System Development for the Estimation of Pollutant Loads on Reservoir

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Abstract: An integrated system of GIS and water quality model was suggested including the pollutant loads from the watershed. The developed system consists of two parts. First part is the information on landuse and several surface factors concerning the overland flow processes of water and pollutants. Second part is the modeling modules which include storm event pollutant load model(SEPLM), non-storm event pollutant load model(NSPLM), and river water quality simulation model(RWQSM). Models can calculate the pollutant load from the study area. The databases and models are linked through the interface modules resided in the overall system, which incorporate the graphical display modules and the operating scheme for the optimal use of the system. The developed system was applied to the Chungju multi-purpose reservoir to estimate the pollutant load during the four selected rainfall events between 1991 and 1993, based upon monthly basis and seasonal basis in drought flow, low flow, normal flow and wet flow.

1. Introduction

For the optimal management of water quality in the large scale reservoir, the pollutant loading from the watershed into the reservoir should be estimated so that the water quality of the reservoir could be predicted and controlled (Shim, et al., 1992). In this study, simply the unit loads of pollutant was accounted for the estimation of pollutant loadings from the point sources, while a large volume of descriptive information on the geo-hydrological and hydraulic characteristics of the watershed was collected and analysed using GIS for the estimation of the non-point source pollutant loadings (MOE and MOST, 1993; Gililand and Baxter-Potter, 1987; Hession and Shanholtz, 1988).

Especially the problems of non-point source pollution can be hardly solved without overall considerations on social and technical factors as well as the geo-hydrological factors of the watershed (Wischmeier and Smith, 1978; MOAF and RDC, 1993). Locations and amounts of potential soil losses and pollutant loads from the watershed should be manifested and accordingly some proper counter measures must be proposed (Kim, 1995).

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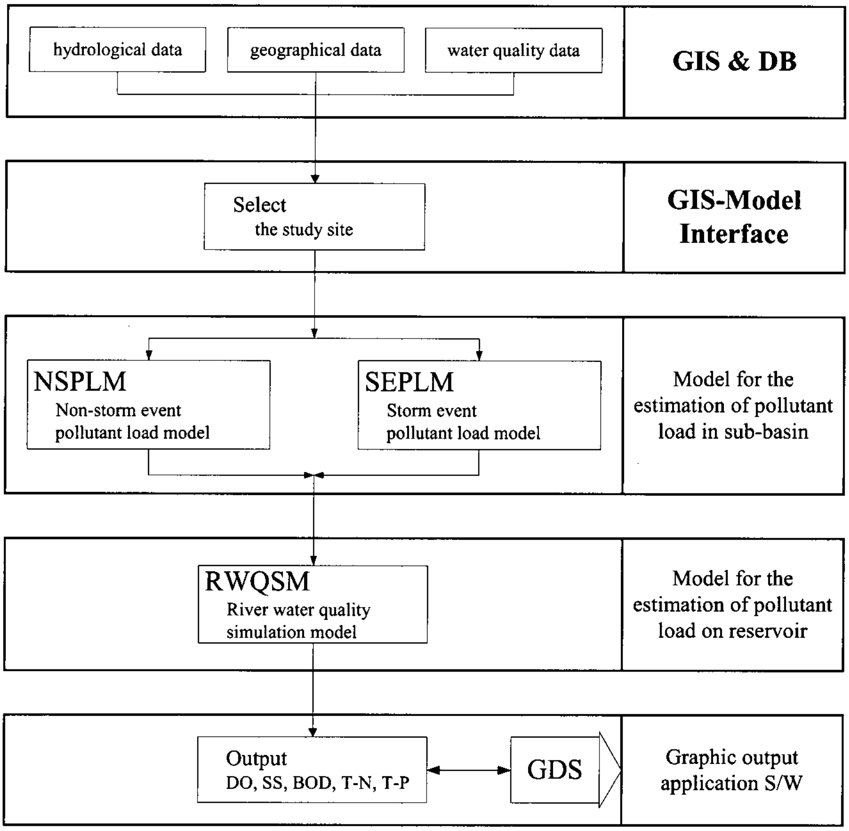

Fig. 1. Concept of Estimation System of Pollutant Loads on Reservoir

The purpose of this study is to develop an estimation system of the pollutant loads on reservoir by integrating water quality models, GIS database and user interface modules as illustrated in Fig. 1.

2. Models

Model subsystem consists of three computational models. First one is a generic model to estimate the T-N, T-P, and BOD loads during non-rainfall periods by accounting for the amount of pollution sources and unit loads of pollutant, which includes the regression equations for the prediction of pollutant loads according to the population, ratio of agricultural lands, and runoff discharges. Second is developed to estimate the T-N, T-P, SS and COD loads during rain from the results of rainfall-runoff computation. Above two models could be applied to estimate the pollutant loads from each sub-basin. The third model is to simulate the water qualities at the river from the boundary conditions that are the results of pollutant loads from the sub-basins in the watershed for the estimation of pollutant loads at the entrance of the reservoir.

2.1 NSPLM

Long term pollutant loads such as during a month or a season could be regarded as steady state. However, its not easy to simulate the process of pollutant loading in a mathematical way.

The Non-Storm event Pollutant Load Model (NSPLM) was developed based upon the concept of pollutant mass and pollutant discharge rate. It seems that the above way can better represent the environmental characteristics of the watershed.

There has been a lot of studies on the pollutant mass and pollutant discharge rate. The pollutant mass has been estimated specifically for the agricultural land, industries, municipal wastes, and forest. And the pollutant discharge rate could be estimated from the water quality sampling at the outlet of the watershed.

In NSPLM, pollutant loading from the water is estimated as the product of pollutant discharge rate and the total amount of pollutant from the watershed which is assumed as the product of total pollutant amount and the pollutant mass.

2.2 SEPLM

In this study, a physically based, distributed model for the estimation of pollutant loading from a watershed is considered. The Storm Event Pollutant Load Model (SEPLM) was developed to estimate the total runoff volume, sediment discharge, and T-N, T-P, COD loads following the heavy rainfall storm.

The SEPLM is a parameter model which uses the physical characteristic data of the watersheds and a distributed model which computes the hydrologic and pollutant loading processes for each grid cell and integrate the total volumes of above parameters according to the flow paths in the watershed.

The model algorithm follows the AGNPS model which was developed based upon the SCS method and requires such groups of information as rainfall and watershed parameters as input data.

The rainfall parameters include the total rainfall amount, intensity and duration, and the watershed parameters include a series of data that describe the distributed cells of the watershed.

The watershed parameters are the areas, slopes, flow directions, soil characteristics, roughness, USLEs K, P, and C factors, land practices of the cells, and so on. Most parameters can be determined through the interface module between the database and models.

2.3 RWQSM

Pollutants discharged from the watershed vary in their concentration flowing through the river. As mentioned above, this study focuses on the pollutant loads on reservoir which is expressed as the water quality at the entrance of the watershed.

QUAL2E model developed by US EPA is the most famous and used at many countries that can simulate the river water quality.

River Water Quality Simulation Model (RWQSM) was developed based on the algorithms and structure of QUAL2E model. RWQSM uses the pollutants discharged from each sub-basin which is estimated by SEPLM or NSPLM as the boundary condition and simulate the water quality at the entrance of the reservoir.

3. Application

3.1 Study Area

For the verification of the developed system, a case study of the system was carried out. Chungju multi-purpose reservoir was chosen for the case study.

Chungju multi-purpose reservoir is located at the upstream of the Han-river, the watershed area of which is the largest in Korea. The watershed area of the Chungju multi-purpose reservoir is about 6,648km^2 and the main purpose of the reservoir is to supply the water to the capital city of Seoul Metropolitan, Korea.

In order to simulate the rainfall-runoff and pollutant loads from the watershed, the watershed was devided into 14 sub-basins and hourly rainfall records of Danyang, Yeongwoll, Sujoo and Paikwoon stations and water level records of Yeongwoll and Yeongchun were collected and used as input for the models.

Population and its increase rate, number of cattles and other pollution sources of each sub-basin were calculated according to the area.

3.2 Geographic Information

3.2.1 Basic Map

Julien, et al. (1995) showed the advantages of the raster based GIS in the practical use with computational models. In this study, all the geoinformation were converted into the raster format.

Basic map for all kinds of GIS works are mostly the digital elevation map which expresses the ground elevation of each square cell or point in the covering area. The digital elevation map of the target area is shown in Fig. 2 and other basic maps such as of stream network, sub-basins, soil and landuse are respectively presented in Fig. 3, 4, 5 and 6.

The landuse map was generated through the image processing and classification of the Landsat TM setellite image, while the soil map was generated by digitizing the 1:50,000 scale soil maps developed in 1971 by the Rural Development Administration.

Transverse Mercator coordinate system is adopted for the maps and size of each grid cell is 500m×500m.

3.2.2 Thematic Maps

Thematic maps for input to the models were generated as follows by using digital elevation map, stream network map, soil map and landuse map.

a. Land slopes and slope aspects that govern the direction of overland flow

b. USLE K-factor,

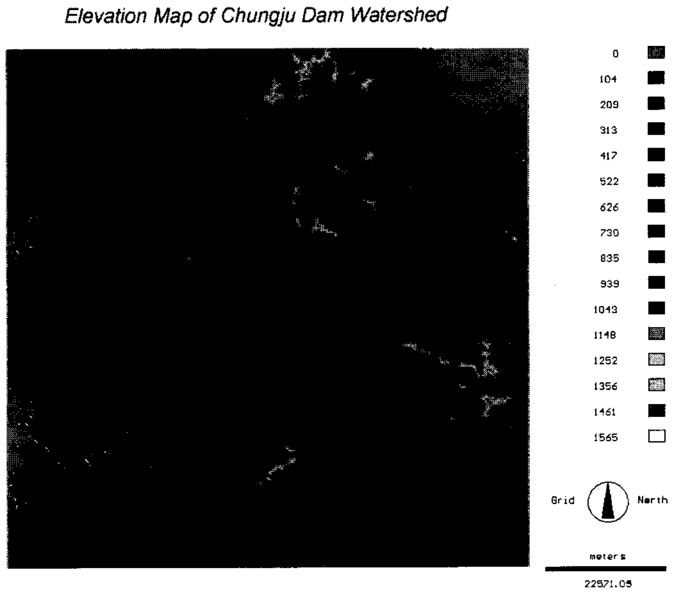

Fig. 2. Digital Elevation Map of Chungju Dam Watershed

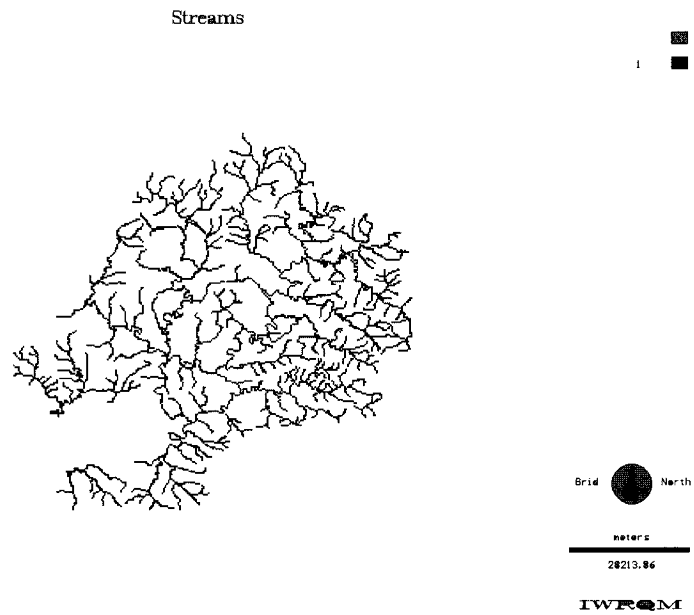

Fig. 3. Stream Network Map of Chunghu Dam Watershed

C-factor, and P-factor that govern the sediment and pollutant yields

c. Hydrologic soil group and soil characteristics that govern the rainfall-runoff processes

d. Pollutant amount such as fertilizer level

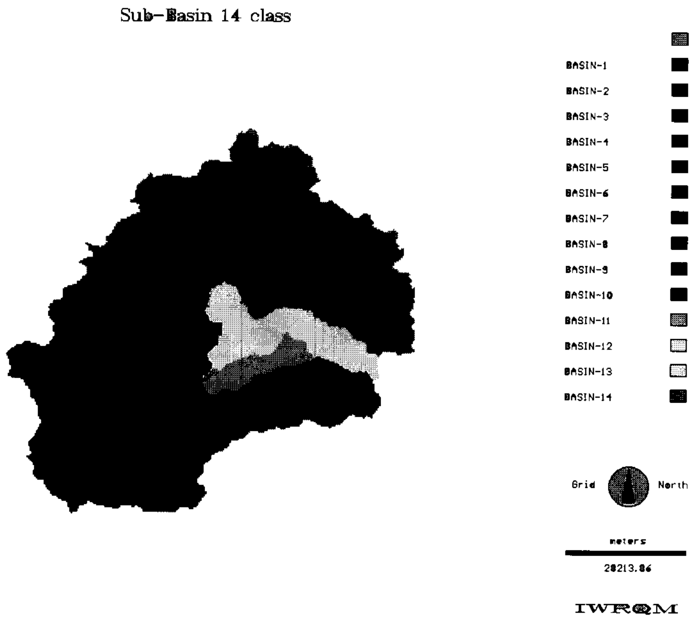

Fig. 4. Sub-basin Map of Chungju Dam Watershed

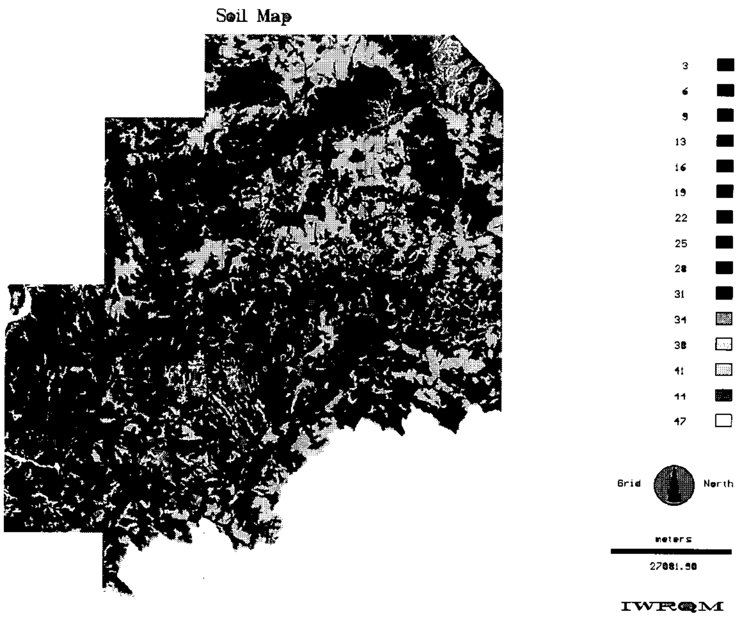

Fig. 5. Soil Map of Chungju Dam Watershed

3.3 Database

Detection of pollution sources in the watershed can not be performed solely by the satellite image processing. Moreover, it is very difficult to detect the non-point sources exactly with the

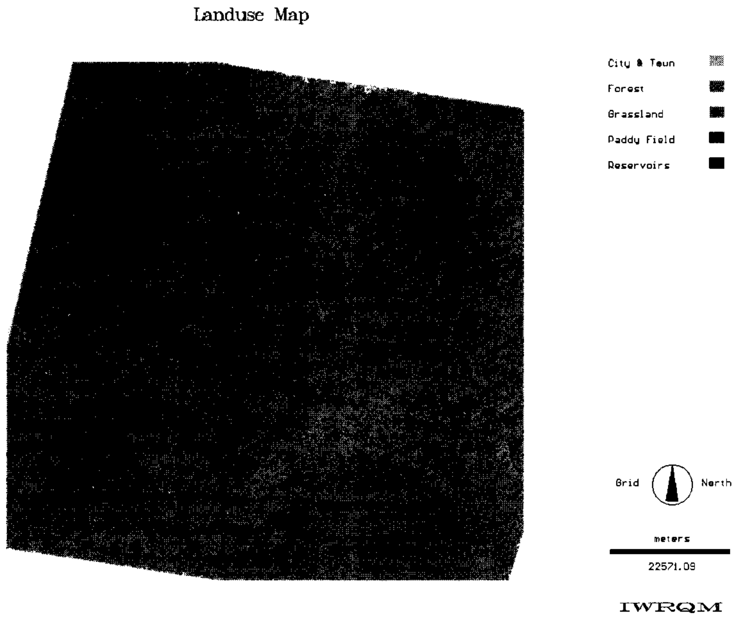

Fig. 6. Landuse Map of Chungju Dam Watershed

satellite image. Therefore, some other additional information are required related to the pollutant loads such as the population, number of cattle and industries, ratio of agricultural land, and so on.

For storing and analysis of the vast data changing dynamically, QuattroPro spreadsheet software was employed. The text database consists of Hydrologic DB, Pollutant DB, Water Quality DB and Soil DB.

3.4 System Construction

3.4.1 Interface between GIS-models

Six interface modules were developed to generate the input for the models as described in Table 1. These modules also reformat the outputs from NSPLM and SEPLM into the proper input to the RWQSM and graphically show the calculated total load of each pollutant.

3.4.2 System Integration

Models, database and interface modules were integrated to be operated easily and conceivably by users. The integrated system, running on a personal computer, generates the geo-spatial input data for the model using IDRISI GIS package, calls the model and interface module programs following the user's requests through menu system. Fig. 7 illustrates the structure of the system schematically and the screen menu of the system is as shown in Fig. 8.

Using this integrated system, users can quickly and easily calculate the pollutant loads from the watershed into the reservoir with simple collection of basic information on the target watershed and calibration of model parameters such as for rainfall-runoff, soil loss, landuse,

Table 1. Subprogram of GIS-PLM

Sub program	Main function
DATAGEN	1. give a cell number and the matrix 2. produce a cell value include cell matrix at every parameter 3. calculate in case of parameter modify 4. make a input file, provide the parameter as a form
TOPO	1. read cell elevation and calculate the difference of elevation between cell 2. produce the slope map and the aspect map
STRMCONV	1. calculate a slope and aspect to read cell elevation 2. produce the stream slope map and stream aspect map
KFACONV	1. calculate a K-factor value from cell of soil map 2. produce the K-factor map
HYDSOIL	1. decide to soil type to read soil map 2. produce the hydrologic soil group map
READSOIL	1. refer to characteristics of soil 2. provide reference result to call program

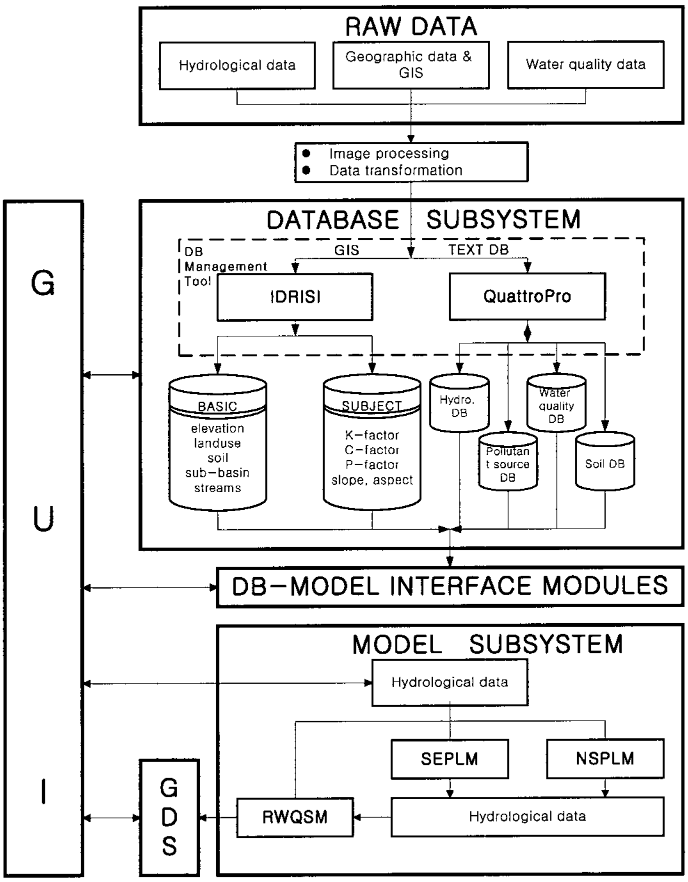

Fig. 7. Schematic Representation of the System Structure

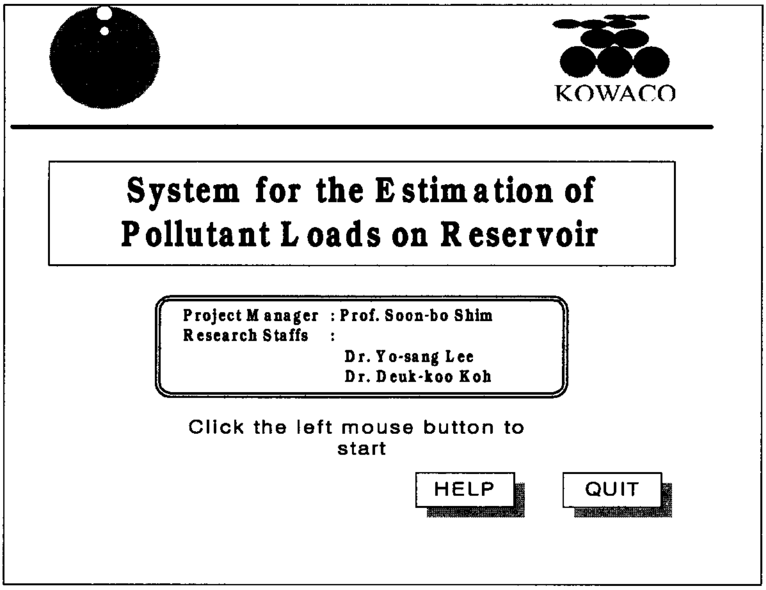

Fig. 8. Features of Main Menu Screen of the Integrated System

and practice and water quality through repeated runs.

4. Results and Discussion

4.1 NSPLM & RWQSM

For the non-storm periods, the pollutant loads from the Chungju dam watershed in 1993 was estimated by NSPLM. Thereafter, the results of NSPLM was input to the RWQSM for the simulation of water quality, DO, SS, BOD, T-N and T-P at upstream of Chungju reservoir. The graphs of simulated water quality are presented in Fig. 9 and Fig. 10.

DO was simulated to decrease at the downstream, while BOD, SS, T-N and T-P increased. Rapid changes of the concentration of pollution at some points prove that tributary inflows

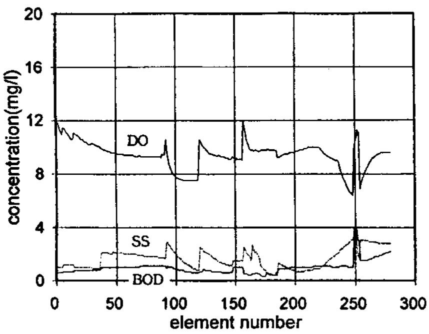

Fig. 9. Water Quality of South-Han River (185Day Base Flow : DO, SS, BOD)

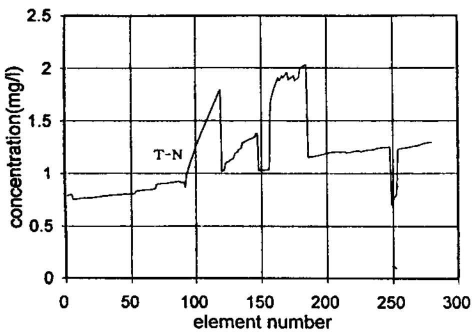

Fig. 10. Water Quality of South-Han River (185Day Base Flow : T-N, T-P)

Table 2. Seasonal Pollutant Load on Chungju Reservoir

Unit : ton/day

Season \ Item	BOD	T-N	T-P	Discharge (CMS)
Drought flow	2.41(2.2)	2.89(2.636)	0.081(0.074)	12.684
Low flow	2.67(1.7)	3.32(2.117)	0.093(0.059)	18.167
Normal flow	3.23(1.3)	4.60(1.850)	0.109(0.044)	28.752
Wet flow	7.92(0.8)	11.12(1.123)	0.158(0.016)	114.596

affect the water quality at the downstream. Also, the increase DO and decreased other pollution were found in the flood season.

As shown in Table 2, BOD loading was ranged from 0.8 to 2.2mg/l, and 11.123~2.636mg/l of T-N and 0.016~0.074mg/l of T-P loading were estimated, which showed the comparably good water quality and large gap between drought and flood seasons.

Comparison results between these values and the observed at the Cheongpoong bridge shows the applicability of NSPLM and RWQSM.

4.2 Verification of SEPLM

The watershed is divided into 14 sub-basins and each basin is divided into the 500m×500m square grid cells for model applications.

Four rainfall events during 1991 to 1993 were chosen for the runoffs and pollutant loading estimation. Unfortunately, no water quality measurement data during the period was found, so the runoff volumes were the only measure for the comparison.

Runoff discharges simulated by SEPLM at Youngweol 2 and Youngchun stations were compared with the observed to show the reasonable differences in the acceptable ranges. Simulated T-N ranges from 0.84 to 1.32mg/l, and T-P 0.05~0.15mg/l.

5. Conclusions

The estimation system for Pollutant loading on reservoir was developed and a case study on the watershed of Chungju multi-purpose reservoir was carried out.

The results and findings through the study can be summarized and concluded as follows:

1. Pollutant loading models such as SEPLM and NSPLM was developed for estimating the pollutant loading from the watershed respectively during the rainfall and monthly or seasonal basis. RWQSM was developed to estimate the water quality at the entrance of the reservoir, which can be translated as the pollutant loading on the reservoir.

2. Interface modules were developed to link the database and models, models and users, and database and users. Interface modules are equipped with the graphic capability for users convenience in operating the system.

3. From the case of the developed system on the Chungju multi-purpose reservoir, Korea, it was concluded that the system could be utilized for the real field application through the continuous expansion of the database.

4. It seems that this works are relatively objective in comparison with building data set manually with printed maps and running models by hand.

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