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A Study on Runoff Characteristics of Combined Sewer Overflow(CSO) in Urban Area Using GIS & SWMM

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Abstract : The runoff characteristics of combined sewer overflow(CSO) in the urban area of Jeonju were investigated and analyzed by using the SWMM (Storm Water Management Model) and GIS. From August to November 2004, investigations on two rainfall events were performed and flowrate, pH, BOD, COD, SS, T-N and T-P were measured. these data were used for model calibration. Using GIS technique, watershed characteristics of study area were calculated. that is, divide into sub_basin, total width, slope, make soil map etc. On the basis of the measured data and the simulation results by SWMM, it could be known that the 80-90% of pollution load are discharged in early-stage storm runoff. SMC(site mean Concentration) for combined sewer system area were BOD 28.1, COD 31.5, SS 186 ppm etc. this is shown that during the rain fall, high concentration of waste was loaded to receiving water. Unit loads of combined sewer system area were BOD 306, COD 410, SS 789, T-N 79, T-P 6.8 kg/ha/yr.

Keywords : Non-point source pollutions, SWMM (storm water management model), Rainfall- Runoff

Introducton

The Increase or change of land_use by the population growth and the development of industry leads complexity of hydrologic phenomena. Inflows of industrial and domestic waste water worsen water quality and become restriction of water usage for drinking water sources. In general, water quality is influenced by pollution loads from watershed and flow rate of stream and its chemical, physical or biological self purification. To manage the water quality effectively, more accurate control of water pollutant sources is needed using systematic method. It is comparatively easy to manage the water quality by reducing the amount of the discharge from point sources because they are readily identified and controlled. In contrast to controlling the point sources, pollutants from non-point sources are not easy to characterize the sources and need the specific management tool to estimate and control the accurate amount of pollutants (Lee, 2001).

In case of point sources, discharge units for pollution loads have been studied and presented in many previous researches. However, discharge units for non-point sources have been rarely studied. Furthermore quantifying the pollution loads using the discharge unit of non-point sources has the limit.

GIS technique, which was developed for treatment and analyzing geographical data, is the method having powerful functions in presenting the possible solutions of controlling non-point pollutants (Lee, 2000). In addition, commercial tool with useful techniques in multilateral aspects have been developed. It becomes practicable to analyze with GIS program without additional development of algorithms.

Water quality policies in Korea are concentrated on sewage and industrial wastewater treatment, but in fact, most of pollutants in water system are caused by non-point pollutants. Non-point pollution breaks out by runoff and it is difficult to measure and quantify the amount of runoff pollutants. The more removal efficiency of sewage treatment process increase, economical status progresses and the land use intensifies, the more influence of runoff pollutants to water quality increases. Especially urban areas having more non-point pollutant resources need specific management policies compare to rural areas having exact point resources (Paik, 2002).

In this study, we modeled discharge pattern of

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non-point pollutants in Jun-Ju stream as a model stream to analyze the effluent characteristic of combined sewage system in urban area when runoff using GIS technique and SWMM model.

Materials and Methods

Procedure for Study

Simulation test was carried out for determine the effluent characteristics of combined sewage system. We surveyed the watershed characteristics, assessed the sewage piping system and measured flow-rate of runoff.

This study includes as follows

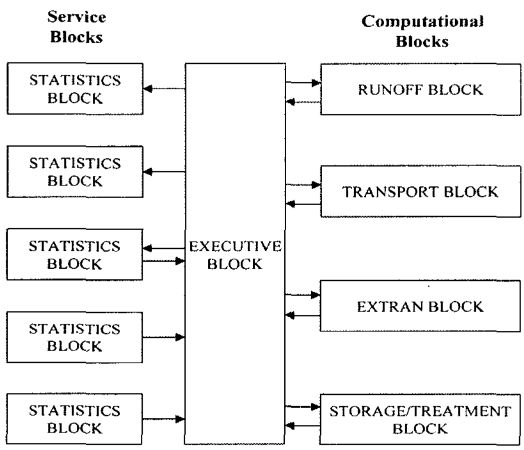

Fig. 1. Relationship of blocks for SWMM.

- Survey of water quality and flow-rate
- Survey of Study Area
- Analysis of Conduit Network
- Configuration of Input data for model
- Calibration and Verification of SWMM
- Simulation for Rainfall Events

SWMM(Storm Water Management Model)

Since SWMM model was developed by US EPA in 1971, improved the function of continuous simulation and became one of the most popular model for estimating non-point pollutants. SWMM have been widely used for estimating the amount of runoff and water quality in urban and rural area. It is known as the most robust model.[3]

SWMM was consist of 6 computational block in early stage of development. but The Current version of SWMM have two major components as service blocks and computational blocks. As the components have systematic relationship, the SWMM can simulate flow-rate and water quality.

Survey of Flow Rate and Water Quality of Study Area

The study area for analyzing runoff characteristics of CSO in urban area is located in Junju city and shows in Fig. 2. We sampled and measured runoff flow-rate at the edge of CSO.

The watershed includes general residence area and commercial area (sports complex) and is typical

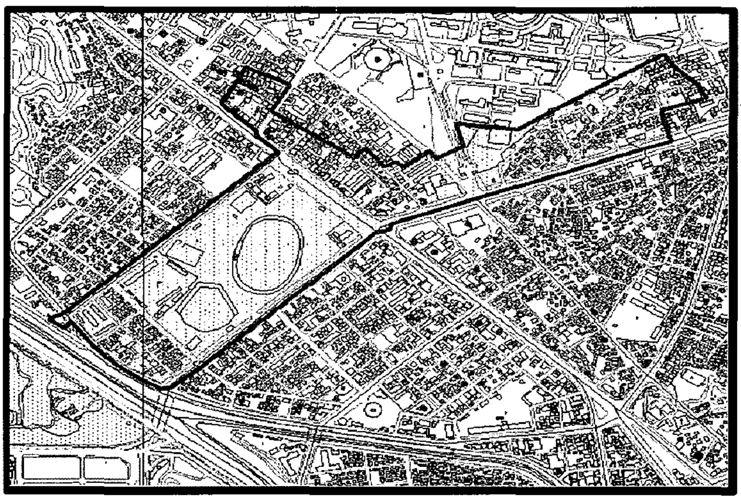

Fig. 2. *Study area in Junju.*

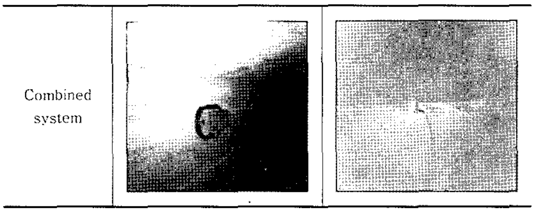

Fig. 3. Sampling points measured continuously by flow rate meters.

out-mode area naturally formed. The entire sewage water flows into sewage treatment system through the sewage Piping system in case of no rainfall, but when the over flow happens by the rainfall event the excess flow discharges into JunJu stream through storm out-fall sewer.

Sampling were conducted every 20 min until 2 hour after rainfall, every 30 min between 2 and 4 hour and every 60 min until 24 hour after the event. We used water flow meter (America sigma Inc 910) to measure the water depth and flow velocity as follows and calculated the flow-rate.

- sampling period : 2004. 9. 7., 2004. 11. 1.
- sampling point : storm out-fall point of combined sewer system
- measured items :
  flow-rate (America Sigma Inc 910)
  water quality (BOD, COD, SS, T-N, T-P)

The Fig. 3 shows the flow meter installed in sampling point.

Result and Discussion

SWMM Input Data

In this study, RUNOFF block and TRANSPORT block of Storm Water Management Model (SWMM) were used for estimating the runoff water quality and runoff curve.

Stream map, DEM and Sewer network were used to determine watershed Delineation. Watershed was divided into sub watershed according to its effluent discharge characteristics. We calculated area and slope of sub watershed, length of sewer and bottom slope using GIS technique. And we collected the other information from literatures.

Among weather input data, like precipitation, snowfall and evaporation, precipitation data from the JunJu weather station were only used in this study. Applied rainfall event was on 7th of September and 1st of November.

Watershed Characteristic Data

The sewer system of the study area was created using Arc/info and sewage network diagram of JunJu city (Junju city, 1998, scale of 1:3,000). the watershed was divided into 12 zone ans area, width, slope and non-penetration area were determined for each zone.

1. Width of Watershed

A typical shape was assumed as rectangular shape in SWMM model. The followed equation was used to calculate the width.

$$W = (2 - S_k) \cdot L$$

$$S_k = (A2 - A1)/A$$

W : Total width of overland flow(=2L) (m)
L : length of main drainage channel (m)
S_k : skew factor $(0 \le S_k \le 1)$ (dimensionless)

2. Slope

If watershed has simple geometrical figure, slope was calculated by altitudinal difference divided by sewer length. If not, slope was obtained as weighted average by conduit length. In this study, we used DEM data and sub-watershed map for slope using Arc/info.

3. Sewer Conduit Characteristics

Sewer Conduit Characteristics are calculated by

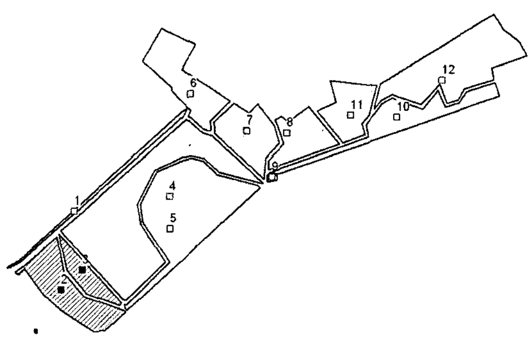

Fig. 4. Sub_basin in combined drainage system.

Table 1. Properties of Sub_basin in combined drainage system

Catchment ID	Area (ha)	Width (m)	Slope (%)
1	0.814	1352.8	1.877
2	3.420	217.5	0.192
3	1.567	382.7	0.487
4	10.951	556.1	1.877
5	7.295	664.3	2.136
6	3.463	111.3	2.289
7	2.966	317.6	2.149
8	2.437	265.4	2.030
9	0.094	66.9	1.666
10	3.317	1309.2	5.533
11	2.488	167.4	2.341
12	6.322	779.6	9.406

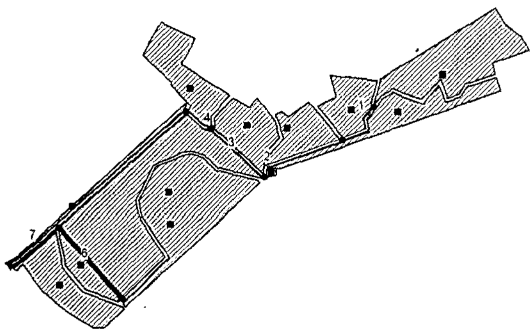

Fig. 5. Sewer conduit of Combined drainage system.

Table 2. Properties of Sewer conduit in combined drainage system

Conduit ID	Shape	Length (m)	Diameter (m)	Height (m)	Manning n
1	Box	169.0	1.0	1.0	0.013
2	Box	241.0	1.0	1.0	0.013
3	Box	236.0	1.5	1.0	0.013
4	Box	104.5	2.0	1.0	0.013
5	Box	792.5	2.5	1.0	0.013
6	Box	308.0	1.5	1.0	0.013
7	Box	238.0	2.5	1.0	0.013

sewage network diagram of JunJu city(Junju city, 1998, scale of 1:3,000).

4. Land Use and Pavement Rate

Land use was divided into 6 zones like park district,

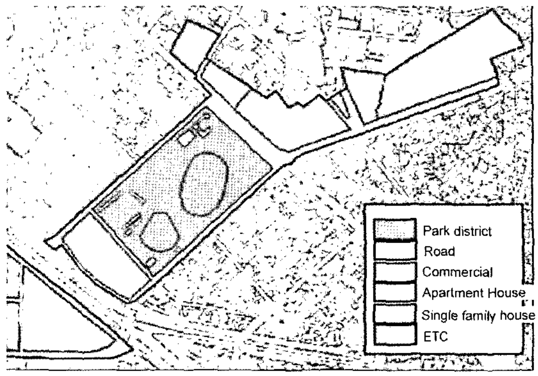

Fig. 6. Land Use of the study area.

road, comercial area, single family house area, apartment house area, etc. We remarked surveyed data on numerical map and calculated the area and land use rate. The pavement area was calculated for each sub-watershed according to land use(Fig. 6).

5. Soil Characteristics

The soil permeability is estimated by digital soil

Table 3. Manning coefficient in surface flow

Source	Ground cover	Manning n	Range
Crawford and Linsley (1996)[a]	Smooth Asphalt	0.012	
	Asphalt of concrete paving	0.014	
	Packed clay	0.03	
	Light turf	0.20	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.4	
Engman (1986)[b]	Concrete or asphalt	0.011	0.01-0.013
	Bare sand	0.01	0.01-0.016
	Graveled surface	0.02	0.012-0.03
	Bare clay-loam (eroded)	0.02	0.012-0.033
	Range (natural)	0.13	0.01-0.32
	Bluegrass sod	0.45	0.39-0.63
	Short grass prairie	0.15	0.10-0.20
	Bermuda grass	0.41	0.30-0.48

Note)[a]Obtained by calibration of Stanford Watershed Model
[b]Computed by Engman (1986) by kinematic wave and storage analysis of measured rainfall-runoff data.
Quotation) Huber and Dickinson, 1988.

Table 4. Manning coefficient in conduit flow

Material	Typical manning roughness coefficient
Concrete	0.012
Gravel bottom with sides	
- concrete	0.020
- mortared stone	0.023
- riprap	0.033
Natural stream channels	
Clean, straight stream	0.030
Clean, winding stream	0.040
Winding with weeds and pools	0.050
With heavy brush and timber	0.100
Flood plains	
Pasture	0.035
Field crops	0.040
Light brush and weeds	0.050
Dense brush	0.070
Dense trees	0.100

Quotation)Chow *et al.*, 1988.

map of the Institute of Agricultural Science and Technology of Korea.

6. The Other Parameter

The Manning loughness coefficient, depression storage, Horton's permeabl parameter are refer to other references (Table 3, 4, 5, 6).

Table 5. Surface retention by surface indentation

Soil condution			Depth of storage (cm)	Represent value (cm)
Impervious	Covered shed		0.13-0.40	0.25
	Roof	Horizon	0.25-0.80	0.25
		Slope	0.13-0.25	0.13
Pervious	Glass		0.50-1.25	0.75
	Forest		0.50-1.50	1.00

Quotation)Lee *et al.*, 1994.

Table 6. Infiltration coefficient according to Horton formula

Description	SCS soil			
	A	B	C	D
Final Impervious f_c (mm/hr)	25.4	12.7	6.4	2.5
Initial Impervious f_0 (mm/hr)	254	203	127	76
Declining coefficient	0.00056(1/sec) = 2.016(1/hr)			

Quotation)Lee *et al.*, 1994.

7. Configuration of SWMM Input Data

We created the input data of sub watershed, Conduit and joint point using US EPA SWMM (Ver. 5.0) and configured input data for each rainfall event (Fig. 7).

Calibration and Verification of SWMM

We conducted calibration and verification for

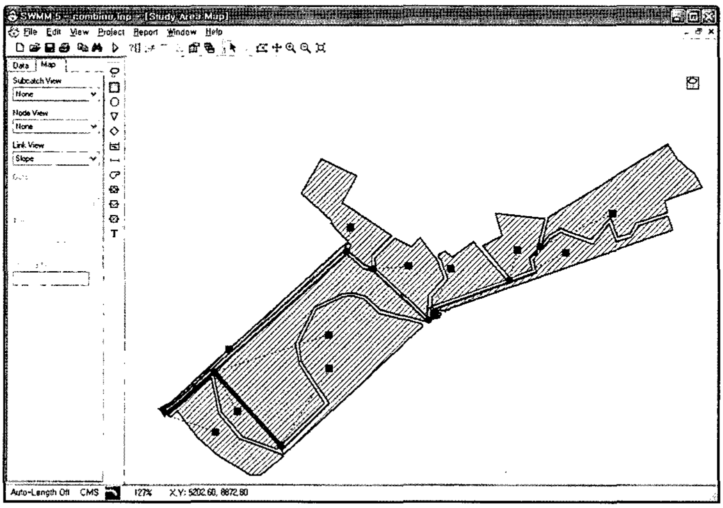

Fig. 7. Input data for combined drainage system.

Table 7. Verification results of SWMM for combined conduit basin

Date	Item	BOD5		COD		SS		T-N		T-P	
		Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.
2004. 11. 1.	Y	0.53		0.71		0.88		0.7		0.41	
	RE	13.7		13.0		19.4		28.2		26.6	
	N	14		14		14		14		14	
	Min.	43.5	41.0	61	52	79.6	52	6.2	9.8	1.7	2.4
	Max.	163.4	179.4	249	256	484.9	248	23.5	25.7	9.9	8.8
	Avg.	82.7	90.6	103	109	217.3	116	16.9	16.9	4.8	5.1

Note) Pred.: predicted values, Meas.: Measured values.

runoff flow rate and water quality using SWMM RUNOFF block and TRANSPORT block. Input data for calibration was 7th of September in 2004 and for verification used data for 1st of November in 2004.

Results of calibration and verification were assessed by following equation.

$$RE = \frac{|C_M - C_E|}{C_M} \cdot 100(\%)$$

in which

C_M = measured Data

C_E = Predicted Data

Table 7 shows summary of verification result. Correlation coefficients were 0.41-0.88. Relative errors were 13.7-28.2%, indicates that this model properly describes the runoff characteristics.

Table 8. Rainfall event for SWMM simulation

Event	Rainfall (mm)	Rainfall duration time (hr)
2004. 4. 26	24	14
2004. 6. 17	35	25
2004. 6. 20	70.5	38
2004. 7. 02	23.5	30
2004. 7. 07	37.5	32
2004. 9. 11	30	19

Simulation of Discharge from Non-point Pollution Source

The characteristics of discharge of non-point pollutant loads was estimated using rainfall events data (Table 8) by SWMM after calibration and verification.

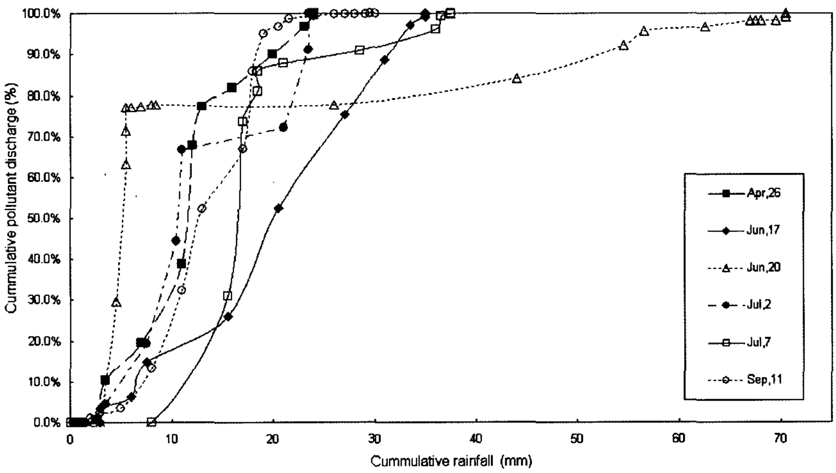

Fig. 8. Cumulative mass loading according to cumulative rainfall.

We analyzed the characteristics as Cumulative mass loading according to cumulative rainfall, SMC (site mean concentration), Unit load of nonpoint pollution.

1. Cumulative Mass Loading According to Cumulative Rainfall

We estimated cumulative mass loading according to cumulative rainfall to characterize runoff of non-point pollutants.

Fig. 8 shows changes of cumulative mass loading according to cumulative rainfall for 6 rainfall events. As shown in Fig. 8, when cumulative rainfall is 10-30 mm, cumulative mass loading is 80-90% except data of 20th of June. Therefore, to protect the non point pollution load effectively, we will design treatment plant for initial 10-30 mm.

2. Event Mean Concentration and Site Mean Concentration

Event mean concentration (EMC) and site mean concentration was used to characterize the non-point pollutants runoff by rainfall event. EMC and SMC were calculated for six events.

$$\mathrm{EMC} = \frac{\text{Total Pollution Load(kg)}}{\text{Total Runoff}(\mathrm{m}^3)} = \frac{\sum_{i=1}^{n} \text{Concentration} \times \text{Runoff}_i}{\sum_{i=1}^{n} \text{Runoff}_i}$$

where,

SMC = Average or Median (log-normal distribution) of concentration of area

Table 9. EMC and SMC for study area

		Combined system				
		BOD	COD	SS	T-N	T-P
EMC	Event 1	29.5	33.6	76	21.66	3.41
	Event 2	26.5	30.6	365	14.32	2.34
	Event 3	35.2	43.2	212	12.13	1.98
	Event 4	38.4	45.8	189	16.23	2.17
	Event 5	17.3	22.3	220	11.09	2.03
	Event 6	23,2	25.4	156	15.09	3.09
SMC		28.1	31.5	186	13.66	3.41
COV		0.42	0.69	0.62	0.60	0.31

Table 10. Non-point pollutant Unit loadings

(Unit : kg/ha/yr)

Conduit System	BOD	COD	SS	T-N	T-P
combined	306	410	789	79	6.8

Calculated values of EMC and SMC for six events were presented in Table 9. SMC of combined sewage system was 28.1 for BOD, 31.5 for COD, 186 for SS, 13.66 for T-N and 3.41 for T-P, which were much higher than concentration of receiving water body (Junju chun).

3. Estimation of Discharge Unit of Non-point Pollution

The discharge unit of non-point pollution was defined as the amount of pollutants discharged from unit area per unit time.

Experimental method and actual concentration detection method are commonly used for estimating discharge unit of non-point pollutant loads.

In this study, discharge unit of non-point pollutant loads was calculated by mean concentration of rainfall event for each watershed and site specific mean concentration multiply surface runoff coefficient of each watershed and annual mean precipitation (International Erosion Control Association, 2002).

$$\text{Unit Load(kg/ha/yr)} = P \times Pj \times C \times SMC$$

where, P = yearly mean rafall

Pj = Calibration coeffient for no runoff (0.9)

C = runoff coefficient (runoff/rainfall)

$= 0.858i^3 + 0.78i^2 + 0.774i + 0.04$

(i = impervious rate)

Calculated discharge unit of combined sewage system was summarized in Table 10, showing high concentration during rainfall.

This implies that controlling runoff of the combined sewage system is needed to improve water quality of studied stream. The possible solutions to manage the overflow runoff are to treat the initial runoff using additional treatment process or to increase the capacity of sewage treatment system. Especially if Dam or reservoirs are located in downstream it becomes more difficult to improve water quality without treating initial runoff.

Conclusion

In this study, SWMM model was used to analyze the characteristic of runoff in urban area. Study area was a part of Junju stream watershed and measured flow rate and water quality data for two rainfall events were used for the study. After calibration and verification of model using measured data, Model simulation was carried out in various conditions.

Summarized results of this study are as follows.

1. SS increased in manner of rainfall intensity and closely connected to the precipitation. Especially SS concentration was influenced by not only discharged pollutants by runoff but also re-suspension of settled SS in conduit by increased water velocity.

2. The correlation coefficients for BOD, COD, SS, T-N and T-P ranged each 0.54-0.91, 0.24-0.88, 0.38-0.84, 0.72-0.83 and 0.12-0.66. It is indicates that the SWMM properly describes the runoff characteristics.

3. Initial rainfall(10~30 mm) mostly caused 80-90% of pollutant loads, inferring the necessity of treating initial rainfall to effectively control non-point pollutants loads.

4. The discharge unit of combined sewage system was 306 kg/ha/yr for BOD, 410 for COD and 789 for SS. This value is much higher than value of the general separated Sewer system. Therefore, The treatment of combined sewage overflow (CSO) is needed.

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