환경영향평가 제8권 제4호 : 1~12

A Water Quality Management System at Mokhyun Stream Watershed Using GIS and RS+

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GIS와 RS를 이용한 목현천 수질관리 정보체계+

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Abstract

The purpose of this study is to develop a Water Quality Management System(WQMS), which calculates pollutant discharge and forecasts water quality with a water pollution model. Operational water quality management requires not only controlling pollutants but acquiring and managing exact information.

A GIS software, ArcView 3.1 was used to enter or edit geographic data and attribute data, and Avenue Script was used to customize the user interface. PCI, a remote sensing software, was used to derive land cover classification from 20 m resolution SPOT data by image processing.

WQMS has two subsystems, database subsystem and modelling subsystem. The database subsystem consisted of watershed data from digital maps, remote sensing data, government reports, census data and so on. The modelling subsystem consisted of NSPLM(NonStorm Pollutant Load Model) and SPLM(Storm Pollutant Load Model). It calculates the amount of pollutant and predicts water quality. These two subsystems were connected through a graphic display module.

This system has been calibrated for and applied to Mokhyun Stream watershed.

Keyword : Water Quality Management System, Geographic Information Systems(GIS), Remote Sensing(RS)

+This research was supported by Faculty Research Fund, Sungkyunkwan University, 1998

요 약 문

본 연구의 목적은 지리정보시스템과 원격탐사를 이용하여 체계적이고 효율적인 수질관리 자료기반을 구축하고, 유역의 오염부하를 산정하여 장래의 수질을 예측할 수 있는 수질관리시스템을 구축하는데 있다. 수질관리를 위해서는 오염물질의 최적처리 등의 기술적 측면뿐만 아니라 수질환경에 관한 정확한 정보의 취득과 관리가 필요하다.

본 연구에서는 지형 및 속성정보의 입력 및 편집을 위해 ArcView 3.1을 사용하였으며, Avenue Script를 이용하여 사용자환경을 갖추도록 하였다. 또한, 토지피복분류를 위하여 20m 해상도의 SPOT XS영상을 대상으로 PCI 소프트웨어를 이용하여 분석하였다.

수질관리시스템은 데이터베이스 보조시스템과 Modeling 보조시스템으로 구성된다. 데이터베이스 보조시스템은 수치지형도에서 추출한 수치표고모델에서 분석한 유역분할도, 위성영상자료, 정부보고서, 통계자료들로 구성되며, Modeling 보조시스템은 강우 시와 비강우 시의 유역의 오염부하량을 산정하고 수질예측을 하는 SPLM(Storm Pollutant Loading Model)과 NSPLM(Non-Storm Polutant Loading Model)으로 구성된다. 각각의 보조시스템은 그래픽 출력 부분과 결합하여 분석결과 및 유역현황을 표시하도록 설계되었다.

개발된 수질관리 시스템은 경기도 광주군 광주읍에 위치한 목현천 유역을 대상으로 적용되고 수정되었다.

1. Introduction

Industrialization needs additional land for development, so agricultural fields, hilly terrain, riverside area have been changed for that purpose. This exploitation causes water resource shortage and water quality deterioration. It is therefore required for municipalities to manage water resources based on land use management.

Water quality in rivers is determined by the amount of water, pollutant input, and land use patterns. Amount of pollutants is determined by pollutants of basin, physical · chemical · biological processes during the inflow. For effective control of water quality, information about each pollutant source and influence of pollutants to water quality is required. Especially amount of non-point source pollutants is influenced by land use, topography, soil and so on.

For effective water quality management, technical methods, legal · executive restriction and exact information of water contamination are needed. It also requires various informa-tion such as physical environment, topography, water quality measurement, soil, meteorology, and so on. These data are huge in size and managed by several agencies independently. So, information system is required. GIS(Geographical Information Systems) and RS(Remote Sensing) are effective tools to enter, edit, store, retrieve, analyze and display information in establishing WQMS (Water Quality Management System) for Environmental Impact Assessment(EIA) according to the change of land use.

The purpose of this study is to establish the WQMS using GIS and RS. WQMS consists of database for stream management and modeling for prediction of further water quality.

II. Study Method

1. Study Procedure

Fig. 1 shows the study procedure. After selecting a study site, data were collected and measured in the field, then the system was established. This system was applied and calibrated in the study site.

2. Study Site

The study site is Mokhyun Stream watershed. Mokhyun Stream is located at Kwangju-eup, Kyunggi-do which is the lower part of Kyung-an stream. This stream flows into the Paldang Reservoir. The upper part of Mokhyun watershed is hilly terrain and has a golf course, while the lower part is urban area. Total area of the site is 20.9 km^2. Figure 2 shows the study site.

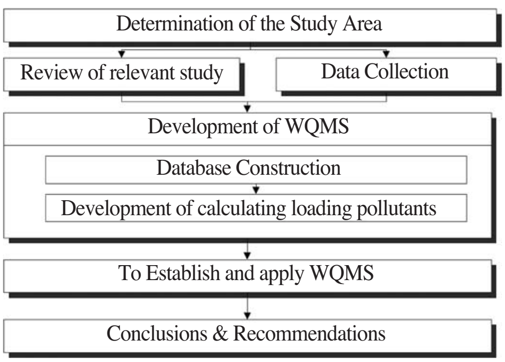

Fig. 1. Procedure Used in the Study

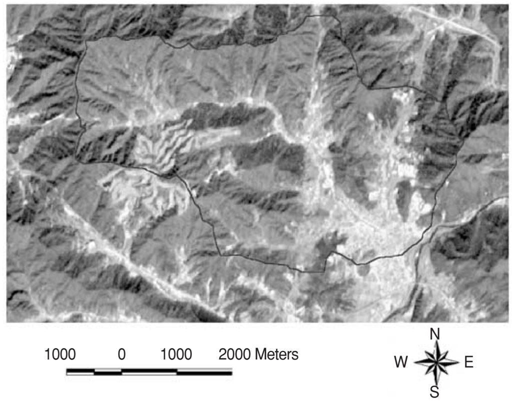

Fig. 2. The Study Site

3. Development of WQMS

WQMS consists of two subsystems which are database and model. Its data consists of geographic data and attribute data. Geographic data are digital topographic map, soil map, vegetation map, RS data and so on. These data are inputted into the database subsystem through the GIS/DB interface and image processing. Other attribute data are also inputted into the database.

Measured data are used to model subsystem via DB-Model interface. Model subsystem calculates the amount of pollutant according to weather conditions and predicts water quality.

Each subsystem is connected with Graphic Display Module(GDM) in order to show results. Fig. 3 shows the structure of WQMS.

1) Data Acquisition and Database Construction

In order to establish database, literature survey was performed. Field-surveying, and visiting many relevant agencies were also carried out, and finally water quality was analyzed. Table 1 shows thematic maps and Table 2 shows pollutant sources. Water quality

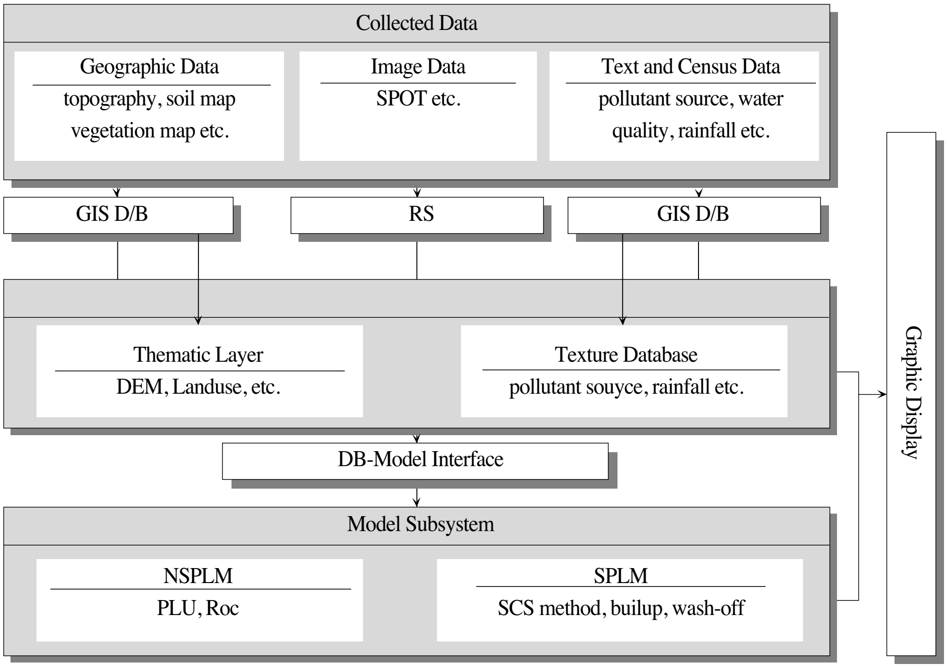

Fig. 3. Schematic Structure of WQMS

data were collected from the Ministry of Environment and Kwangju-kun municipality office.

Water quality data used were BOD_5 (5 day Biochemical Oxygen Demand), T-N (Total-Nitrogen), T-P (Total-Phosphate).

2) Development of Modeling Subsystem

The Model subsystem consists of NSPLM (Non-Storm Pollutant Loading Model) and SPLM(Storm Pollutant Loading Model) according to rainfall condition.[2] Constant discharge of pollutants occurs from point sources while weather-dependent discharge of pollutants occurs from non-point sources. So, water sampling was done on storm event during this study.

Table 1. Thematic Layer

Thematic Map	Scale	Source Data	Attribute Value
Stream Network	1 : 5,000	Digital topographic map	Stream name
Administrative boundary	1 : 85,000	Kwangju-kun administrative map	Administrative name
Watershed	1 : 5,000	DEM from digital topographic map	Watershed
Hydro-soil map	1 : 25,000	Soil map	Hydrologic soil group
Landuse	20 × 20 m	SPOT XS	Landuse
SCS CN map	20 × 20 m	Landuse, Soil map	CN number
DEM	20 × 20 m	Digital topographic map	Elevation

Table 2. Pollutant Source Data

Division	Details	Year	Source
Human being	Population of sewage treatment or un-treatment	1998	Kwangju-kun municipality
Domestic Animals	Cow and Pig	1998	Kwangju-kun municipality
Industrial discharge	Factory and Sewage disposal plant	1998	Kwangju-kun municipality
Landuse	Forest, residential, cultivated field and golf course	1996	SPOT XS

a) NSPLM(Non-Storm Pollutant Loading Model)

To analyze water quality in dry weather pollutant loading unit and rate of concentration were used. Pollutant load unit represents pollutants discharged by a unit of pollutant source during one day or one year.[16] Part of pollutants are discharged into watershed, treated and/or un-treated.

Amount of discharged pollutants occurred were unable to be measured actually. It is therefore universally accepted that amount of pollutant are calculated by pollutant loading unit.[9]

Generally, derived pollutant decreased during the runoff. It can be explained with rate of concentration. It is the amount of arrival pollutants at the base point of disposal amount in watershed. Total amount of pollutants from actual measurements to total amount of pollutants from pollutant load factor is the rate of concentration. It can be used in predicting and calculating water quality.

$$\text{Rate of Concentration} = \frac{\text{Amount of arrival pollutants at base point (kg/day)}}{\text{Amount of Discharged pollutants in watershed (kg/day)}} = \frac{\text{Water quality (Kg/m}^3) \times \text{Water volume(m}^3\text{/day)}}{\text{Amount of Discharged pollutants in watershed (kg/day)}} \quad \text{(Eq.1)}$$

b) SPLM(Storm Pollutant Loading Model)

SPLM consists of hydrological processes, calculating pollutants and determining runoff direction in each cell.

Water quality models are widely used in EIA. However, the study of basin property such as geo-hydrology, topography, soil, etc., and model coefficients are not sufficient. Because existing models were developed in foreign countries, they are not calibrated to domestic conditions and determination of coefficients is difficult.

Hydrological process

Rainfall is affected by hydrological factors such as topography, soil, vegetation and so on. Before landing on the surface, rainfall is intercepted by plants and animals and evapotranspirated. The portion of surface detention rainfall are infiltrated and others flow by surface runoff. Infiltrated water contributes to sub-surface runoff and ground runoff. Sum of surface runoff and sub-surface runoff is the direct runoff, and ground runoff is called base runoff.

Because runoff time is short and slope is steep, it was assumed that sub-surface runoff and evapotranspiration did not occur in this study.

Volumes of surface runoff was calculated according to the SCS Method. In this model, the relation of total rainfall and runoff volume is explained with equation 2.

Initial abstraction can be calculated by an empirical equation based on the field work.[14)]

$$Dr = \frac{(P - Ia)^2}{(P - Ia) + S} \quad \text{(Eq.2)}$$

where, Dr = Depth of runoff(mm)

P = Depth of 24 - h rainfall(mm)

Ia = Initial abstraction, the losses of rainfall before runoff begins(mm)

S = potential maximum retention after runoff begins(mm)

Therefore.

where S (potential maximum retention after

$$Ia = 0.2\,S \quad \text{(Eq.3)}$$

runoff begins) represents the hydrologic land-

$$Dr = \frac{(P - 0.2S)^2}{(P + 0.8S}$$

cover complexes such as landuse, soil condition and so on.

CN is the runoff curve number. It was determined by soil type and landuse.

$$S = \frac{25{,}400}{CN} - 254 \quad \text{(Eq.4)}$$

The soil types between the two major determinants were classified into four groups according to the infiltration capacity.

The other determinant has an effect on interception and infiltration. The runoff curve numbers are experimentally determined with these two factors. Standards for CN determination are shown in Table 4.

SCS AMC(Antecedent Moisture Condition) shows the soil moisture condition. Usually, it is classified into growing season and dormant season by P5(antecedent runoff amount 5 days).

Table 5 is applied in AMCII. CNs of growing(AMCIII) and dominant(AMCI) seasons are calculated with equations 5 and 6.

Calculating of pollutant amount

$$AMCI = \frac{4.2 \times AMCII}{10 - 0.058 \times AMCII} \quad \text{(Eq.5)}$$

$$AMCIII = \frac{23 \times AMCII}{10 + 0.13 \times AMCII} \quad \text{(Eq.6)}$$

To calculate pollutant loads, the concepts of buildup and washoff were used. It is also used in SWMM, STORM, HSPF and so on. Buildup has general meaning of accumulation, wind erosion etc,. That is, these processes bring a buildup of pollutants, and buildup pollutants

Table 3. Hydrologic soil group

Soil Group	Soil type	Character
A	sand, loamy sand, sand loam	low runoff potential high infiltration rates
B	silt loam, loam	moderate infiltration rates
C	sandy clay loam	low infiltration rates
D	clay loam, silty clay loam, sandy clay, clay	high runoff potential very low infiltration rates

source : Ferguson, Bruce. K., 1990, "On site stormwater management", application for landscape and engineering 2nd ed., New York, pp.19-54

Table 4. Runoff Curve Number by Soil-Landuse complexes (In case AMCII, Ia = 0.2S)

Land-use description		Hydrologic soil group			
		A	B	C	D
Cultivated land:					
Without conservation treatment		72	81	88	91
With conservation treatment		62	71	78	81
Pasture or range land:					
Poor condition		68	79	86	89
Good condition		39	61	74	80
Meadow: Good condition		30	58	71	78
Wood or forest land:					
Thin stand, poor cover, no mulch		45	66	77	83
Good cover		25	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc:					
Good condition: grass cover on 75% or more of the area		39	61	74	80
Fair condition: grass cover on 50 to 75% of the area		49	69	79	84
Commercial and business area (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential:					
Average lot size	Average % impervious				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.		98	98	98	98
Streets and roads:					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Paddy#		78	78	78	78
Forest(very sparse)#		56	75	86	91
Water surface#		100	100	100	100

Additional item for this study. * Adapted from Chow et al., 1964.

are washed-off during storm event.

Power-Linear equation was used for this study. It is a exponential asymptote function, which is used in SWMM model.

$$Ma = ACCU \times DT^{a} \quad \text{(Eq.7)}$$

where Ma : Amount of buildup at time t (kg)

ACCU : Ratio of buildup(kg/day)

DT : Dry days (day)

a : Numerical index

ACCU and Ke are dependent on urbaniza-

Table 5. Classification of Antecedent Moisture Condition(AMC)

AMC group	Total 5-day antecedent rainfall(mm)		AMC
	Dormant season	Growing season	
I	Less than 12.7	Less than 35.6	Lowest runoff potential. The watershed soils are dry enough for satisfactory plowing and cultivation to take place.
II	12.7 to 27.9	35.6 to 53.3	The average condition.
III	Over 27.9	Over 53.3	Highest runoff potential. The wantershed is practically saturated from antecedent rains

Soure: USDA, National Engivneer Handbook, 1972

$$Me_t = Ma \times (1 - e^{Ke \cdot dr(t) \cdot t}) \qquad \text{(Eq.8)}$$

where Met : Amount of washoff at time t (kg)

Ke : Washoff coefficient

dr(t) : Runoff depth at time t(mm)

tion, climate and so on. Ke(washoff coefficient) is suggested as 0.18^{-1}, this value needs to be calibrated in each basin.

III. Results and Discussion

1. Database Construction

The study area was delineated with DEM from digital topographic map. This was done using ArcView 3.1 Spatial Analyst(See Figure 2). To calculate pollutant amount, pollutant source data were collected and entered into database. Point sources were grouped into population, domestic animal, and industrial sewage.

For the non-point sources, landuse map was obtained by landcover classification with 20m resolution SPOT XS image. land cover classification can be done by either digital classification or visual interpretation by human being.

In this study, visual interpretation method by human being was used, because it is helpful for high density landuse areas such as the study site in Korea(Lee et al., 1999). Remote sensing data used in this study were scanned on July 1, 1997(See Figure 2). And, other thematic maps were prepared by spatial analysis such as map query, overlay, map calculator and so on. Field measurement of water quality and quantity were done three times during storm events (July 8, 1999, July 22, 1999, October 28, 1999) The water velocity was measured with tachometer.

2. Calculation of Pollutant Amount

a) NSPLM

Table 8. shows the total amount of point source and rate of arrival pollutant. Water quality and quantity data used in this study were measured by Kwangju-kun municipality from September, 1997 to December, 1997 and natural source pollutants were are not included.

Table 6. Total Amount of Pollutant and RoC(Rate of Concentration)

Section		BOD_5	T-N	T-P
Total amount of pollutant with PLU(kg/day)	Point source	2266.70	567.00	63.88
	Non-Point source	36.26	25.84	0.44
Total amount of pollutant with actual measurement(kg/day)		13.12	25.72	1.61
Rate of Concentration(%)		0.58	4.54	2.52

Figure 5 to 7 show the producing pollutant amount by pollutant sources.

b) SPLM

To determine water quality, runoff volume and pollutant load during storm events were needed. SCS CN was determined according to hydro-soil group and landuse(See Figures 8 and 9).

Average value of CN on watershed was 45 under the AMCII condition. It was used to calculate the runoff volume on SPLM. Only rainfall on July 22 had the runoff volume.

Runoff volume by modeling was underestimated. The difference between these results was too large to explain the hydrology of this study site. Thus, SPLM model was not applied to this study.

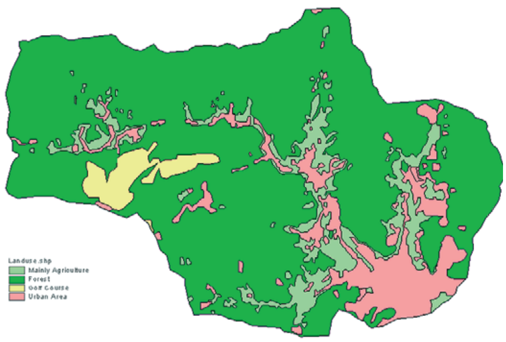

Fig. 4. Landuse Map for Pollutant Calculating

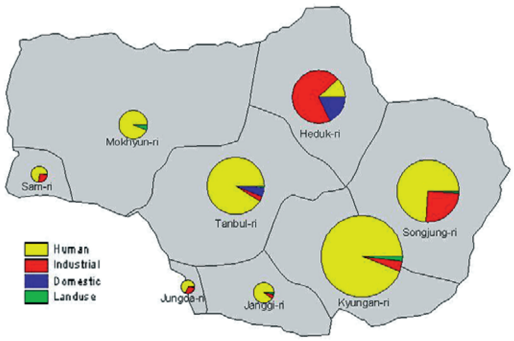

Fig. 5. BOD Loading Amount by pollutant source

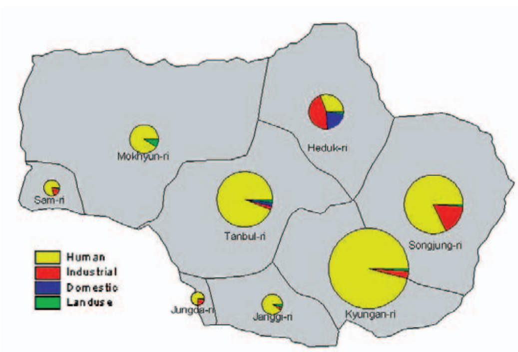

Fig. 6. T-N Loading Amount by pollutant source

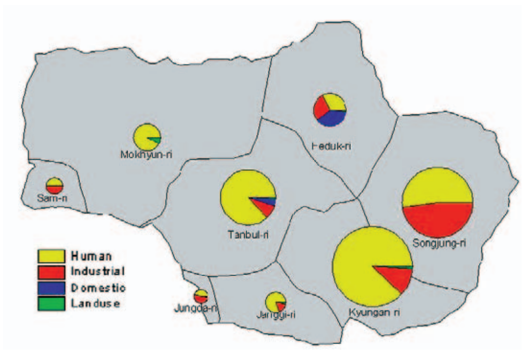

Fig. 7. T-P Loading Amount by pollutant source

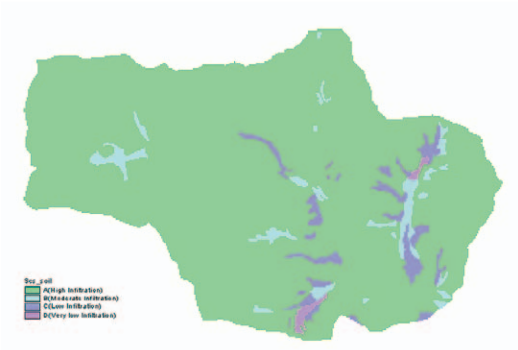

Fig. 8. Hydrological Soil Group

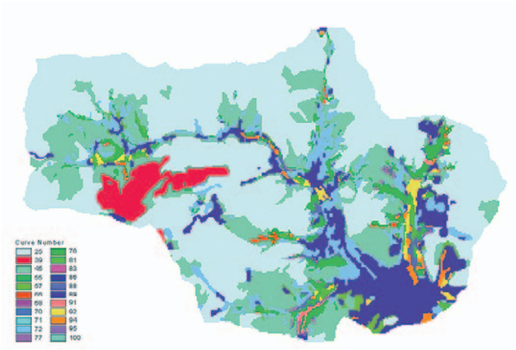

Fig. 9. SCS Curve Number Map

3. Application of WQMS

WQMS consists of two subsystems, and these are linked through graphic display module in order to show the result of analysis and information searching.

Database subsystem was constructed with topographic map, stream network, SCS curve number map, landuse and so on. In addition, attribute data such as pollutant source, PLU, rainfall etc, were also put into the database.

Modeling subsystem was established using ArcView avenue script. It calculates the pollutant amount and predicts water quality based on the database.

For the user interface, the system was customized to show results, present condition of the watershed and to enter the modeling factor. Additionally, it performs the modeling. Figures 10 and 11 show screenshots of the interface system.

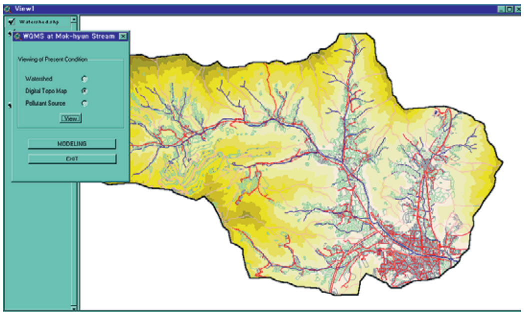

Fig. 10. Displaying study site topography

IV. Conclusions

The pollutant load in the watershed was calculated using WQMS developed in this study. It was developed using GIS, RS, database and water quality model. It managed database and calculated the amount of pollutants from each pollutant source.

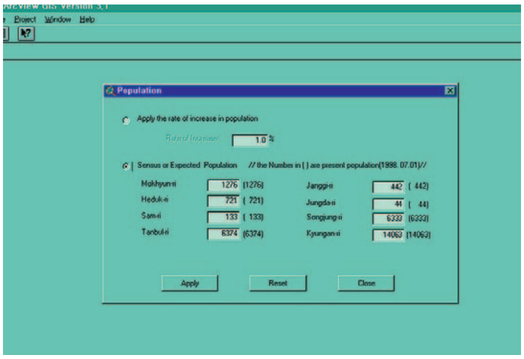

Fig. 11. The Modeling(NSPLM) : Enter and Edit Pollutant Source

Table 7. Runoff Volume in SPLM (Suwon) and Modeling Results

Date	19990722					
Time	14:00	15:00	16:00	17:00	18:00	19:00
Accumulated Rainfall(mm)	56.3	56.3	58.5	72.5	81.5	81.5
Depth of Runoff(mm)	0	0	0	0.34	1.14	1.21
Depth of Runoff increase by time(mm)	0	0	0	0.34	0.81	0
Volume(m^3/sec)	0.59	0.59	0.59	0.68	0.87	0.87
Amount of pollutant(BOD g/sec)	3.26	3.26	3.26	3.57	3.68	3.68
Measured volume(m^3/sec)	0.59	0.61	0.57	0.57	2.39	2.34
Measured pollutant(BOD g/sec)	3.26	2.45	2.64	2.24	23.92	27.64

1. In order to calculate the pollutant loading amount of point source pollutants during non-storm event, NSPLM was developed. And, SPLM was built up by considering surface runoff in rainy day and hydrologic condition.
2. To create the landuse map, landcover classification was done with 20 m resolution SPOT XS image. Visual interpretation on high density landuse like the study site are helpful. It saves time and efforts. Familiarity of ground truth is useful in enhancing the accuracy of landcover classification. But, it has limitations in applying to the wide area.
3. Landuse map was generated via image processing. DEM, and stream network were also generated from the digital topographic map. Using these data, many thematic maps concerning water quality management were generated such as SCS curve number map.
4. Pollutant discharge amount was estimated with database construction and pollutant loading unit. Pollutant discharge results of NSPLM show that BOD_5 is 2266.70kg/day, T-N is 567.00kg/day, T-P is 63.88 kg/day. The measured pollutant discharge were 13.12 kg/day for BOD_5, 25.72 kg/day for T-N, 1.61 kg/day for T-P. Therefore, rates of concentration are 0.58%, 4.54%, and 2.52%, respectively. Amounts of producing pollutant discharge of non-point sources are 36.26 for BOD_5, 25.84 for T-N, 0.44 for T-P. It is built-up during sunny days and is washed-off during storm events.
5. To calibrate the adaption of SPLM, pollutant amounts in the end of Mokhyun Stream watershed were measured. And these data were used to build the SPLM module. Actual measurements and the results of SPLM modeling were considerably different. It might be due to the lack of rainfall data for the study site because there is no weather station. Instead, rainfall data of Suwon, Seoul, Yichun and Yangpeang were used in this study. The model adapted in this study might not work well in Korean situation. This is the part which requires further study.

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