Field Survey and Alternative Estimation on Runoff Load from Urban Areas

Etude de terrain et estimation alternative de la charge de pollution due au ruissellement pluvial sur les zones urbaines

Norihide Tamoto, Toshiaki Yoshida and Kazuya Fujiu

Wastewater System Division, Water Quality Control Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport, Government of Japan

Asahi 1 Tsukuba City Ibaraki 305-0804, Japan (tamoto-n92ta@nilim.go.jp)

RESUME

L'article présente une étude de terrain de la charge de pollution due au ruissellement urbain ainsi que la méthode d'évaluation de la charge utilisée. L'accent mis sur le contrôle des sources ponctuelles de pollution a eu pour effet d'augmenter l'importance relative du contrôle des sources de pollution diffuses. Toutefois, la charge de pollution urbaine diffuse due aux réseaux sanitaires séparatifs n'est pas encore totalement maîtrisée même si le Japon à adopter des mesures drastiques pour diminuer les déversements de réseaux unitaires. Dans cette étude, on présente une analyse de terrain qui s'est concentrée sur la surveillance des paramètres standards de la qualité de l'eau, sur les métaux lourds, les produits perturbateurs de fonction endocrine, etc. Ensuite, une méthode d'estimation simplifiée de la charge de polluants urbains diffus a été mise en oeuvre pour vérifier la possibilité d'utiliser ce paramètre comme variable indépendante pendant la période précédant le temps sec.

ABSTRACT

This paper presents a field survey of urban pollution load and the related load estimation method. The promotion of point source control has increased the relative importance of nonpoint source control, however urban nonpoint pollutant load through separate sanitary sewers is not yet fully addressed, while drastic measures on combined sewer overflows alleviation were initiated in Japan. In this study, a field survey was conducted targeting on conventional water qualities, heavy metals, endocrine disrupting chemicals, and so forth. Then, simplified estimation method of urban nonpoint pollution load was also investigated as a use of prior dry weather days as an independent variable.

KEYWORDS

Estimation method, field survey, nonpoint source, pollution load.

1 INTRODUCTION

As sewerage works progress, the impact of urban nonpoint pollution load on water bodies has gradually increased especially in the basins of closed water bodies. Sewage systems play an important role in reducing the pollution load from urban areas. Nevertheless, pollution loads from separate storm sewer have not been vigorously controlled in Japan while Comprehensive Basin-wide Planning of Sewerage Works (CBPSW), which is implemented to meet ambient water quality standards, considers urban nonpoint sources and combined sewer overflows (CSOs) have become a target of controls. Additionaly, in the United States, most stormwater discharges are considered point sources and require coverage by National Pollutant Discharge Elimination System (NPDES) permit **(USEPA, 2005)**. Under the NPDES storm water program, operators of large, medium and regulated small municipal separate storm sewer systems (MS4s) require authorization to discharge pollutants under an NPDES permit. Overall, it is possible to say that urban nonpoint pollution loads through separate sewer are not yet fully addressed in Japan.

Sewage works are carried out in accordance with CBPSW in Japan **(JSWA, 2000)**. In formulation of CBPSW, at first, generating loads including nonpoint source on a watershed are estimated using unit pollution load data, and runoff loads are calculated through pollution analysis. Secondly, the allowable load is calculated based on the water quality standard at a target point in the concerned water body, and the pollution load that should be reduced, referred to as the reduction load, is determined as the difference between the total generating load and the allowable load. Lastly, the reduction load is distributed to each pollution source category such as public sewerage, industrial, livestock, and nonpoint source (e.g. urban, farm). As the process of estimating generating loads of nonpoint source, existing data in other watersheds are frequently applied instead of collecting data for a target watershed for the reasons of costs and the difficulty of performing investigations. However, on calculation process of generating pollution load, it is frequently applied by preparing other basin data without collecting data for the target basin for reasons of costs and the difficulty of performing investigations.

Therefore, it is necessary to establish alternative and simplified methods of estimating nonpoint source pollution. This research, based on a field survey of nonpoint source pollution, aims at the development of alternative methods of predicting nonpoint pollution loads.

2 FIELD SURVEY

2.1 Study Site

Field surveys began in fiscal 2004 and were conducted at three study sites; Drainage areas A, B and C. Their profiles are shown in **Table 1 and 2**. Each drainage area is located in an urban area served by a separate sewer system in the same prefecture. The impervious area ratio and land use of each drainage area were estimated by calculating detailed digital information issued by the Geographical Survey Institute, Ministry of Land, Infrastructure and Transport (investigated in 2000).

	Area (ha)	Impervious area ratio	Land use	Arterial roads
Drainage area A	95	69%	High/medium-rise residential and Commercial	Included
Drainage area B	18	67%	Residential	Included
Drainage area C	67	61%	Residential	Not included

Table 1 Profile of Study Sites

	Mountains	Farm	Vacant land	Low-rise residential area	High- and midium-rise residential area	Commercial	Road	Park	Public use
Drainage area A	0%	0%	2%	16%	18%	13%	22%	7%	21%
Drainage area B	0%	8%	12%	32%	3%	19%	15%	6%	4%
Drainage area C	5%	5%	10%	54%	0%	1%	21%	3%	0%

Table 2 Land Use of Study Sites

2.2 Target Rainfall and Sampling

The surveys were carried out at the storm sewer outlets of three drainage areas simultaneously during the same rainfall, concerning four rainfall events as of the end of the fiscal 2005. Characteristics of observed rainfalls and runoff coeficients are shown in **Table 3**. To clarify the runoff characteristics and to calculate the pollution loads, the rainfall close to the sampling point and the flow rate at the sampling point were also measured.

	Drainage area A				Drainage area B				Drainage area C			
	NDD (d)	Total (mm)	Max (mm/hr)	Runoff cofficient	NDD (d)	Total (mm)	Max (mm/hr)	Runoff cofficient	NDD (d)	Total (mm)	Max (mm/hr)	Runoff cofficient
Rainfall 1	7	14.5	2.5	0.27	7	15	3.5	0.06	7	14.5	3	0.05
Rainfall 2	10	6	2.5	0.48	10	9.5	2.5	0.27	10	8	2.5	0.14
Rainfall 3	63	37.5	11	0.85	63	42.5	10.5	0.04	63	43.5	9.5	0.07
Rainfall 4	3	16.5	6	0.47	-	-	-	-	12	15.5	5.5	0.08

Note ; NDD: Number of prior dry weather days (d), Total: Total precipitation (mm), Max: Maximum precipitation intensity (mm/hr), "-" means field survey was not conducted.

Table 3 Characteristics of Observed Rainfalls

The samples were obtained by manually taking 14 to 20 bottles from each investigation point. The water quality constituents that were analyzed were SS, VSS, BOD, COD_{Mn}, TN, and TP, but some surveys also analyzed the samples for their content of heavy metals (copper, zinc, lead, cadmium) plus Benzo [a] pyrene (B(a)P) and Bisphenol A (BPA).

2.3 Results

Figure 1 and 2 present, as typical cases, the change over time of constituent concentration, precipitation and flow rate in rainfall 3. Concentration varies by order of magnitude, corresponding to the rainfall runoff flow. First flushes are observed with their variation of degree among constituents and drainage areas.

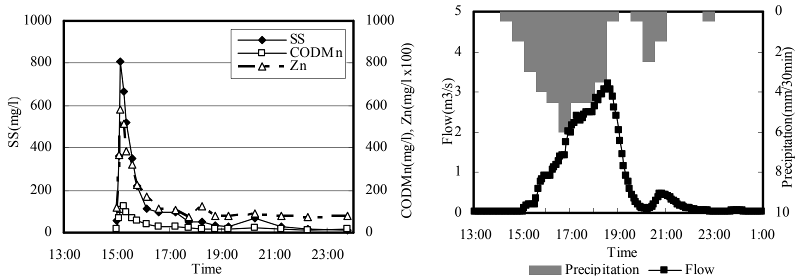

Figure 1 Runoff concentration and flow rate of Rainfall 3 from Drainage area A

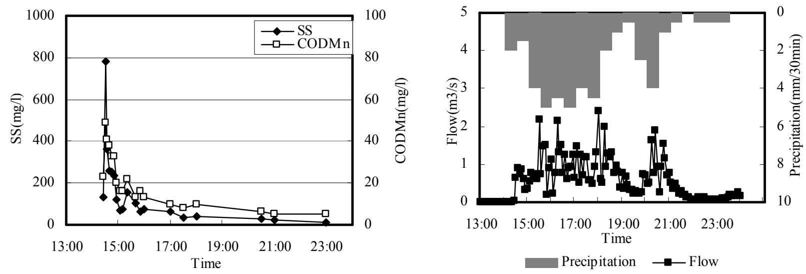

Figure 2 Runoff concentration and flow rate of Rainfall 3 from Drainage area C

In order to characterise concentrations of rainfall runoff, which can vary widely during a storm event, Event Mean Concentrations (EMCs) were calculated as shown in **Table 4**. Event Mean Concentration (EMC) is defined as following equation **(Huber, 1993)**.

$$EMC = \frac{\int C(t)Q(t)dt}{\int Q(t)dt} \qquad \text{Eq. 1}$$

(where, *C(t)*: constituent concentration at time *t*; *Q(t)*: stormwater discharge at time *t*)

Comparison with Environmental Quality Standards (EQSs) **(Environmental Agency, 1971)** or Predicted No Effect Concentrations (PNECs) **(Ministry of Environment, 2003)** shows that EMCs of almost all constituents exceed EQSs or PNECs, and they could have not an ignorable effect on receiving waters. Especially, EMC of zinc, recently incorporated into EQSs in Japan, is larger than the standard almost by order of ten **(Figure 3)**. Moreover, EMC of BPA is much lower than PNEC while EMC of B(a)P exceeds PNEC **(Figure 4)**. As a result, though not so heavily polluted, rainfall runoff through storm sewers could be a source of ambient water quality degradation.

Specific loads per rainfall event are shown in **Table 5**. The variation of specific loads was also observed among different rainfalls similarly to EMCs. According to Table 3 and 5, it is implied that specific loads tend to be in proportion to total precipitation.

		SS (mg/L)	BOD (mg/L)	COD_{Mn} (mg/L)	TN (mg/L)	TP (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	BPA (μ g/L)	B(a)P (μg/L)
Drainage area A	Rainfall 1	66	12.8	15.5	2.9	0.30	-	0.07	0.008	0.001	0.21	0.007
	Rainfall 2	86	19.8	29.3	4.0	0.51	0.06	0.35	N.D.	N.D.	0.23	0.025
	Rainfall 3	72	11.2	23.5	2.4	0.27	0.27	1.10	0.006	N.D.	0.08	0.011
	Rainfall 4	62	5.4	12.0	2.0	0.22	0.03	0.25	0.021	0.004	-	-
	Mean	71	12.3	20.1	2.8	0.32	0.12	0.44	0.009	0.001	0.17	0.015
Drainage area B	Rainfall 1	27	4.0	5.7	2.1	0.12	0.00	0.04	2.300	3.354	0.11	0.018
	Rainfall 2	83	21.3	28.9	3.3	0.25	0.04	0.38	0.015	N.D.	0.67	0.041
	Rainfall 3	84	6.5	11.0	2.1	0.24	0.20	0.38	0.000	N.D.	-	-
	Mean	65	10.6	15.2	2.5	0.20	0.08	0.26	0.772	1.118	0.39	0.030
Drainage area C	Rainfall 1	31	4.6	9.0	2.1	0.12	0.03	0.09	N.D.	N.D.	0.08	0.014
	Rainfall 2	54	12.4	20.2	2.4	0.16	0.05	0.14	0.001	N.D.	0.16	0.033
	Rainfall 3	68	7.0	11.4	1.6	0.19	-	-	-	-	-	-
	Rainfall 4	29	3.2	6.5	1.7	0.07	0.12	0.07	0.014	0.003	-	-
	Mean	46	6.8	11.8	1.9	0.14	0.07	0.10	0.005	0.001	0.12	0.023
EQS		25	(2, 3)	(3, 5)	(0.4, -)	(0.03, 0.05)	-	0.03	0.01	0.01	-	-
PNEC		-	-	-	-	-	-	-	-	-	11	0.005

Note : "N.D." means not detected. "-" means deficiency, not measured, or not applicable. In EQS of BOD, CODMn, TN, and TP, (,) means (EQS of receiving water of Drainage areas A and B, EQS of receiving water of Drainage area C).

Table 4 Event Mean Concentrations of Urban Runoff

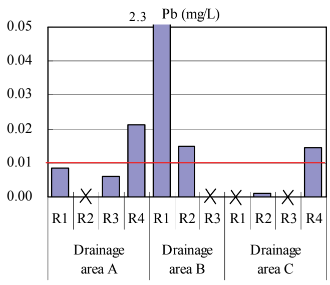

Figure 3 Comparison of EMC (Pb)

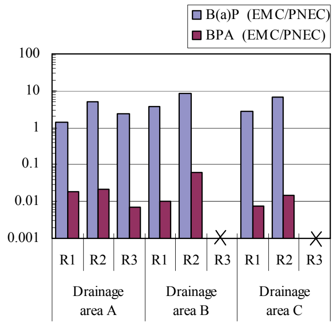

Figure 4 Ratio of EMC and PNEC (B(a)P and BPA)

		SS (kg/ha)	BOD (kg/ha)	COD_{Mn} (kg/ha)	TN (kg/ha)	TP (kg/ha)	Cu (g/ha)	Zn (g/ha)	Pb (g/ha)	Cd (g/ha)	BPA (mg/ha)	B(a)P (mg/ha)
Drainage area A	Rainfall 1	3.83	0.751	0.908	0.172	0.0174	-	4.4	0.49	0.035	12.04	0.42
	Rainfall 2	2.25	0.519	0.767	0.104	0.0135	1.6	9.1	N.D.	N.D.	6.05	0.65
	Rainfall 3	22.95	3.566	7.478	0.763	0.0845	84.6	349.2	1.87	N.D.	24.79	3.65
	Rainfall 4	4.44	0.382	0.852	0.145	0.0156	1.8	17.8	1.53	0.250	-	-
	Mean	8.37	1.304	2.501	0.296	0.0327	29.3	95.1	0.97	0.071	14.29	1.58
Drainage area B	Rainfall 1	0.17	0.026	0.037	0.013	0.0008	0.0	0.2	0.02	0.022	0.73	0.12
	Rainfall 2	0.47	0.122	0.165	0.019	0.0014	0.2	2.2	0.09	N.D.	3.84	0.23
	Rainfall 3	1.34	0.103	0.175	0.033	0.0039	3.2	6.0	0.00	N.D.	-	-
	Mean	0.66	0.083	0.126	0.022	0.0020	1.1	2.8	0.03	0.007	2.28	0.18
Drainage area C	Rainfall 1	0.14	0.020	0.040	0.009	0.0005	0.1	0.4	N.D.	N.D.	0.35	0.06
	Rainfall 2	0.27	0.063	0.103	0.012	0.0008	0.3	0.7	6.18	N.D.	0.84	0.17
	Rainfall 3	2.21	0.226	0.372	0.051	0.0061	-	-	-	-	-	-
	Rainfall 4	0.32	0.035	0.071	0.019	0.0008	1.3	0.7	0.16	0.029	-	-
	Mean	0.73	0.086	0.146	0.023	0.0021	0.6	0.6	2.11	0.010	0.59	0.11

Note : "N.D." means not detected. "-" means deficiency, or not measured.

Table 5 Specific Loads of Urban Runoff

3 ALTERNATIVE ESTIMATION

3.1 Estimation methods for pollution loads

In the future, it will be necessary to undertake wide area nonpoint load measures. **Table 6** shows principal methods of estimating pollutant loads. In general, surveys are carried out in regions where measures are taken in order to calculate the pollutant load as an annual average value. However, surveying each site where measures are taken in this way cannot be said to be necessarily efficient from temporal and economic perspectives. In order to address this problem, we would like to discuss an alternative method of estimating runoff load by using a regression equation based on accumulating nonpoint runoff load data set. For example of such method, **Tasker and Driver (1988)** prepared a regression models to estimate the annual average load using the NURP Database that was constructed by USEPA. Moreover, **Nakamura (1993)** performed multiple regression analyses with the rainfall and the initial accumulated load for each event as the explanatory variables in order to predict the runoff load. In addition, **Fukushima et al. (2004)** reported that it could be possible to predict concentration of nutrients and metals by considering relationships between turbidity and particle substances and those between EC (Electric Conductivity) and dissolved substances.

No.	Method	Typical Equation	Notation
(1)	Product of annual average concentration, annual precipitation, and runoff percentage	$\sum L = k \cdot C \cdot \sum R$	$\sum L$: Unit load (kg/ha/year) k: Runoff percentage C: Annual average concentration (kg/ha/mm) $\sum R$: Annual precipitation (mm/year) A: Catchment area (ha) D_i: Runoff coefficient for land use "i" for pollution at the concerning point L_i: Pollution load from land use "i" A_i: Area of land use "i" in catchment area (ha) L: Pollution load per a rainfall event (kg/ha) $\sum r$: Event precipitation (mm) *a, b*: Coefficients in multiple regression equation *NDD*: Number of prior dry weather days (day)
(2)	Summation of pollution loads from each land use area	$\sum L = (1/A) \cdot \sum (D_i \cdot L_i \cdot A_i)$	
(3)	Summation of pollution loads per rainfall event, which are calculated with correlation equation between event precipitation and runoff load	---	
(4)	Summation of pollution loads per rainfall event, which are calculated with multiple regression equation	$L = a \cdot \sum r + b \cdot NDD$	

Table 6 Principal Estimation Methods for Pollution Loads

3.2 Multiple regression analysis

Pollutants which accumulated on ground surface consist of atmospheric depositions, tire scraps, fallen leaves, and other waste materials, and the friction velocity when they are transported varies according to rainfall and rainfall intensity. Thus, the runoff load per event could depend on meteorological and precipitation conditions that are assumed to be the major factors that determine the runoff load in each drainage area.

Accordingly, we selected total precipitation and number of prior dry weather day as the explanatory variables, and performed regression analysis. The data of the said field survey was used for the analysis. In this study, we used the following equation as similar form of **Nakamura (1993)**.

$$L = a \cdot \sum r + b \cdot NDD \qquad \text{Eq. 2}$$

(where, *L*: Specific load per rainfall event (kg/ha); *Σr*: total precipitation per event (mm); *NDD*: Number of prior dry weather day (day); *a*, *b*: constants)

Figure 5 and 6 present comparisons of measured and estimated values in drainage areas A and C. The comparison of the runoff pollution loads of SS, COD_{Mn}, TN, TP, and zinc predicted by equation 2 with measured values has revealed that the predicted values closely conformed with the measured values among two drainage areas. **Table 7** shows the result of regression. In both drainage areas A and C, the most coefficients of determination of the regression equation were 0.9 or higher and the runoff load could almost be explained by the total rainfall and the number of prior dry weather days.

However, it will be necessary to deepen our inquiries into the following two points. The first point is that there are few data and no certainty about the question of whether or nor this trend has universality. The second point is that the coefficients *a* and *b* have their own physical meanings and represent the characteristics of drainage areas, so it is necessary to consider then along with the state of land use etc.

		SS	BOD	COD_{Mn}	TN	TP	Zn
Drainagre area A	*a* (kg/ha/mm)	0.211	0.021	0.025	0.0077	0.0174	-0.0010
	b (kg/ha/day)	0.243	0.046	0.106	0.0077	-0.0050	0.0062
Drainage areaC	*a* (kg/ha/mm)	-0.0120	-0.0003	0.0005	0.00065	-0.00003	-
	b (kg/ha/day)	0.0414	0.0038	0.0057	0.00048	0.00011	-

Table 7 Result of Regression

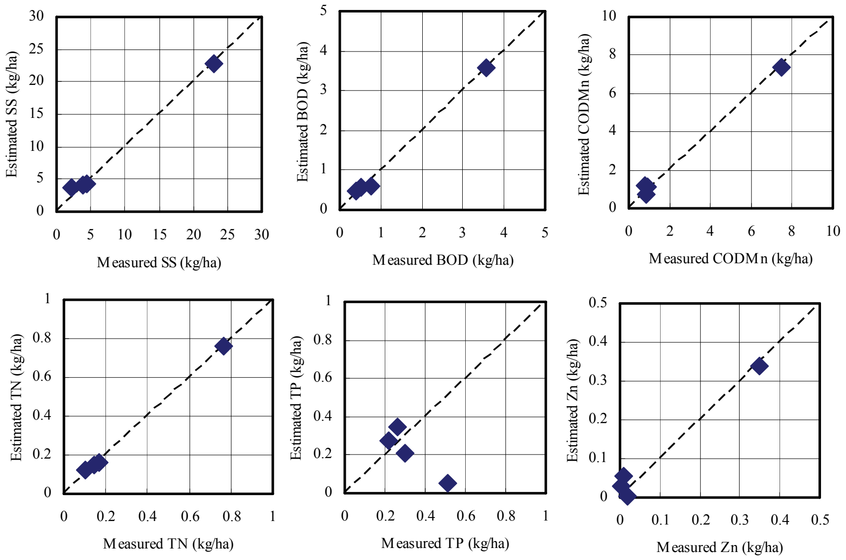

Figure 5 Comparison of Measured and Estimated Values (Drainage area A)

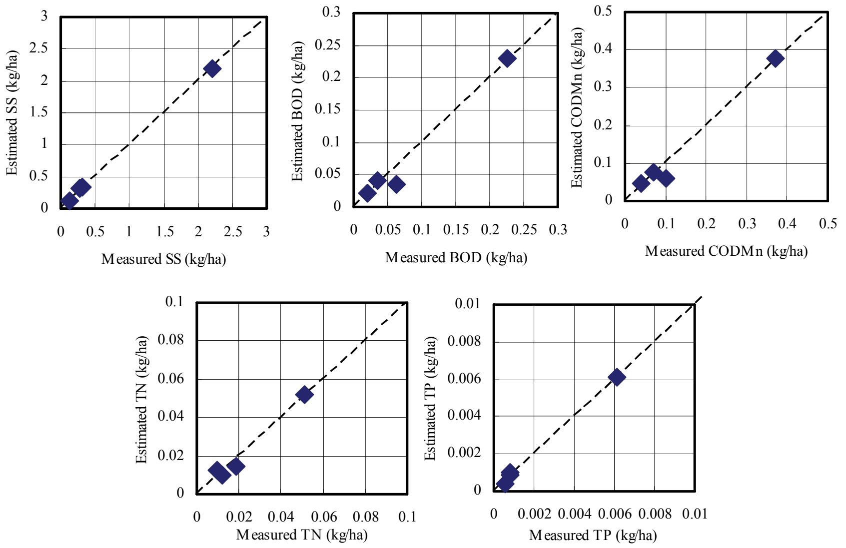

Figure 6 Comparison of Measured and Estimated Values (Drainage area C)

4 CONCLUSION

The difficulty of estimating runoff loads is one cause of the difficulty of planning and implementing nonpoint load measures. Carrying out field survey which is focusing on the clarification of the state of runoff of conventional constituents, heavy metals and endocrine disrupting chemicals, we studied a simplified method of estimating runoff loads which are necessary at the stage when a plan is prepared for nonpoint countermeasures. The following are the conclusions that we reached.

(1) The observed EMCs and pollutant loads vary greatly according to the drainage area and the amount of rainfall.

(2) EMCs of almost all constituents including heavy metals and chemical substances exceeded EQSs or PNECs and were not at an ignorable level for protecting the environment of receiving waters.

(3) According to the field survey data, it was suggested that the multiple regression equation, which is incorporates meteorological and hydrological information in each rainfall event, can adequately estimate runoff pollutant loads.

This survey, aims at collecting basic data of urban runoff loads, is now ongoing. We wish to construct a rainfall information database in Japan by accumulating nonpoint load data obtained by this survey and by collecting data from surveys carried out by other organizations.

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LIST OF REFERENCES

Environmental Agency (1971). Notification of Environmental Quality Standards on Water Pollution. (amended in 1974, 1975, 1982, 1985, 1986, 1991, 1993, 1995, 1998, 1999, 2000, and 2003) (in Japanese)

Environmental Risk Assessment Office, Ministry of the Environment (2003). Environmental Risk Assessment on Chemical Substances. March 2003 (in Japanese)

Fukushima T., Shirasuna H., Matshushige K., Imai A. and Ozaki N. (2004). Runoff and Loads of Nutrients and Heavy Metals from Urbanized Area. Proc. 8th International Conference on Diffuse/Nonpoint Pollution, Kyoto, 365-372

Huber, W. C. (1993). Contaminant Transport in Surface Water. In *Handbook of Hydrology*. D. R. Maidment (Ed.), McGraw-Hill, Inc., New York, N.Y.

Japan Sewage Works Association (JSWA) (2002). Sewage Works in Japan, JSWA, Tokyo

Nakamura, E. (1993). Loadings Characteristics of Stormwater Runoff. Journal of Japan Sewerage Works Association, Vol.30, No.364, 1-13, (in Japanese)

Tasker, G. and Driver, N. (1988). Nationwide Regression Models for Predicting Urban Runoff Water Quality at Unmonitored Sites. Water Resources Bulletin, Vol. 24, No. 5, 1091-1101

USEPA (2005). National Management Measures to Control Nonpoint Source Pollution from Urban Areas

Water Quality Management Division, Water Quality Conservation Bureau, Environmental Agency (1990). Manual for Research of Nonpoint Pollution Load. March, 1990 (in Japanese)