"Upgrading the runoff quality simulation model ""PWRI Load Model"" -Development of the ""WSD Model"""

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Amélioration du modèle de simulation de la qualité des rejets ''PWRI Load Model '' - Développement de '' WSD Model ''-

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RESUME

Le modèle de charge PWRI, fréquemment utilisé au Japon pour la simulation des ruissellements urbains, a été mis à niveau au moyen de trois approches : (i) le développement en modèle distribué à partir du modèle type global, (ii) par inclusion des nutriments, et (iii) par le développement de son interface utilisateur. Des études sur site ont été effectuées pour recueillir des données destinées au développement et à la confirmation des caractéristiques de charge dans les ruissellements urbains. Ce travail a confirmé que le modèle pouvait expliquer le phénomène avec un niveau raisonnable de SS, DBO, DCOMn, T-N et T-P.

ABSTRACT

The PWRI Load Model, frequently used urban runoff load model in Japan, was upgraded by taking three approaches; (i) development into distributed model from lumped type model, (ii) incorporating nutrients, and (iii) development of its user interface. Field surveys were conducted to provide data for the development and confirm urban runoff load characteristics. It was confirmed that the Model could explain the phenomenon in a reasonable level in SS, BOD, CODMn, T-N, and T-P.

KEYWORDS

CSO ; pollution load ; PWRI Load Model ; simulation ; urban drainage ; WSD Model.

1 INTRODUCTION

To estimate runoff load from combined sewer systems, a variety of urban drainage simulation models are available. In Japan, the runoff quality simulation model "PWRI Load Model", developed by the then Public Works Research Institute (**Nakamura, 1980**), has frequently been used to design improved combined systems among sewerage managers along with a runoff quantity model such as the revised RRL method. The PWRI Load Model is a lumped type model and its main feature is an adoption of simple empirical models. On the other hand, simulation software packages such as InfoWorks CS, MOUSE, and XP-SWMM are popularly used these days and have different features. They are distributed models with physical submodules, and the equations used in these models tend to be overparametrised. Especially, it was shown that the default parameter values should be used with great care as big differences are observed between the modelling results generated by InfoWorks and MOUSE using their respective values, which implies that a huge effort in collecting data for the physically based model parameters is required (**Bouteligier, 2004**). Also, HydroWorks, MOUSE, and XP-SWMM have several problems in use in Japan such as the necessity to establish parameters suitable for the drainage basins in the country (**Shinoda et al., 1999**).

For the PWRI Load Model, three approaches can be taken to enhance the practice of estimating urban runoff loads. Firstly, the model can be upgraded from a lumped type to a distributed type. CSO controls have been taken over a catchment area rather than at the discharging point, which requires a distributed type model for appropriate load estimation. Secondly, more reliable model development in terms of nutrients is another task. The Model basically deals with three water quality constituents: suspended solids (SS), 5-day 20°C biochemical oxygen demand (BOD) and manganate chemical oxygen demand (COD_{Mn}). Though runoff characteristics of total nitrogen (T-N) and total phosphorus (T-P) and applicability in the Model were researched based on field surveys in one city (**Matsubara and Morita, 2002**), still confirmation in other cities is required for model reliability. Lastly, a user interface has yet to be developed as application of the model is left entirely to the users.

This paper describes the upgrade of the PWRI Model by taking the said approaches. Field surveys were conducted to provide data for the Model upgrade and also to confirm urban runoff load characteristics. The model upgrade was accompanied with comparison of estimated and observed values.

2 POLLUTION LOAD DISCHARGE CHARACTERISTICS

2.1 Field survey

To collect data for model development, field surveys of combined wastewater runoff were conducted in three cities in Japan. Profile of the study sites are shown in **Table 1**. In City A, a 168ha urbanised area with combined sewerage was selected, and its discharging point (Sta. A-1) and a point with 30ha drainage area (Sta. A-2) in the area were set to monitoring stations. Likewise, Cities B and C have two monitoring stations respectively. The study sites in Cities A and B are highly urbanised areas while the study site in City C has 20% of mountains, forests or wastelands (**Table 2**).

Observations were conducted four times in City A and twice in Cities B and C in wet weather. Also, dry weather surveys were conducted. The interval of the sampling was one or two hours in dry weather. In wet weather, the first stage of rainfall was observed in five minutes, and then the interval of the investigation time was extended with the changes in the runoff quantity. Water quality constituents were BOD, COD_{Mn}, SS, T-N and T-P. Rainfall and flow in sewer were also measure. The profile of wet weather observations is shown in **Table 3**.

CIty	Monitoring Station	Drainage area (ha)	Population (capita)*	Sewer		
				Shape	Diameter (mm)	Gradient (%)
A	A-1	168	18,000	Rectangular	H:2500 x W:2500	0.38
	A-2	30	5,900	Circle	1350	0.51
B	B-1	454	52,000	Rectangular	H:3500 x W:4900	0.32
	B-2	109	16,000	Rectangular	H:1950 x W:2400	0.20
C	C-1	321	33,000	Circle	2000	0.20
	C-2	33	3,500	Circle	1350	1.00

Note: *) Nighttime population

Table 1 Profile of study sites

City	Monitoring Station	Land use					
		Residential	Commercial	Road	Park/Grassland	Mountain/Forest/Wasteland	Other public uses
A	A-1	41%	11%	16%	13%	0%	13%
	A-2	48%	12%	22%	2%	0%	15%
B	B-1	62%	11%	13%	2%	1%	8%
	B-2	70%	8%	11%	1%	2%	7%
C	C-1	48%	5%	19%	3%	19%	2%
	C-2	47%	2%	24%	4%	20%	1%

Table 2 Land use of study sites

Rainfall	Monitoring Site	Date	Preceding dry weather days	Total rainfall (mm)	Max. 5 min. rainfall (mm/5min)
RA1	A-1, A-2	4-5 Mar., 2000	7 (160hr)	9.1	0.5
RA2	A-1, A-2	16-17 Mar., 2000	4 (92hr)	18.0	0.5
RA3	A-1, A-2	23-24 Mar., 2000	4 (97hr)	17.9	1.3
RA4	A-1, A-2	20-22 Oct., 2000	4 (100hr)	46.4	1.8
RB1	B-1, B-2	13-14 Dec., 2001	7 (169hr)	6.0	0.5
RB2	B-1, B-2	17-18 May, 2002	6 (152hr)	28.0	1.5
RC1	C-1, C-2	31 May, 2003	4 (98hr)	76.0	3.5
RC2	C-1, C-2	20-21 Sep., 2003	23 (557hr)	87.0	1.5

Table 3 Profile of wet weather survey

2.2 Results and considerations

As examples of field survey results, **Figure 1** shows the runoff situation of water qualities in dry and wet weather. In dry weather slight rises in concentration were observed once in the morning while in wet weather high concentrations were observed in the first stage of the rainfalls and then fell below those in dry weather. This tendency was confirmed in other observations.

Figure 2 shows relationships between flow and loading rate as a typical case. Plotting of these data in time series draws a clockwise loop on full-logarithmic paper, representing first flush in the flow rising stage and later sedimentation in sewers. According to **Figure 2**, it was suggested that loading rates of BOD, COD_{Mn}, T-N and T-P tend to be in proportion to flow rate, whereas loading rate of SS tend to be in proportion to the square of flow rate. This result has been reported by **Nakamura (1980)** and **Matsubara and Morita (2002)**. However, results of T-N and T-P were checked just for two drainage areas in City A which is described in this paper. Other investigations of four drainage areas in Cities B and C was also organized and this tendency was confirmed.

In order to discuss runoff characteristics in combined sewers, another analysis was conducted based on pollutographs. Similar to water quality concentrations, pollution loading rates behave higher in the flow rising stage and later from certain point below from pollution loading rate during dry weather as in **Figure 3**. Two loads, L(+) and L(-), were defined to characterise runoff loads, that is L(+): a total pollution loading rate of the part where the wet weather load is greater than that of dry weather, and L(-): a total pollutant load discharge of the part where dry weather is greater than wet weather (**Figure 3**). L(+) is expected to come from sedimentation in sewers and runoff from ground surface such as streets while L(-) is equivalent to sedimentation in sewers in a low flow rate. When L(+)/L(-)=1, the runoff load in wet weather equals to sedimentation in sewers, which means a runoff load in wet weather is just from sewer sedimentations and little from ground surface runoff. The ratio L(+)/L(-) were calculated for each wet weather survey and summarised in **Figure 4**. Though variation among rainfalls as well as drainage areas are large, the tendency was observed that BOD < COD_{Mn} <SS and that the ratio for T-N and T-P were almost identical to that for BOD. This result, already reported by **Nakamura (1980)** and **Matsubara and Morita (2002)**, was confirmed through more field survey data in three cites. Consequently, it was assumed that T-N and T-P have the runoff characteristics similar to BOD and COD_{Mn}.

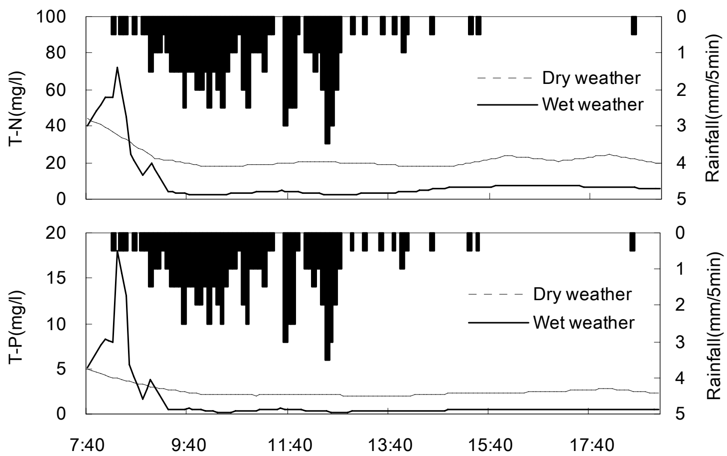

Figure 1 Water Quality in wet weather flow (St.C-2, Rainfall RC1)

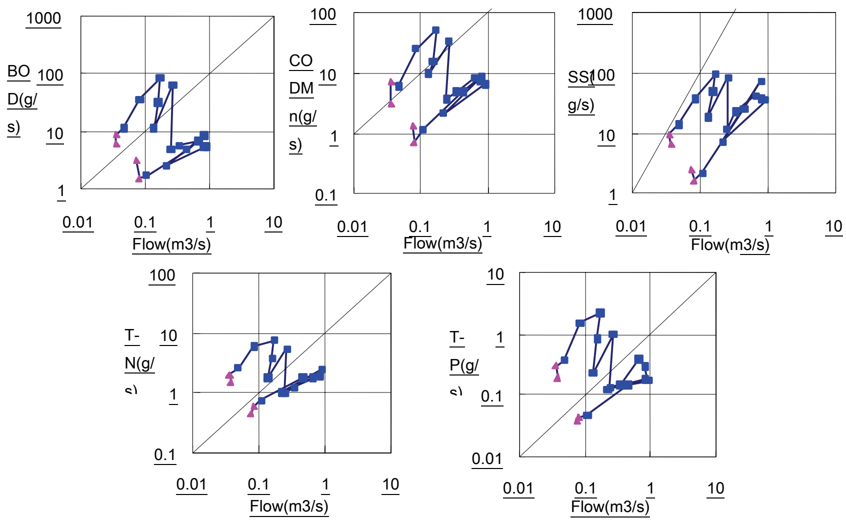

Figure 2 Relationship between pollution loading and flow rate (St.C-2, Rainfall RC1)

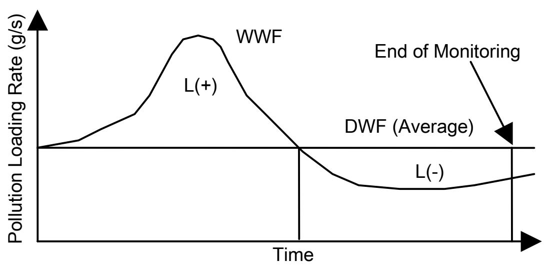

Figure 3 Definition of loads to characterise runoff loads

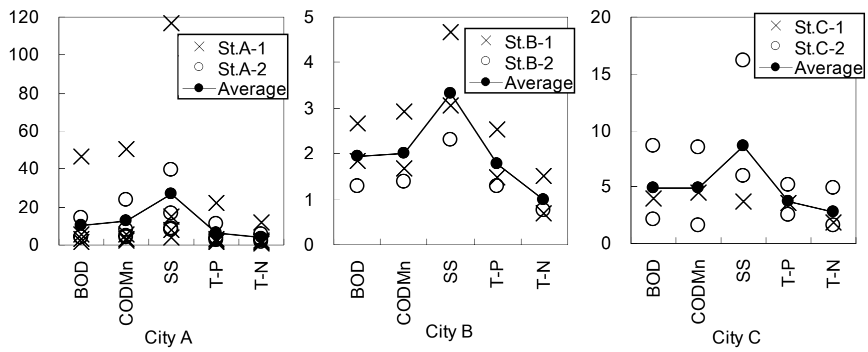

Figure 4 Analysis of runoff load in terms of L(+)/L(-)

3 DEVELOPMENT OF SIMULATION MODEL

3.1 Distributed model development

The distributed model was developed through a natural extension of the PWRI Load Model, a lumped type model. The developed model was named the WSD Model, which is an abbreviation of Wastewater load Simulation Distributed Model, as well as an abbreviation of Wastewater System Division Model, since the Division of the National Institute for Land and Infrastructure Management is its developer. A lumped model deals with a catchment uniformly, so a pollution abatement measure in a catchment is divided proportionally in the catchment and the discharging loads are calculated. A distributed model, on the other hand, divides the catchment into subcatchments and estimate the pollution loads separately, which enables a proper reflections of pollution generation or its change. In the WSD Model, a catchment is divided into subcatchments and a discharging load of the point concerned can reflect each of the contributing subcatchments.

The WSD model was composed of two submodels: catchment model and in-sewer model as in **Figure 5**. Catchment model consists of two submodels: surface model and sewer model. The surface model expresses wash-off loads from residuals on roofs or roads, as does the sewer model in sewers. The catchment model's equations were **Eqs. 1-4**, based on the PWRI Load Model. It was assumed that surface wash-off loads (L_S) contribute to sewer residual load (P_p). In the lumped Model, a discharging pollution load is a summation of L_S and P_p and both are dealt with separately, which causes inconsistency in the most upstream subcatchments in the distributed Model. The constants m and n in sewer model are characteristic of water quality constituents, and set to (m, n) = (1, 1) of SS and (m, n) = (2, 0) of BOD, COD_{Mn}, T-N and T-P from the empirical relationship between pollution loading and flow rates. The in-sewer model' equations are **Eqs. 5-6**, assuming a completely mixed system.

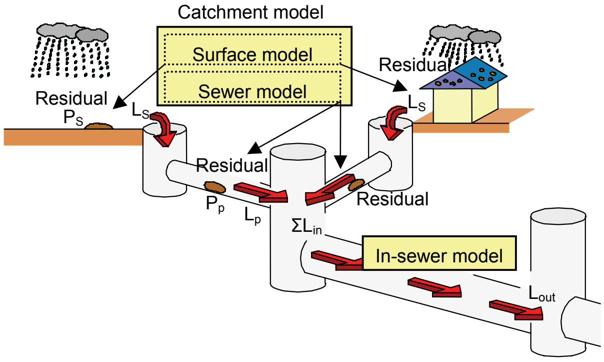

Figure 5 Schematic on WSD model

[Sewer model]

$L_p = C\ P_p^m\ Q^n\ (Q - Q_c)$ (1) $dP_p/dt = D + L_s - L_p$ (2)

[Surface model]

$L_s = K\ P_s\ (r_e - r_c)\ A\ Imp / 3.6$ (3) $dP_s/dt = a - K\ P_s\ (r_e - r_c) / 3.6$ (4)

[In-sewer model]

$L_{out} = C_c\ Q_{(B)}$ (5) $d(S\ C_c)/dt = \Sigma L_{in} + L_s - L_{out}$ (6)

(where L_s = surface wash-off load (g/s), K = surface wash-off load coefficient, r_e = effective rainfall intensity (mm/hr), r_c = critical rainfall intensity (mm/hr), A = cathcment area (ha), Imp = impervious area ratio, P_s = surface residual load (g), a = surface pollution build-up (g/s/ha), L_p = sewer wash-off load (g/s), C = sewer wash-off load coefficient, P_p = sewer residual load (g), Q = flow rate (m^3/s), Q_c = critical flow rate (m^3/s), m and n: constants, D = sewer pollution build-up (g/s), L_{out} = discharging load at the end of the sewer (g/s), C_c = water quality in the sewer (g/m^3), $Q_{(B)}$ = flow rate at the end of the sewer (m^3/s), S = wastewater volume in the sewer (m^3), ΣL_{in} = inflow load from the upper sewer(s) (g/s), t = time (s).)

The calculated values in the WSD model were compared with those in the PWRI model and with the measured values. The example of the comparison is shown in **Figure 6**. The WSD model prediction showed reasonable agreement overall though it still had inability in accurate peak estimation, as mentioned in **Matsubara and Morita (2002)**.

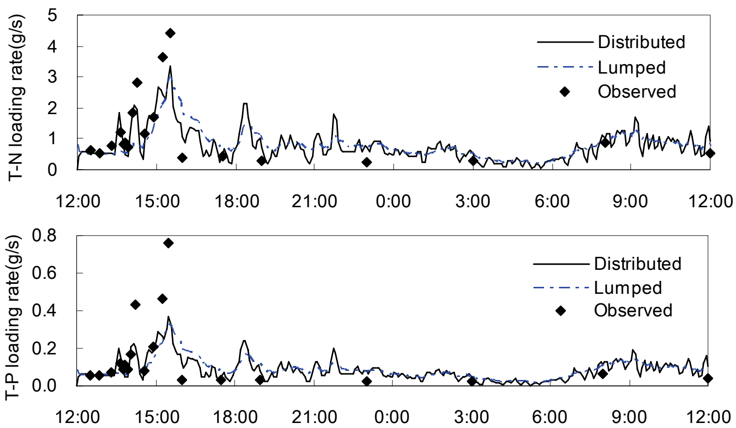

Figure 6 Comparison of the measured and estimated values (St.C-2, Rainfall RC2)

3.2 User interface development

To improve usability of the WSD Model and facilitate further model and interface development, the user interface was developed on Microsoft Windows. The base of the interface is FORTRAN programs and the required application is Microsoft Excel. After setting a new project name or selecting an existing project, analysis conditions, input data and model parameters are set and runoff quantity data are imported (the 1st step). Runoff quantity data, provided by any runoff quantity model, should be in CSV file format. In the second step, analysis is executed with parameter calibration, followed by result data and graph generation in Microsoft Excel. The result data with graphs are displayed by selecting a Microsoft Excel file on the interface (the 3rd step).

Officially released in April 2006, the WSD Model's source code, its user interface, and the relevant technical documents are available at no charge from the Wastewater System Division's website: http://www.nilim.go.jp/lab/ebg/wsdmodel/wsdmodel.html. For international use, the English version will be provided in 2007.

4 CONCLUSION

The distributed urban runoff simulation model, the WSD Model, was developed through a natural extension of the PWRI Load Model, a lumped type model. Field surveys in three cities were conducted to provide data for the development and confirm urban runoff load characteristics. The developed model is characteristic in empirical simple model, not composed of numerous physical models, which involve many calibration-needed parameters. It was confirmed that the Model could explain the phenomenon in a reasonable level in SS, BOD, CODMn, T-N, and T-P. The user interface of the Model was also developed to improve usability facilitate further model and interface development.

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