Non-Point Heavy Metal Loads Discharged from Urban Area in Wet Weather Conditions

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都市域での水環境への重金属面源負荷についての考察

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本研究では，近年注目されている合流式下水道改善に関連し，都市域から排出される年間金属負荷量を把握するため，モデル流域を対象に AR モデルと 2 段流出モデルを用い，原単位評価をふまえて Pb 元素を含む 4 種の金属元素について排出負荷量を定量した．さらに，年間金属負荷量の試算結果をもとに，合流式下水道の改善効果について下水遮集量の増加と下水貯留量の増加の両施策について評価し，晴天時時間最大汚水量の 4 倍まで下水遮集量を増加させると粒子状鉛の排出量を約 86 % 削減でき，4 *mm* 相当の貯留池の建設によって粒子状鉛の排出負荷量を約 86 % 削減できることを示した．

1 Introduction

In rainy days, combined sewer systems sometimes discharge raw wastewater (called as combined sewer overflows, CSOs) to public water body [1] [2]. Due to the overflow, water quality and appearances of the receiving watershed are often deteriorated. To cope with these problems, several solutions were suggested and some of the approaches have been already applied [3] [4]. In recent years, there are a lot of reports on pollutant loads in combined sewer systems [5] [6]. However, there are a few researches calculating annual pollutant loads discharged from urban area and also few on heavy metal loads. In this paper, to understand annual heavy metal loads discharged from urban area in rainy days, AR (auto-regressive) model and two-stage runoff model were applied to target drainage watershed to calculate annual heavy metal loads. Based on the calculations, quantitative evaluations were carried out for the improvement plans of existing combined sewer systems.

2 Materials and Methods

2.1 Setting of target drainage watershed

The target drainage watershed covers the area of Meguro, Ota and Setagaya in Tokyo, where combined sewer systems are dominant, and annual heavy metal loads were calculated on this target watershed. Outline of the geological characteristics of the target watershed is shown in **Table 1**.

2.2 AR method

(1) Principle of AR method [7]

AR model is a model which estimates runoff profiles from precipitation data. Among surface runoff, intermediate runoff and groundwater runoff, surface runoff would be the most influential runoff for flow rate in urban sewer systems. Therefore, urban runoff could be treated as surface runoff and AR model was applied to estimate urban runoff profiles.

An expression of AR model correlates runoff volume Q with effective precipitation R' and previous runoff volumes as shown below;

$$Q_i = a_1 Q_{i-1} + a_2 Q_{i-2} + a_3 Q_{i-3} + \dots + a_p Q_{i-p} + b \lambda R_{i-1}' \qquad (1)$$

where a and b are coefficients of runoff volume Q and effective precipitation R', respectively, and λ is a transformation coefficient of effective precipitation R' into runoff volume Q. When the units for runoff volume Q and effective precipitation R' are [m^3 / 10 *min*] and [*mm* / 10 *min*], respectively, then λ is 10 times of district area A [*ha*]. The above **Eq. (1)** is finally transformed into the following **Eq. (2)**.

$$Q_i = \lambda (h_0 R'_i + h_1 R'_{i-1} + h_2 R'_{i-2} + \dots + h_m R'_{i-m} + \dots + h_{i-1} R'_1) \qquad (2)$$

Table 1 Geological characteristics of the target drainage watershed

Drainage watershed	Area (*ha*)	**Population** (*person*)	Population density (*per./ ha*)	Roof area (*ha*)	Percentage of roof area (%)	Impervious area (*ha*)	Percentage of impervious area (%)
Total	13,224	1,749,361	132	3,679	28	5,737	43
Meguro	1,470	255,486	174	545	37	801	54
Ota	5,946	662,416	111	1,390	23	2,240	38
Setagaya	5,808	831,459	143	1,744	30	2,696	46

$$h_0 = 0,\ h_1 = b,\ h_2 = b\,a_1,\ h_m = \sum (h_{m-j}\,a_j) \quad (m \geq 2) \qquad (2\text{-}1)$$

As to the appropriate dimension of AR coefficient *a*, it is generally accepted that drainage watershed consisting of pumping system is thought to be treated with one dimension [8] and drainage watershed consisting only of gravity collection system is to be treated with two dimensions [9]. However, previous researches show that when AR model is applied to the estimation of runoff profiles, one dimension analysis is acceptable even in the gravity collection system [10] [11]. Therefore, the dimension of AR coefficient *a* was assumed to be one in this study in order to simplify the expression. Then h_m is given by the following **Eq. (2-2)**.

$$h_m = b a^{m-1} \quad (m \geq 1) \qquad (2\text{-}2)$$

(2) Estimation of AR coefficient

Previous researcher shows that an estimate value of AR coefficient *a* from reaching time, reading a value in relationship diagram between AR coefficient *a* and reaching time shown in **Fig. 1**, is acceptable [12]. Generally speaking, it is difficult to assume reaching time based on hydrograph and hyetograph. Consequently reaching time was estimated from multiple regression analysis against the area of the drainage watershed *A* [*ha*] and effective precipitation *R*' [*mm*] with the use of least-square method and variance analysis. The reference data used in this analysis is based on the other researcher's report [9].

$$\text{Reaching time } T = 11.19 + 0.0265\,A + 0.137\,R' \qquad (3)$$

Although the area of the target drainage watershed is approximately 6,000 [*ha*], which is much greater than that of individual reference data ranging from 12 [*ha*] to 540 [*ha*] used in the regression analysis, obtained reaching times for the target area were at most 3 hours, which was considered to be reasonable. Consequently, reaching time was calculated by the above **Eq. (3)** and then AR coefficient *a* was estimated. **Figure 2** and **Figure 3** show the observed runoff profiles in the reference data and estimated runoff profiles obtained by the AR model using estimate values of reaching time. Judging from **Figure 2** and **Figure 3**, two kinds of runoff profiles by the estimation and by the observation were quite similar and the application of AR model with the use of estimate value from reaching time was successful.

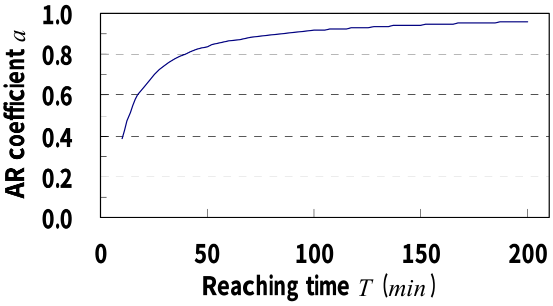

Fig. 1 Dependence of AR coefficient *a* on reaching time *T*

2.3 Calculation methods of heavy metal loads

(1) Conversion of SS loads to heavy metal loads

Wet weather heavy metal loads were calculated by multiplying SS loads with transformation coefficient. This transformation coefficient means heavy metal content per dry weight of SS.

In combined sewer systems, wet weather SS loads consist of contaminants in rainwater and in wastewater. Considering the difference in metal content per dry weight of SS in rainwater and wastewater, the transformation coefficients have been obtained separately. Heavy metal loads derived from rainwater were calculated from SS loads multiplied by heavy metal content contained in the soil deposited at street inlets. Similarly, heavy metal loads derived from wastewater were calculated from SS loads multiplied by heavy metal content contained in the depositions of combined sewer pipes.

(2) Metal content in suspended solids

In order to estimate the metal content derived from SS in rainwater, soil matters were collected at 83 sampling points in Tokyo in 2003. Additionally, road side depositions were also collected at the same places in 2005 to find a relationship between soil matters inside street inlets and road side depositions. In the case of SS derived from wastewater, heavy metal contents per dry weight of soils deposited at the bottom of combined sewer pipes were used based on the literature survey [13].

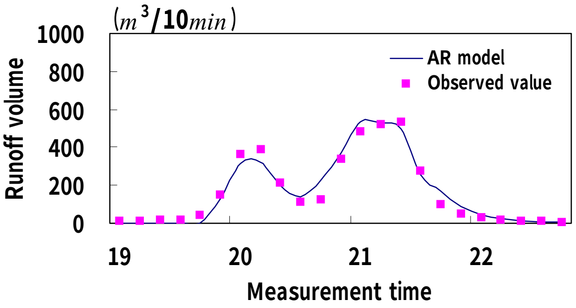

Fig. 2 Verification of AR method by estimation and observation, Hanakuma in Sep. 1st, 1974

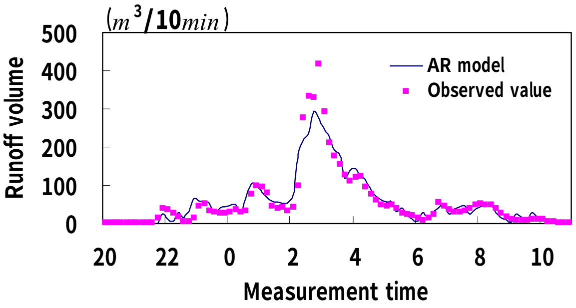

Fig. 3 Verification of AR method by estimation and observation, Hanakuma in Oct. 1st, 1974

2.4 Runoff model of SS loads

To give a discharge profile in time-series of SS loads derived from rainwater, two-stage runoff model [14] was applied to five separate sewer service areas.

$$Q_s = a_1 Q^2 + b_1 S_1 Q \tag{4}$$

where a_1 and b_1 are coefficients, Q is flow rate and S_1 is initial pollutant depositions. Then there are three unknown parameters in the above **Eq. (4)**, a_1, b_1 and S_1. The multiple regression analysis was applied to the reference drainage watersheds shown in **Table 2** and the unknown parameters are correlated with the land use, characteristics of the watershed and the precipitation.

$$S_1 = A_{imp}(-0.6942 + 0.453R + 1.592R_i) \tag{5}$$

$$a_1 = 0.282exp(-0.0194PER_{Aimp} - 0.0701R) / A \tag{6}$$

$$b_1 = 0.226exp(-0.0166PER_{Aimp} - 0.182DT - 0.0792Ri)/A \tag{7}$$

where A is an area of drainage watershed (ha), A_{imp} is an impervious area (ha), R is amount of precipitation (mm), R_i is a rainfall intensity (mm / hr), DT is a rainfall duration (hr) and PER_{Aimp} is percentage of impervious area ($\%$). Using above multiple regressive **Eqs. (5)**, **(6)** and **(7)**, initial pollutant depositions S_1 and coefficients a_1 and b_1 were obtained and then runoff profiles of SS loads were examined. **Figure 4** and **Figure 5** show the runoff profiles of SS loads based on calculation together with the observed value. Judging from these figures, runoff profiles of SS loads were satisfactory estimated by using above multiple regressive **Eqs. (5)**, **(6)** and **(7)**.

On the other hand, runoff profiles of SS loads derived from sewage water in time series were estimated by the same two-stage runoff model applied to four combined sewer service areas.

$$Q_s = a_2 Q^2 + b_2 S_2 Q \tag{8}$$

where a_2 and b_2 are coefficients, k is a SS loads in dry weather, Q is flow rate of stormwater and S_2 is an initial pollutant depositions. Unknown parameters in the above **Eq. (8)** were also estimated by multiple regression analysis over the reference watershed shown in **Table 3**.

$$S_2 = A(-4.49 + 2.01R + 2.39DT - 0.0682R_p) \tag{9}$$

$$a_2 = 0.789exp(0.0270PER_{roof} - 0.172R - 0.0988R_i - 0.0314R_p) / POP_d \tag{10}$$

$$b_2 = 0.00823exp(-0.0125POP_d) / R \tag{11}$$

where A is an area of drainage watershed (ha), R_i is a rainfall intensity (mm / hr), R is amount of precipitation (mm), R_p is amount of precipitation in previous rain event (mm), DT is a rainfall duration (hr), POP_d is a population density ($person$ / ha) and PER_{roof} is percentage of roof area ($\%$).

Using above multiple regressive **Eqs. (9)**, **(10)** and **(11)**, initial pollutant depositions S_2 and coefficients a_2 and b_2 were obtained and then runoff profiles of SS loads derived from combined water were examined. **Figure 6** and **Figure 7** show the runoff profiles of SS loads based on the calculation together with observed value. Judging from these figures, runoff profiles of SS loads were satisfactory estimated by using above multiple regressive **Eqs. (9)**, **(10)** and **(11)**.

2.5 Evaluation methods of improved sewer systems

The increase in interception volume and the increase in off-line storage were considered as CSOs control technologies in this study. **Figure 8** shows the schematic concept of evaluating improvement plans on

Table 2 Characteristics of separate sewer drainage watersheds used for the calculation in model parameters

Drainage watershed	Area (*ha*)	**Population** (*person*)	Population density (*per./ ha*)	Roof area (*ha*)	Percentage of roof area (*%*)	Impervious area (*ha*)	Percentage of impervious area (*%*)
Hanakuma	**17.2**	**2,695**	**157**	**6.4**	**37.2**	**11.9**	**69.5**
Kitasuma	**26.8**	**3,227**	**121**	**17.4**	**65.0**	**22.4**	**83.7**
Satsukigaoka	**93.2**	**12,125**	**130**	**11.2**	**12.0**	**24.4**	**26.2**
Midorichou	**13.7**	**1,089**	**80**	**5.6**	**41.0**	**7.3**	**53.3**
Shimizugawa	**106.4**	**24,568**	**231**	**78.0**	**73.3**	**85.0**	**79.9**

Table 3 Characteristics of combined sewer drainage watershed used for the calculation in model parameters

Drainage watershed	Area (*ha*)	**Population** (*person*)	Population density (*per./ ha*)	Roof area (*ha*)	Percentage of roof area (*%*)	Impervious area (*ha*)	Percentage of impervious area (*%*)
Senbon	**148.5**	**25,280**	**170**	**83.2**	**56.0**	**114.5**	**77.1**
Oji	**57.6**	**3,718**	**65**	**8.0**	**13.9**	**15.0**	**26.0**
Shirakawa	**39.5**	**1,780**	**45**	**16.2**	**41.1**	**23.7**	**60.1**
Haccho	**68.4**	**8,358**	**122**	**29.6**	**43.3**	**49.8**	**72.9**

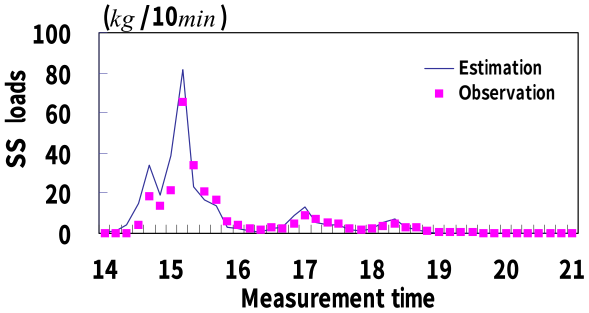

Fig. 4 Verification of 2-stage runoff model by estimation and observation, Kitasuma in Dec. 4th, 1978

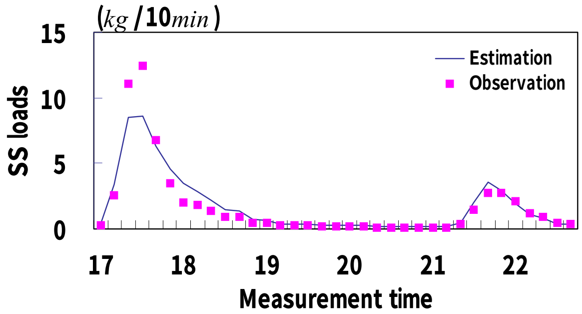

Fig. 5 Verification of 2-stage runoff model by estimation and observation, Satsukigaoka in Jan. 18th, 1982

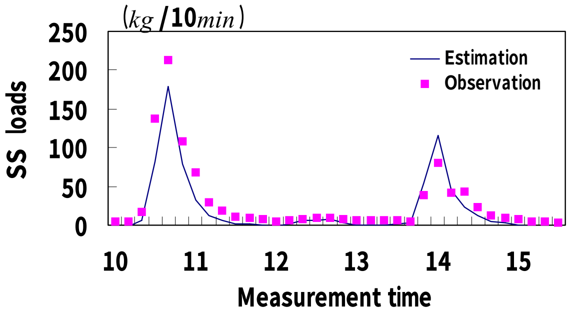

Fig. 6 Verification of 2-stage runoff model by estimation and observation, Oji in Nov. 8th, 1977

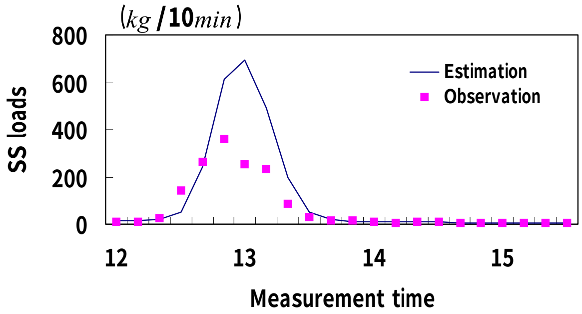

Fig. 7 Verification of 2-stage runoff model by estimation and observation, Haccho in Aug. 26th, 1976

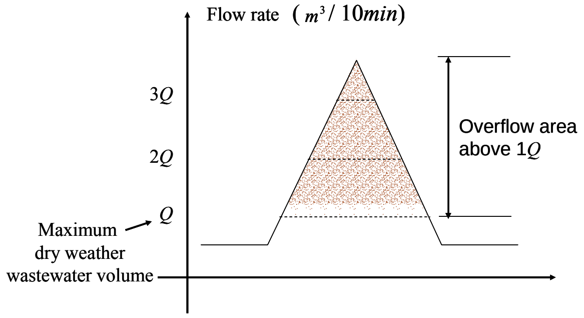

Fig. 8 Schematic concept of evaluating improvement plans on increased interception volume

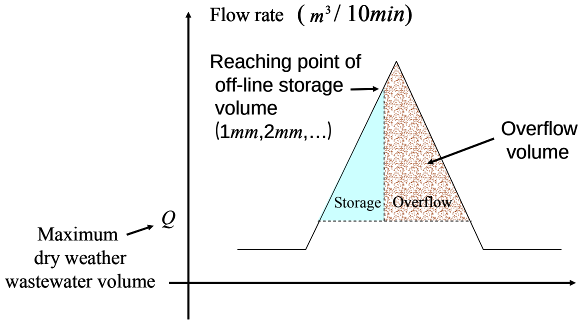

Fig. 9 Schematic concept of evaluating improvement plans on increased off-line storage volume

increased interception volume. When the interception volume is $1Q$, overflow volume is the area above $1Q$ line. **Figure 9** shows the schematic concept of evaluating improvement plans on increased off-line storage volume. Overflow volume is the area above $1Q$ line only after the storage volume reached the assumed storage volume.

3. Results and Discussions

3.1 Metal content in suspended solids

Table 4 summarizes the contents of four elements of heavy metals adsorbed to SS derived from combined water based on literature survey for depositions in sewer popes [13] and from rainwater based on field survey for street inlet [15], and in addition, the heavy metal contents adsorbed to roadside depositions were given as reference. **Table 4** shows that lead and copper contents contained in SS derived from combined water are considerably higher than both in SS derived from rainwater and in roadside deposition. On the other hand, zinc and manganese contents contained in SS derived from rainwater are quite similar to those in SS derived from combined water, and at the same time, a little lower than those in roadside deposition.

3.2 Calculation of heavy metal loads

Table 5 shows the simulation result on annual heavy metal loads for lead, copper, zinc and manganese discharged from the target drainage watershed in 2004 considering all 68 rain events in that year. Heavy metal loads derived from wastewater were calculated by subtracting heavy metal loads derived from rainwater from heavy metal loads derived from combined water. **Table 5** shows that 25.30 *tons* of lead loads are assumed to be discharged from the target drainage watershed in 2004, of which lead loads derived from wastewater contributes 97.5 *%* and 2.5 *%* from rainwater. In the case of copper, zinc and manganese, pollutant loads derived from combined water are 22.28 *tons*, 64.20 *tons* and 35.59 *tons*, respectively, of which contribution ratios for loads derived from wastewater are all approximately 95 *%*. Consequently, according to the simulation results, heavy metal loads derived from wastewater are assumed to contribute more than 95 *%* to wet weather heavy metal loads discharged from urban area. Therefore, to cope with the problem of wet weather pollutant loads, cleaning of soil matters deposited at combined sewer pipes is considered to be effective.

3.3 Quantitative evaluations of improvement plans for combined sewer systems

To evaluate improvement plans for combined sewer systems, the increase plans of interception volume and of off-line storage volume were considered. The planned interception volumes in the calculation were from 1*Q* to 10*Q*. **Figure 10** shows that annual overflow frequency decreases with the increase in the interception volume. **Figure 11** shows the annual lead loads in raw wastewater discharged from the target drainage watershed to public water body. The improvement plan to intercept three times or four times as much volume as the maximum dry weather wastewater volume gives considerable reduction in discharging lead loads and over four times of interception volume does provide only slight reduction. When the interception volume is four times as much volume as the maximum dry weather wastewater volume, annual discharge of lead loads was calculated to be 360 kilograms and reduction ratio was expected to be 86 *%* from two times of interception volume.

In the case of off-line storage volume, the storage volumes from 1 *mm* to 10 *mm* cases were assumed. Taking lead loads for example shown in **Figure 12**, 3 *mm* storage or 4 *mm* storage can reduce discharge of lead loads to a certain extent, and further increase in storage volume showed only slight effect. In the case of 4 *mm* storage volume, annual discharge of lead loads was calculated to be 1,205 kilograms and reduction ratio was expected to be 86 *%* from 0 *mm* storage volume. The reduction mechanism is the collection of the so-called first flush as shown in **Figure 13**. The pollutants are discharged in the initial storage of the flow rate increase in the calculation, which phenomenon is consistent with field observation [16].

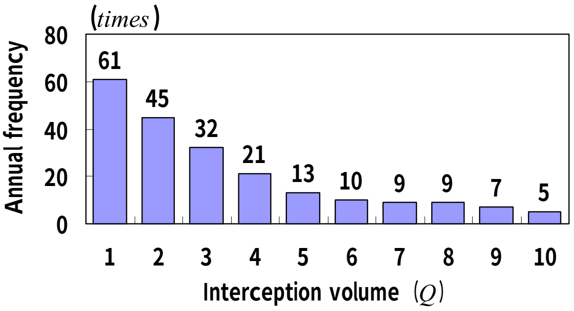

Fig. 10 Annual overflow frequency correlating to the increase of interception volume

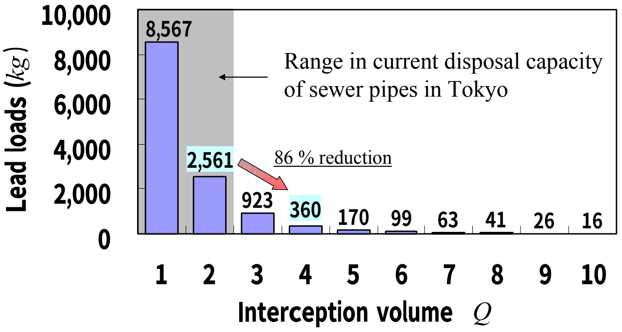

Fig. 11 Annual discharge of lead loads correlating to the increase of interception volume

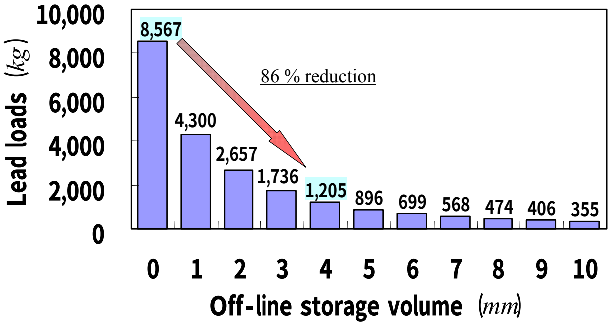

Fig. 12 Annual discharge of lead loads correlating to the increase of off-line storage volume

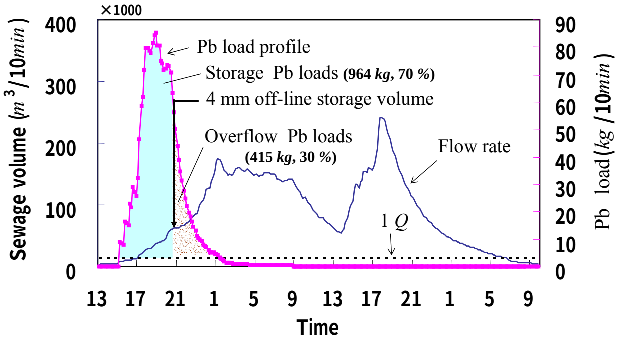

Fig. 13 One of the Simulation results of sewage volume - Pb loads curve

Table 4 Specific concentrations of heavy metal elements used in the conversion from SS loads into heavy metal loads

mg/g	Pb	Cu	Zn	Mn
Soil matters collected inside street inlets	0.120	0.180	0.690	0.400
Soil matter collected inside combined sewer pipes	0.284	0.246	0.698	0.386
Road side deposion	0.142	0.159	0.781	0.467

Table 5-1 Annual heavy metal loads discharged from the target drainage watershed in 2004

No.	Mon.	Duration time of precipitation (*hr*)	Precipitation (*mm*)	Heavy metal pollutant loads (*kg*)											
				Lead			**Copper**			**Zinc**			**Manganese**		
				Rain water	**Waste water**	**Sewage water**	**Rain water**	**Waste water**	**Sewage water**	**Rain water**	**Waste water**	**Sewage water**	**Rain water**	**Waste water**	**Sewage water**
1	Jan.	3	5	2	157	160	4	136	140	14	386	400	8	213	222
2	Feb.	7 1/6	12	7	457	464	11	395	406	41	1,121	1,163	24	620	644
3		3	11	10	337	346	14	291	306	55	827	882	32	457	489
4	Mar.	3 1/6	7.5	5	276	281	8	239	247	29	679	708	17	375	392
5		6 1/2	12.5	8	452	460	13	391	403	49	1,109	1,158	28	613	642
6		14 2/3	26	11	385	396	17	333	349	65	945	1,009	38	522	560
7		12 1/6	6.5	2	207	208	2	179	181	9	507	516	5	280	286
8		10 5/6	14.5	8	459	467	11	397	409	43	1,128	1,172	25	624	649
9		8 5/6	62	28	465	493	42	402	444	161	1,143	1,304	93	632	725
10	Apr.	6 1/3	21	16	186	202	24	161	185	93	457	550	54	253	306
11		9 1/2	11	6	333	339	8	288	297	32	819	851	19	453	471
12		2	5	3	143	146	5	124	129	19	352	370	11	194	205
13		7 5/6	10.5	6	464	470	9	401	410	34	1,140	1,174	20	630	650
14		5 1/6	12	8	382	390	13	330	343	49	937	986	28	518	546
15		1/6	2.5	2	-2	0	3	-2	1	10	-5	5	6	-3	3
16		7 1/2	7.5	3	394	398	5	341	346	20	968	988	12	535	547
17	May	1 1/6	2.5	1	14	14	1	12	13	3	34	37	2	19	21
18		6 1/2	11	7	474	481	10	410	420	39	1,165	1,203	22	644	666
19		19 1/6	13.5	3	394	397	5	341	346	19	968	987	11	535	546
20		7 1/2	7	3	279	282	4	241	246	17	685	702	10	379	389
21		4 2/3	3	0	66	66	1	57	58	2	162	164	1	90	91
22		13	28	14	406	420	21	351	372	79	997	1,076	46	551	597
23		19 2/3	70.5	17	648	666	26	561	587	100	1,592	1,693	58	880	938
24		5/6	4	4	2	5	6	1	7	21	4	25	12	2	15
25	June	14	17	9	537	547	14	465	478	53	1,320	1,373	31	730	760
26		6 1/6	9.5	5	300	305	8	259	267	30	736	766	18	407	424
27		16 2/3	15.5	6	447	453	9	387	396	35	1,098	1,133	20	607	627
28		5 1/3	4.5	1	124	126	2	107	109	7	305	313	4	169	173
29		10	23	14	401	415	21	347	368	80	986	1,066	46	545	591
30		2 1/2	13.5	14	258	272	21	223	244	82	633	716	48	350	398

Table 5-2 Annual heavy metal loads discharged from the target drainage watershed in 2004

No.	Mon.	Duration time of precipitation (*hr*)	Precipitation (*mm*)	Heavy metal pollutant loads (*kg*)											
				Lead			**Copper**			**Zinc**			**Manganese**		
				Rain water	**Waste water**	**Sewage water**	**Rain water**	**Waste water**	**sewage water**	**Rain water**	**Waste water**	**sewage water**	**Rain water**	**waste water**	**sewage water**
31	June	5 1/3	17.5	15	397	412	23	343	366	89	975	1,064	52	539	591
32		2 1/2	4.5	2	98	100	3	85	88	13	241	254	7	133	141
33		7	4.5	1	165	166	2	143	145	6	406	412	4	224	228
34		7 1/6	8	4	414	418	6	358	364	24	1,017	1,041	14	562	576
35	July	3	5	1	5	7	2	5	6	7	13	20	4	7	11
36		7 1/6	12	2	26	28	4	22	26	14	63	77	8	35	43
37		3	11	3	84	88	5	73	78	19	207	226	11	114	125
38		3 1/6	7.5	8	557	565	12	482	494	48	1,368	1,415	28	756	784
39	Aug.	6 1/2	12.5	12	314	326	18	271	289	70	770	840	40	426	466
40		14 2/3	26	9	433	442	14	374	388	54	1,063	1,117	31	588	619
41		12 1/6	6.5	0	59	59	1	51	52	2	145	147	1	80	81
42		10 5/6	14.5	6	581	587	9	503	512	35	1,428	1,463	20	789	810
43		8 5/6	62	8	243	251	12	210	223	48	597	645	28	330	358
44	Sep.	6 1/3	21	32	531	563	49	459	508	186	1,304	1,491	108	721	829
45		9 1/2	11	4	43	47	6	37	44	25	106	130	14	59	73
46		2	5	10	113	123	15	97	113	59	276	335	34	153	187
47		7 5/6	10.5	7	101	108	10	87	97	38	248	286	22	137	159
48		5 1/6	12	2	98	100	3	84	87	12	239	252	7	132	139
49		1/6	2.5	12	405	417	18	350	368	70	994	1,063	40	549	590
50		7 1/2	7.5	21	524	545	31	453	484	120	1,286	1,406	70	711	781
51	Oct.	1 1/6	2.5	25	494	519	38	427	465	144	1,213	1,358	84	671	755
52		6 1/2	11	10	359	369	16	310	326	60	882	941	35	487	522
53		19 1/6	13.5	9	1,069	1,078	14	924	938	54	2,625	2,680	32	1,451	1,483
54		7 1/2	7	35	2,221	2,256	52	1,921	1,973	199	5,456	5,655	116	3,016	3,132
55		4 2/3	3	1	15	16	1	13	14	4	37	41	2	20	23
56		13	28	8	451	459	12	390	402	46	1,109	1,155	27	613	640
57		19 2/3	70.5	5	246	251	7	213	220	27	605	632	16	335	350
58		5/6	4	28	1,814	1,842	42	1,568	1,611	161	4,455	4,616	94	2,463	2,556
59		14	17	0	-1	0	1	-1	0	2	-2	0	1	-1	0
60		6 1/6	9.5	9	532	541	14	460	474	52	1,307	1,359	30	722	752
61		16 2/3	15.5	14	582	596	21	503	524	80	1,430	1,510	47	790	837
62	Nov.	5 1/3	4.5	14	112	125	21	96	117	80	274	354	46	152	198
63		10	23	13	382	395	20	330	350	76	939	1,015	44	519	563
64		2 1/2	13.5	15	258	273	23	223	245	86	633	719	50	350	400
65		5 1/3	17.5	8	506	514	12	438	449	45	1,243	1,288	26	687	713
66	Dec.	2 1/2	4.5	20	386	406	31	333	364	118	947	1,064	68	523	592
67		7	4.5	7	237	244	10	205	215	39	583	622	23	322	345
68		7 1/6	8	14	379	393	21	328	349	79	932	1,011	46	515	561

4. Conclusion

Annual heavy metal loads were calculated applying AR model and two-stage runoff model to the target drainage watershed. Based on the calculations, quantitative evaluations of improvement plans for combined sewer systems were discussed. The conclusions were summarized as follows;

1) 25.30 *tons* of lead loads was discharged from the target drainage watershed in 2004, of which lead loads derived from wastewater contribute 97.5 *%* of total particulate lead loads, while only 2.5 *%* from rainwater.
2) In the case of copper, zinc and manganese, pollutant loads in combined wastewater are 22.28 *tons*, 64.20 *tons* and 35.59 *tons*, respectively, of which contribution ratios for loads derived from wastewater are all approximately 95 *%*.
3) By intercepting four times as much volume as the maximum dry weather wastewater volume, estimated annual discharge of lead loads due to combined sewer overflows is 360 kilograms and this is 86 *%* reduction compared with the case of intercepting volume of 2*Q*.
4) Annual discharge of lead loads was decreased with increase in the off-line storage volume in the improvement plans. More storage volume than 3 *mm* or 4 *mm* was considered not to be economical.
5) 4 *mm* of storage volume can reduce 86 *%* annual discharge of lead loads in the same interception volume of 1 *Q*.

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