. 1995. Hydrological simulation program—Fortran (HSPF). In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. WRP, Highlands Ranch, Colorado, USA, pp. 395-442.

Gilroy, E. J., Hirsch, R. M., and Cohn, T. 1990. Mean Square Error of Regression-Based Constituent Transport Estimates. *Wat. Resour. Res.,* 26(9), 2069-2077.

Japan Environmental Agency.1999. Report on Water Quality Standard-Living Environment. Japan Environmental Agency, Japan. (In Japanese)

Johnes, P.J. 1990. An investigation of the effects of landuse upon water quality in Windrush catchment. D.Phil. Thesis, University of Oxford, Oxford.

Johnes, P.J. 1996.Evaluation and management of the impact of landuse change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. *J. Hydrol*. 183(3-4), 323-349.

Knisel, W.G. 1980. CREAMS, A field scale model for chemical, runoff and erosion from agricultural management systems, Conservation Report Number 26, US Department of Agriculture, 442, East Seventh Street, Tucson, Arizona.

Leonard, R.A., Knisel, W.G. and Still, D.A. 1987. “GLEAMS: Groundwater loading effects of agricultural management systems.” *Transactions of ASAE* 30 (5): 1403-1418.

McMahon, G., Alexander, R.B. and Qian, S. 2003. Support of TMDL programs using spatially referenced models. *ASCE J. Wat. Resour. Planning and Management*, 129, 315-329.

Nearing, M.A., Foster, G.R., Lane, L.J., and Finker, S.C. 1989. A process-based soil erosion model for USDA-water erosion soil prediction project technology. *Trans. ASAE* 32:1587-1593.

Sugawara, M. 1974. Tank Model with Snow Component. National Research Center for Disaster Prevention, Japan.

Williams, J.R., Nicks, A.D. and Arnold, J.G. 1985. SWRRB, A simulator for water resources in rural basins. *ASCE Hydraulics J.* 111(6):970-986.

Williams, J.R., Dyke, P.T. and Jones, C.A. 1982. EPIC- A model for assessing the effects of erosion and soil productivity. In *Proc. Third Int. Conf. On State-of-the Art in Ecological Modeling*, Int. Soc. for Ecological Modeling.

Yamada, K., Nishimoto, Y., Ichiki, A., Yoshitomi, M., Nishioka, H. 1991. Pollutant Runoff and Environmental Management in Urban Areas, *Proc. Of 3rd IAWPRC Conference Asian Waterqual ,'91, Shanghai,* 2 pp.IV-23-IV-28.

Yamada, K., Umehara, T., Ichiki, A. 1993. Study on Statistical Characteristics of Nonpoint Pollutants Deposited in an Urban Area, *Wat. Sci. & Tech*., 28(3-5),283-290.

Young, R.A., Onstad, C.A, Bosch, D.D. and Anderson, W.P. 1989. Agricultural non-point source pollution model for evaluating agricultural watersheds. *Journal of soil and water conservation* 44 (2): 168-173.

Young, R.A., Onstad, C.A., Bosch, D.D. and Anderson, W.P. 1994. Agricultural non-point source pollution model. AGNPS User's Guide, Version 4.03. USDA-ARS.

Appendix 1. Model Parameter Estimates Based on the Complete Data Sets

Biological Oxygen Demand (BOD)												
Station	Kikkobashi				Hikawabashi				Omogawabashi			
Model	Concentration		Load		Concentration		Load		Concentration		Load	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	0.206*	0.052	6.569*	0.052	-0.041*	0.075	4.907*	0.075	1.040*	0.051	5.943*	0.051
ln[Q/Qo]	-0.120*	0.069	0.880*	0.069	-0.244*	0.091	0.756*	0.091	-0.216*	0.060	0.784*	0.060
ln[Q/Qo]^2	-0.052*	0.055	-0.052*	0.055	-0.056*	0.082	-0.056*	0.082	-0.078*	0.052	-0.078*	0.052
T-To	-0.082*	0.021	-0.083*	0.021	0.048*	0.026	0.048*	0.026	0.051*	0.017	0.051*	0.017
[T-To]^2	-0.089*	0.015	-0.089*	0.015	-0.016	0.019	-0.016	0.019	-0.042*	0.013	-0.042*	0.013
Statistics												
s	0.38085		0.3809		0.51073		0.51073		0.35297		0.35297	
N	144		144		144		144		144		144	
R^2	58.9		65.6		36.9		40.6		57.8		58.7	
Chemical Oxygen Demand (COD)												
Station	Kikkobashi				Hikawabashi				Omogawabashi			
Model	Concentration		Load		Concentration		Load		Concentration		Load	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	0.755*	0.055	7.118*	0.055	0.571*	0.061	5.519*	0.061	1.428*	0.048	6.332*	0.048
ln[Q/Qo]	0.013*	0.067	1.013*	0.067	-0.012	0.072	0.988*	0.072	-0.051*	0.057	0.949*	0.057
ln[Q/Qo]^2	0.036*	0.053	0.036*	0.053	0.176*	0.062	0.176*	0.062	-0.004	0.049	-0.004	0.049
T-To	0.078*	0.021	0.078*	0.021	0.157*	0.020	0.157*	0.020	0.129*	0.016	0.129*	0.016
[T-To]^2	-0.055*	0.015	-0.055*	0.015	-0.004	0.015	-0.004	0.015	-0.023*	0.012	-0.023*	0.012
Statistics												
s	0.38085		0.3809		0.41402		0.41402		0.33726		0.33726	
N	144		144		144		144		144		144	
R^2	58.9		65.6		42		73.4		46.5		75.1	

Continued …Appendix 1

Suspended Solids(SS)												
Station	Kikkobashi				Hikawabashi				Omogawabashi			
Model	Concentration		Load		Concentration		Load		Concentration		Load	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	1.407*	0.089	7.770*	0.089	1.151*	0.090	6.098*	0.090	2.643*	0.103	7.546*	0.103
ln[Q/Qo]	0.429*	0.110	1.429*	0.110	0.308*	0.107	1.308*	0.107	0.168*	0.122	1.168*	0.122
ln[Q/Qo]^2	0.217*	0.086	0.217*	0.086	0.415*	0.093	0.415*	0.093	0.074*	0.106	0.074*	0.106
T-To	0.006	0.034	0.006	0.034	0.032*	0.030	0.032*	0.030	0.095*	0.035	0.095*	0.035
[T-To]^2	-0.034*	0.024	-0.034*	0.024	0.020*	0.023	0.020*	0.023	-0.024*	0.026	-0.024*	0.026
Statistics												
s	0.65727		0.6573		0.61945		0.61945		0.72179		0.72179	
N	144		144		144		144		144		144	
R^2	26.3		67.1		41.6		69.8		18.6		47.5	
Phosphate Phosphorus (PO4-)												
Station	Kikkobashi				Hikawabashi				Omogawabashi			
Model	Concentration		Load		Concentration		Load		Concentration		Load	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-4.255*	0.218	1.940*	0.218	-3.887*	0.146	1.398*	0.146	-3.051*	0.082	2.032*	0.082
ln[Q/Qo]	-0.581*	0.281	0.419*	0.281	-0.134*	0.154	0.866*	0.154	-0.374*	0.086	0.626*	0.086
ln[Q/Qo]^2	-0.219*	0.456	-0.219*	0.456	0.167*	0.126	0.167*	0.126	0.018*	0.067	0.018	0.067
T-To	-0.240*	0.130	-0.240*	0.130	-0.140*	0.065	-0.140*	0.065	0.030*	0.018	0.030*	0.018
[T-To]^2	-0.068*	0.138	-0.068*	0.138	0.086*	0.055	0.086*	0.055	0.020*	0.008	0.020*	0.008
Statistics												
s	0.38987		0.3899		0.65002		0.65002		0.43846		0.43846	
N	24		24		57		57		90		90	
R^2	26.8		60.4		21		53.8		27.1		62.3	

Here , s denotes the standard deviation of residuals from ordinary least square fit; N, the number of observation used to fit the model; and R^2 for concentration and load, the “variability explained” by the models for logarithm of concentration and load respectively.

* Statistically different from zero at 5% level.