2010 INTERNATIONAL SWAT CONFERENCE

AUGUST 4-6, 2010

MAYFIELD HOTEL
SEOUL, KOREA

Conference Proceedings

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Contents

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August 4-6 | Mayfield Hotel, Seoul, Korea

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Foreword

These conference proceedings consist of papers presented at the 2010 International SWAT Conference, which convened in Seoul, Korea. The conference provided an opportunity for the international research community to gather and share information about the latest innovations developed for the Soil and Water Assessment Tool (SWAT) model and to discuss challenges that still need to be resolved to better assess water quality trends. This year, more than 150 people attended from 11 countries.

The SWAT model was developed by researchers Jeff Arnold of the United States Department of Agriculture Research Service (USDA-ARS) in Temple, Texas and Raghavan Srinivasan of Texas AgriLife Research, Director of the Texas A&M University Spatial Sciences Laboratory. SWAT is a comprehensive computer simulation tool that can be used to model the effects of point and nonpoint source pollution from the watershed level down to individual streams and rivers. SWAT is integrated with several readily available databases and Geographic Information Systems (GIS).

Over the last decade, several government agencies, a large number of engineers and scientists in the United States and around the world have become SWAT users and have contributed substantial resources to the model. The research community is actively engaged in developing SWAT improvements for site-specific needs and linking SWAT results to other simulation models. Constant updates by the development team make SWAT a model that is constantly evolving to meet the needs of its users.

Due to the versatility of SWAT, the model has been and continues to be utilized to study a wide range of phenomena throughout the world as documented in over 670 peer-reviewed scientific publications. Over 600 scientists and engineers have been trained in the use of the system, and more than 40 universities are using the tool in academic courses. Software, databases, user interfaces and publications are all available on the SWAT Web site, listed below.

These proceedings contain papers covering a variety of topics including Large Scale Applications, Model Development, Hydrology, BMPs, Climate Change Applications, Database and GIS Application and Development, Biofuel and Plant Growth, Landscape Processes and Landscape / River Continuum, Pesticides, Bacteria, Metals and Pharmaceuticals, Sediment, Nutrients and Carbon, Urban Processes and Management, Sensitivity Calibration and Uncertainty, InStream Sediment and Pollutant Transport, Environmental Applications.

The organizers of the conference want to express thanks to the organizations and individuals who made this conference successful. Organizations that played a key role include USDA-ARS, Texas AgriLife Research, Texas A&M University, and the Korea Institute of Construction Technology (KICT). Sponsors include Doosan Construction and Engineering, Halla Engineering and Construction Corp. Hyundai Engineering and Construction Co. Ltd., Daerim, HNS Engineering, Samsung C&T, Taeyoung E&C, Posco E&C, Esri Korea, SK E&C, GS E&C.

We would also like to thank Dr. Nam-Won Kim and his colleagues in the Korea Institute of Construction Technology for their assistance and support as well as our countless volunteers, scientific committee, organizing committee and participants who spent their time and money to participate and exchange their scientific knowledge.

Conference Objective

Soil and Water Assessment

Natural watershed systems maintain a balance between precipitation, runoff, infiltration and water that either evaporates from bare soil and open water surfaces or evapotranspires from vegetated surfaces, completing the natural cycle. The understanding of this hydrologic cycle at a watershed scale and the fate and transport of nutrients, pesticides and other chemicals that affect water quality is essential for the development and implementation of appropriate watershed management policies and procedures.

In recent years, models have become indispensable for understanding natural processes occurring at the watershed scale. As these processes are further modified by human activities, the application of integrated watershed modeling has become increasingly more important in accounting for changing land-water-atmosphere interactions. The combined effects of practices such as agricultural management, water withdraws from surface and groundwater, the release of sewage into surface and sub-surface areas, urbanization, etc. can be better examined through a modeling approach.

The SWAT (Soil and Water Assessment Tool) model has become an important tool for watershed-scale studies due to its continuous time scale, distributed spatial handling of parameters and integration of multiple components such as climate, hydrology, nutrient and pesticide pollution, erosion, land cover, management practices, channel and water body processes.

The 2010 International SWAT conference in Seoul, Korea, devoted itself to discussions regarding the application of SWAT to watershed problems worldwide. The 5-day program included 2 days of hands-on SWAT program workshops at KICT including both the introductory and advanced levels. The training sessions were followed by three days of conference sessions, covering a variety of topics related to watershed modeling such as hydrology, water quality, land use management, erosion and system analytic topics in calibration, optimization and uncertainty analysis techniques.

Scientists and decision makers associated with research institutes, government agencies and centers for policy making are encouraged to take part in these international conferences in order to become familiar with the latest advances and developments in the areas of watershed-scale modeling and applications.

To learn more about SWAT, go to http://swatmodel.tamu.edu or contact Raghavan Srinivasan at r-srinivasan@tamu.edu.

Wednesday, August 4, 2010

08:30 - 09:30 a.m.	**Participant check-in and Registration** Mayfield Hotel Grand Ballroom	
09:30 - 11:50 a.m.	**Opening Ceremony** Mayfield Hotel Grand Ballroom	**Moderator**: Philip Gassman Iowa State University
09:30 - 09:35 a.m.	**Opening Announcement:**	*Dr. Nam-Won Kim* *LOC-Chair, Korea Institute of Construction Technology, Korea*
09:35 - 09:40 a.m.	**Welcome Address:**	*Dr. Yong-Joo Cho* *President, Korea Institute of Construction Technology, Korea*
09:40 - 10:10 a.m.	**Keynote Speech 1:**	Outlook of SWAT Model as a Total Solution of Water, Pollutant, & Food Problem *Dr. Jeff Arnold* *USDA-ARS, USA*
10:10 - 10:40 a.m.	**Keynote Speech 2:**	Outcomes and Impacts by the Sustainable Water Resources Research Program (2001-2011) in Korea *Dr. Sung Kim* *Director, Sustainable Water Resources Research Center, Korea*
10:40 - 11:10 a.m.	**Model Development History:**	*Dr. Jimmy Williams* *Texas AgriLife Research, USA*
11:10 - 11:40 a.m.	**Recent Development and Features of ArcSWAT:**	*Dr. Raghavan Srinivasan* *Texas A&M University, USA*
11:40 - 11:50 a.m.	**Group Photo** (Garden Hall, Mayfield Hotel)	
11:50 a.m. - 1:00 p.m.	**Lunch** (Orchid room, Mayfield Hotel)	
1:00 - 3:20 p.m.	**SESSION A1 - Large Scale Applications** **SESSION B1 - Model Development**	**(Room A)** **(Room B)**

SESSION A1 - Large Scale Applications

Moderator: Taesoo Lee
Texas A&M University

1:00 - 1:20 p.m.	**A1-1** Hyunwoo Kang	*Improvement SWAT auto-calibration tool with flow clustering EI estimation system using K-means*
1:20 - 1:40 p.m.	**A1-2** Taesoo Lee	*Application of SWAT to estimate inflow to bays from ungaged large watersheds*
1:40 - 2:00 p.m.	**A1-3** Pierluigi Cau	*A relational data paradigm to manage SWAT simulations on the GRID for the Black Sea Catchment observation and assessment system*
2:00 - 2:20 p.m.	**A1-4** Nguyen Duy Binh	*APPLICATIONS OF MODELLING and web TECHNOLOGIES for soil erosion assessment in North western region of Vietnam*
2:20 - 2:40 p.m.	**A1-5** Elham Rouholahnejad	*Hydrological modeling of the Black Sea Catchment using SWAT*
2:40 - 3:00 p.m.	**A1-6** Christine Kuendig	*Preliminary results of the application and calibration of a hydrological model in Europe*
3:00 - 3:20 p.m.	**A1-7** Hua Xie	*Hydrologic calibration of the SWAT model for African river basins using GRACE data*

SESSION B1 - Model Development

Moderator: Daniel Moriasi
USDA-ARS

1:00 - 1:20 p.m.	**B1-1** Jichul Ryu	*Enhancement of the SWAT-REMM system for simulation of T-N reduction efficiency with riparian buffer system at a Bonggok watershed*
1:20 - 1:40 p.m.	**B1-2** Youn Shik Park	*Development of the integrated SWAT-VFSMOD model*
1:40 - 2:00 p.m.	**B1-3** Daniel Moriasi	*New shallow water table depth algorithm in SWAT2005: recent modifications*
2:00 - 2:20 p.m.	**B1-4** Jaehak Jeong	*Modelling onsite wastewater systems in SWAT*
2:20 - 2:40 p.m.	**B1-5** Karim Abbaspour	*SWAT-CUP: A calibration and uncertainty analysis program for SWAT*
2:40 - 3:00 p.m.	**B1-6** Jaehak Jeong	*Development of subdaily erosion and sediment transport models in SWAT*
3:00 - 3:20 p.m.	**B1-7** Philip Gassman	*Simulation trends and other aspects regarding the worldwide use of the SWAT model*

3:20 - 3:40 p.m. **Coffee Break**

3:40 - 5:00 p.m.
SESSION A2 : Hydrology (1) **(Room A)**
SESSION B2: InStream Sediment and Pollutant Transport **(Room B)**
SESSION B3: BMPs **(Room B)**

SESSION A2 - Hydrology (1)

Moderator: Nam-Won Kim
Korea Institute of Construction Technology

3:40 - 4:00 p.m.	**A2-1** Eunjin Han	*Surface soil moisture assimilation with SWAT*
4:00 - 4:20 p.m.	**A2-2** Geun Ae Park	*The spatial analysis between SWAT simulated soil moisture, and MODIS LST and NDVI products*
4:20 - 4:40 p.m.	**A2-3** Ki-Wook Park	*Evaluation of SWAT model for irrigation reservoir operation*

SESSION B2: InStream Sediment and Pollutant Transport **Moderator:** Kwangsik Yoon
SESSION B3: BMPs Chonnam National University

3:40 - 4:00 p.m.	**B2-1** Chulgyum Kim	*Using SWAT for estimating impact of sediment and pollutant export in the Chungju Dam watershed, Korea*
4:00 - 4:20 p.m.	**B2-2** Nguyen Kim Loi	*Assessing the impacts of land use/ land cover changes and practices on water discharge and sedimentation using SWAT: Case study in Dong Nai watershed – Vietnam*
4:20 - 4:40 p.m.	**B3-1** Jae Ho Jang	*Evaluation of watershed management practices on receiving water quality using SWAT model*
4:40 - 5:00 p.m.	**B3-2** Tae Geun Kim	*Estimation of pollutants removal efficiency in the buffer strip using SWAT Model*

6:00- 8:00 p.m. **Welcome Dinner**
(Garden Hall)

Thursday, August 5, 2010

9:00 - 10:00 a.m. **SESSION A2: Hydrology (2)** **(Room A)**
SESSION B4: Database and GIS Application and Development (1) **(Room B)**

SESSION A2: Hydrology (2) **Moderator:** Do Hun Lee
Kyunghee University

9:00 - 9:20 a.m.	**A2-4** Paul D. Wagner	*Analyzing water resources in a monsoon-driven environment – an example from the Indian Western Ghats*
9:20 - 9:40 a.m.	**A2-5** Hyung-Kyung Joh	*Evaluation of mixed forest evapotranspiration and soil moisture using measured and SWAT simulated results in a hillslope watershed*
9:40 - 10:00 a.m.	**A2-6** Il-Moon Chung	*Integrated surface-groundwater analysis considering groundwater use in Pyoseon region, Jeju island, Korea*

SESSION B4: Database and GIS Application and Development (1) **Moderator:** Pierluigi Cau
Center for Advanced Studies, Research and Development in Sardinia

9:00 - 9:20 a.m.	**B4-1** Simone Manca	*The MVC client server architecture of the BSC-OS portal to digest, manage, and query SWAT data collections*
9:20 - 9:40 a.m.	**B4-2** Sudipta K. Mishra	*Development of a field based decision support tool integrated with socioeconomical model for managing water quality and quantity*
9:40 - 10:00 a.m.	**B4-3** Seong Joon Kim	*Evaluation of streamflow and water quality in an agricultural watershed of South Korea using SWAT and KOMPSAT-2 detailed land use information*

10:00 - 10:20 a.m. **Coffee Break**

10:20 a.m. - 11:40 p.m.	**SESSION A3: Climate Change Applications (1)**	**(Room A)**
	SESSION B4: Database and GIS Application and Development (2)	**(Room B)**

SESSION A3: Climate Change Applications (1)

Moderator: Seong Joon Kim
Konkuk University

10:20 - 10:40 a.m.	**A3-1** Hyun-Han Kwon	*Multivarite nonstationary Markov Chain model and its use for SWAT rainfall-runoff Model*
10:40 - 11:00 a.m.	**A3-2** Debjani Deb	*Hydrologic response to climate and landuse change in the Minnesota River Basin*
11:00 - 11:20 a.m.	**A3-3** Se-Woong Chung	*Impact of climate change on water and soil loss in Daecheong Reservoir Watershed*
11:20 a.m. - 11:40 p.m.	**A3-4** Jong-Yoon Park	*Assessment of MIROC3.2 hires Climate and CLUE-s Land Use Change Impacts on Watershed Hydrology using SWAT*

SESSION B4: Database and GIS Application and Development (2)

Moderator: Kyoungjae Lim
Kangwon National University

10:20 - 10:40 a.m.	**B4-4** Won-Ho Nam	*Development of Web-GIS based SWAT data generation system*
10:40 - 11:00 a.m.	**B4-5** Yunseok Choi	*Development of an interface system to couple SWAT2005 and HyGIS*
11:00 - 11:20 a.m.	**B4-6** Ali Najafinejad	*The effect of map spatial resolution on simulation result of SWAT, case study: chelchay watershed, Golestan province in Iran*

11:40 - 1:00 p.m. **Lunch**
(Orchid room, Mayfield Hotel)

1:00 - 6:00 p.m. **Depart for Conference Tour (Seoul City Tour)**
- *Gyeongbokgung Palace (The oldest palace of Joseon Dynasty)*
- *Insadong (Experiencing the traditional culture of Korea)*

Arrival at Mayfield Hotel

7:00 - 9:00 p.m. **Gala Dinner**
(Grand Ballroom)

Friday, August 6, 2010

9:00 - 10:20 a.m.	**SESSION A3: Climate Change Applications (2)**	**(Room A)**
	SESSION B5: Biofuel and Plant Growth	**(Room B)**
	SESSION B6: Landscape Processes and Landscape / River Continuum	**(Room B)**

SESSION A3: Climate Change Applications (2) **Moderator:** Karim Abbospour
EAWAG

9:00 - 9:20 a.m.	**A3-5** Woo Young Choi	*Estimation of climate change effect on nonpoint source pollution in Juam Lake Watershed*
9:20 - 9:40 a.m.	**A3-6** Soo Jun Kim	*The evaluation of climate change impacts on water resources system by using SWAT model*
9:40 - 10:00 a.m.	**A3-7** Hyung Jin Shin	*Projection of future watershed hydrology by applying SWAT through the prediction of vegetation community under MIROC3.2 hires climate change condition*
10:00 - 10:20 a.m.	**A3-8** Min Ji Park	*Comparison of watershed streamflows by using the predicted MIROC3.2hires GCM data and the observed weather data for the period of 2000-2009 under SWAT simulation*

SESSION B5: Biofuel and Plant Growth **Moderator:** Jeff Arnold
SESSION B6: Landscape Processes and Landscape / River Continuum USDA-ARS

9:00 - 9:20 a.m.	**B5-1** Miae Ha	*Hydrologic effects of bio-char applications on corn production fields in Illinois*
9:20 - 9:40 a.m.	**B5-2** Bikesh Shrestha	*Evaluating the impact of biofuel production on watershed hydrology using SWAT*
9:40 - 10:00 a.m.	**B6-1** Jeff Arnold	*An efficient delineation structure in SWAT to simulate the landscape/ river continuum*

10:20 - 10:40 a.m. **Coffee Break**

10:40 - 12:00 p.m.	**SESSION A4: Pesticides, Bacteria, Metals and Pharmaceuticals**	**(Room A)**
	SESSION B7: Environmental Applications	**(Room B)**

SESSION A4: Pesticides, Bacteria, Metals and Pharmaceuticals **Moderator:** Chehra Aboukinane / Virginia Jin
Al Akhawayn University / USDA-ARS

10:40 - 11:00 a.m.	**A4-1** Chehra Aboukinane	*Manipulation of the SWAT code to model veterinary antibiotics in the environment*
11:00 - 11:20 a.m.	**A4-2** Virginia Jin	*Potential soil transport of 17β-estradiol in a beneficial reuse system land-applying class B municipal biosolids for forage production in Central Texas*
11:20 - 11:40 a.m.	**A4-3** Joon Ha Kim	*Modeling approach on resuspension of E. coli from streambed using Soil and Water Assessment Tool (SWAT)*

SESSION B7: Environmental Applications **Moderator:** Jaehak Jeong
Texas AgriLife Research

10:40 - 11:00 a.m.	**B7-1** Jitae Kim	*Modification of stream water temperature calculation equation of SWAT for the Han River Korea using regression analysis*
11:00 - 11:20 a.m.	**B7-2** Christopher L. Shope	*Simulating water quantity and quality and sediment transport under varying land use and climatic conditions in a monsoonal driven watershed*
11:20 - 11:40 a.m.	**B7-3** Katrin Bieger	*Modelling the impact of land use change on the water balance in the Xiangxi catchment (Three Gorges Region, China) using SWAT*

12:00 - 1:20 p.m. **Lunch**
(Orchid Room, Mayfield Hotel)

1:20 - 3:00 p.m. **SESSION A5: Sediment, Nutrients and Carbon** **(Room A)**
SESSION B8: Urban Processes and Management **(Room B)**
SESSION B9: Sensitivity Calibration and Uncertainty **(Room B)**

SESSION A5: Sediment, Nutrients and Carbon **Moderator:** Philip Gassman
Iowa State University – CARD

1:20 - 1:40 p.m.	**A5-1** Khanh Linh Hoang	*Comparison of the SWAT model versus the DAISY-MIKE-SHE model for simulating the flow and nitrogen processes*
1:40 - 2:00 p.m.	**A5-2** Hiroaki Somura	*Application of SWAT for nutrient load discharge estimation*
2:00 - 2:20 p.m.	**A5-3** Jong-Pil Moon	*Study on setting appropriate size of riparian buffer zone in urban basin by using SWAT model*
2:20 - 2:40 p.m.	**A5-4** Phan Dinh Binh	*Land use change effects on discharge and sediment yields of Song Cau Catchment in Northern VietNam*

SESSION B8: Urban Processes and Management **Moderator:** Allan Jones
SESSION B9: Sensitivity Calibration and Uncertainty Texas AgriLife Research

1:20 - 1:40 p.m.	**B8-1** Jeongwoo Lee	*Hydrologic modeling of the White Rock Creek Watershed with SWAT-SWMM*
1:40 - 2:00 p.m.	**B8-2** Allan Jones	*Use of SWAT for urban water management projects in Texas*
2:00 - 2:20 p.m.	**B9-1** Jeongkon Kim	*Analysis of the impacts of spatial input data quality on determination of runoff and suspended sediment in the Imha Watershed using SWAT model*
2:20 - 2:40 p.m.	**B9-2** Sara Moftian	*Calibration of a SWAT hydrologic model for the Tamer Watershed in Northern Iran*
2:40 - 3:00 p.m.	**B9-3** Jaewoon Jung	*Simulation of streamflow using SWAT auto calibration tool over the Saemangeum Watershed*

3:00 - 3:30 p.m. **Break**

3:30 - 4:30 p.m. **Plenary Discussion**

4:30 - 5:00 p.m. **Closing**

Poster Presentations

Moderator : IL Moon Chung
Korea Institute of Construction Technology

SESSION PA1: Large Scale Applications

PA1-1 Jeong Eun Lee	*Runoff simulation using Global Data in the Hwacheon Dam Watershed, Korea*

SESSION PA2: Hydrology

PA2-1 Sangkeun Ha	*Runoff potential and water storage capacity of Korean Soil Mapping Units as affected by different topographic categories*
PA2-2 Sung-Kee Yang	*Analysis of impact of land use change on runoff through several Streams in Jeju Island, Korea*
PA2-3 Do-Hun Lee	*The impact of soil hydraulic conductivity variations on the simulated responses of SWAT model*
PA2-4 Wongeun Lee	*Estimation of reasonable CAPPI mesh size using SWAT model*
PA2-5 Gyo-Cheol Jeong	*Analysis of hydrologic components and water resource increase for the watershed management and groundwater dam construction in Osipcheon, Korea*
PA2-6 Jaewan Choi	*Evaluation of runoff prediction at upper watershed of Daecheong Reservoir using SWAT-K model*
PA2-7 Pushpa Tuppad	*Multi-site landuse based calibration of SWAT simulated hydrologic components*
PA2-8 Ashish Pandey	Assessment of hydropower potential using the SWAT model for southern Mizoram, India

SESSION PA3: Climate Change Applicatoins

PA3-1 Youngdon Choi	*Water supply reliability assessment considering climate changes*
PA3-2 Masoud Taheriyoun	*Assessment of the impact of climate change on watershed phosphorus load and reservoir eutrophication*
PA3-3 *Yakob Mohammed*	*Climate change impact assessment on soil water availability and crop yield in Blue Nile Basin (Case Study Anjeni Watershed), Ethiopia*

SESSION PA5: Sediment, Nutrients and Carbon

PA5-1 Sangjun Im	*Effects of landuse on nonpoint sources pollutant loadings at small watersheds*
PA5-2 Jong-Pil Moon	*Estimation of runoff unit area loads for nutrients from sloping cropland and forest using SWAT model*

SESSION PB2: InStream Sediment and Pollutant Transport

PB2-1 Ah-Hyun Shin	*Modification of BOD simulation module in SWAT for proper water quality management in Korea*

SESSION PB7: Environmental Applications

PB7-1 Dongil Kim	*A study of modeling using linkage of watershed model and river water quality model*
PB7-2 Dongil Kim	*Study for protection of water resources from pollution using SWAT*
PB7-3 Y-H Jin	*Simulation of runoff and water quality data in the Jiseok Stream, Korea by SWAT model*

SESSION A1

Large Scale Applications

A1-1

Improvement SWAT Auto-Calibration tool with Flow Clustering EI Estimation System using K-means

Hyunwoo Kang[1], *Youn Shik Park*[2], *Jonggun Kim*[3], *Won Seok Jang*[4], *Ji Chul Ryu*[5], *Nam Won Kim*[6], *Dong Su Gong*[7], *Kyoung Jae Lim*[8*]
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Abstract

Calibration and validation should be performed to secure accuracies in SWAT simulated results in various hydrology and water quality studies. When calibrating and validating SWAT model with measured data, the Nash-Sutcliffe efficiency coefficient (NSE) is used extensively, also it is used as a goal function of the Auto-Calibration in current SWAT model. However, it has been known that the NSE value is influenced sensitively by bigger values among given data by sacrificing accuracies in estimated lower flow values. In this study, K-means clustering algorithm was incorporated into the SWAT auto-calibration module. With this capability, the SWAT estimated low flow could match measured low flow data well because the NSE is calculated for low and high flow dataset separately. The improved SWAT auto-calibration module will provide very efficient tool for accurate simulation of hydrology and accompanying sediment and water quality with no additional input dataset.

Keywords: SWAT, Nash-Sutcliffe efficiency coefficient, Auto-calibration, K-means clustering

Introduction

Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) model uses Nash and Sutcliffe coefficient (NSE) (Nash and Sutcliff, 1970) when it verifies the simulated flow with measured data. Also it is also used in the Auto-Calibration function in SWAT model currently. But, the NSE value was influenced very strongly by big values in the range of data (Legates and McCabe, 1999; McCuen et al., 2006). In addition, the coefficient of flow regime in South Korea is very high because of intensive precipitation events during monsoon season in summer; it's much higher as compared with other countries' (Woo and Lee, 1993). This indicates that there are higher chances of greater NSE value although simulated data do not match measured data reasonably well for all flow regime..

Thus, the objectives of this study are to 1) modify Auto-calibration using K-means algorithm to improve estimating accuracy for all flow regime, and 2) to evaluate enhanced auto-calibration module to a study watershed.

Methodology

Study area

Soyanggang-dam watershed is located at Gangwon province in South Korea. The basin area of the soyanggang-dam is about 2,703 km^2, and it is consists of forest (89.6%) and agricultural area (5.3%). The coefficient of flow regime at this watershed is very high because the Soyanggang-dam watershed is located in typical monsoon climate area and intensive precipitation take place during the summer. In addition, the average elevation and slope are approximately 650.5 m and 40.6 % respectively (Yoon et al., 2007).

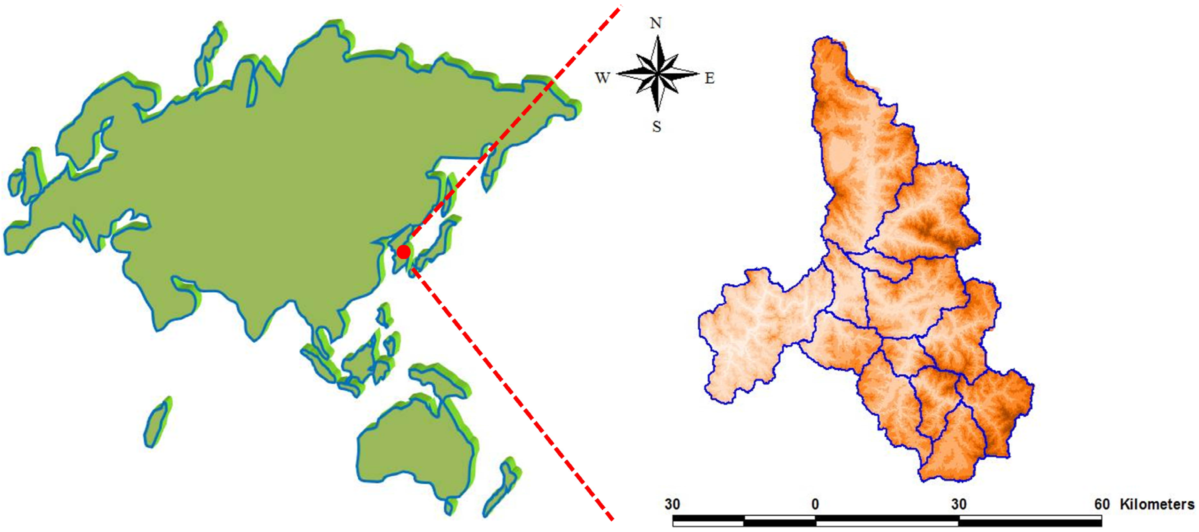
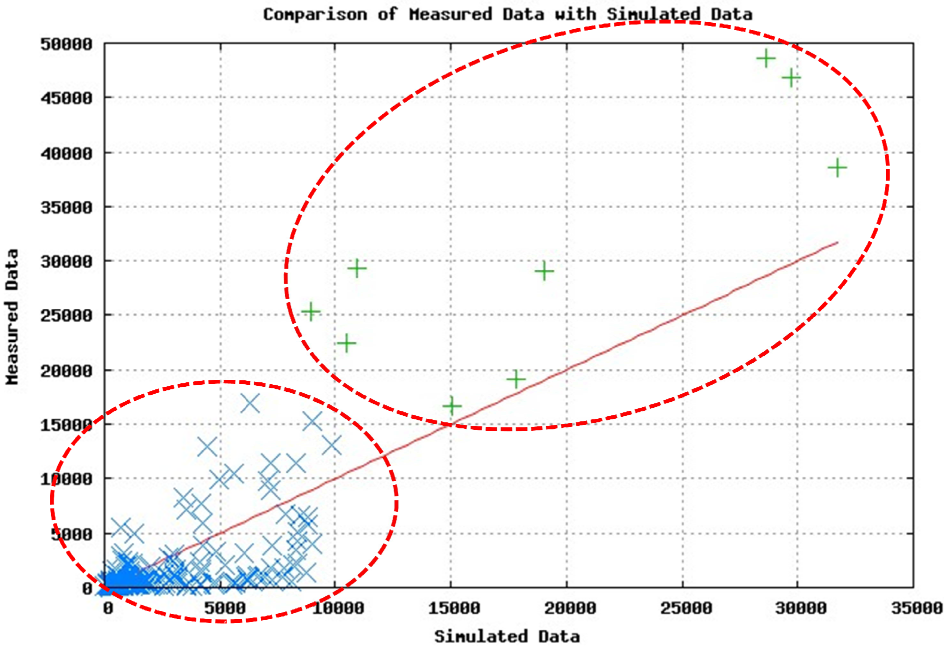


Figure 1. Location of the Soyanggang-dam watershed.

Weekness of Nash-Sutcliffe Coeffient in Evaluating Flow Simulation

In the many SWAT application studies, simulated flow data are usually compared with measured flow data and the NSE is frequently used to evaluate model performance. Park et al.(2007), compared SWAT estimated weekly flow data with measured weekly flow data with the NSE value of 0.683, which could indicate the simulated flow data match measured data reasonably. However, after clustering the entire flow data into flow group I and flow group II using K-means clustering algorithm, the NSE for flow group I (high flow) and flow group II (low flow) were very low, even became negative, implying average of measured data in flow group II (low flow) can be used instead. (Figure 2). This result revealed that the use of NSE for flow evaluation for watershed summer monsoon climate areas is not recommended.



Total NSE	0.683
NSE for low flow	-0.482
NSE for high flow	0.058

Figure 2. Comparison of NSE values w/ or w/o clustering.

Modification of Auto-calibration using K-means algorithm

K-means (MacQueen, 1967) is one of the simplest unsupervised learning algorithms to solve clustering problems. In this study, the auto-calibration was enhanced using K-means clustering algorithm to verify high and low flow simulation separately. To enhance auto-calibration, Parameter Solution (parasol) (Van Griensven and Meixner, 2006) module in the SWAT 2005 was changed. This parasol uses the SSQ as an objective function and the NSE as goal function to determine the best parameter sets.

As shown in Figure 3, the objective function that was used previously was substituted by new objective function that was estimated with the data clustered using K-means algorithm to define better parameters for two flow regime separately to remove effect of bigger number.

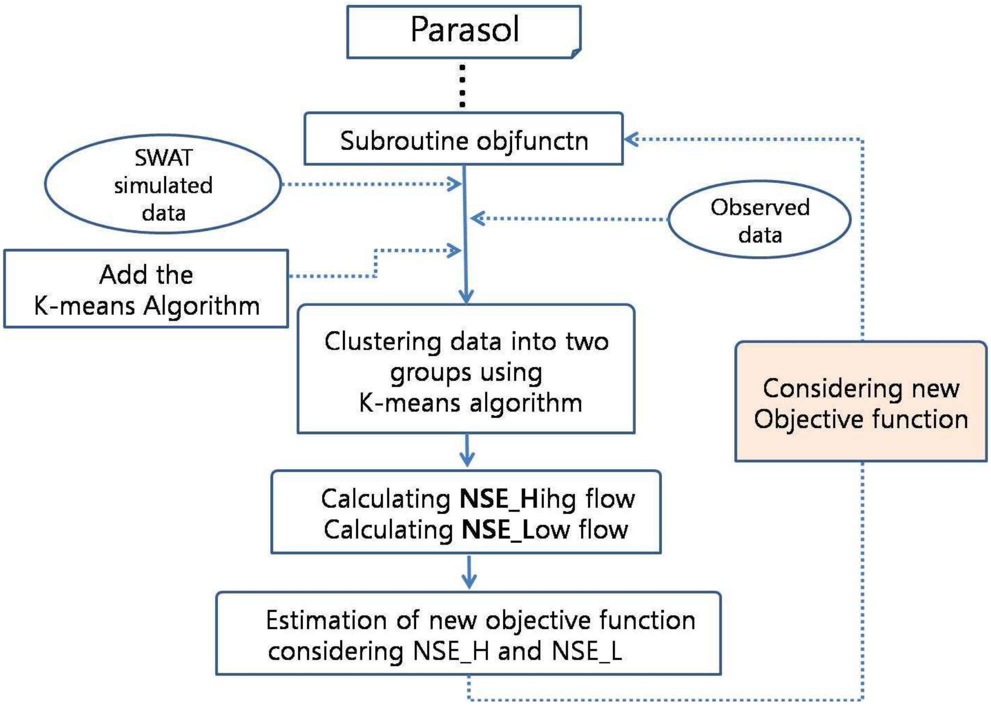


Figure 3. Enhancement of Parasol Algorithm using K-means clustering algorithm for SWAT flow calibration

In addition, the preprocessor was developed to extract main outlet number from the watershed dataset. In some cases, the greatest subwatershed number is not for main outlet (Figure 4). This information is used to read the flow output at the watershed main outlet from the SWAT estimated values to determine best parameter sets.

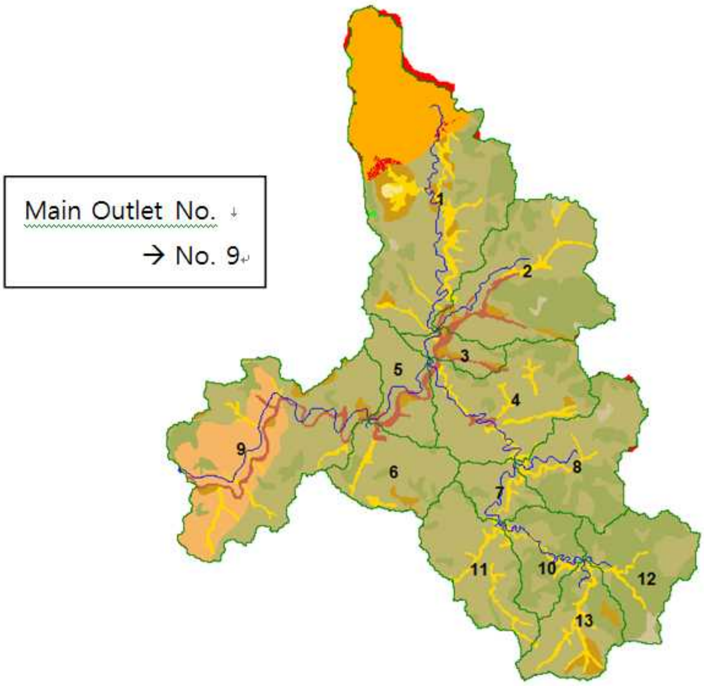


Figure 4. Determination of the number of main outlet in watershed for flow calibration

Application of enhanced auto-calibration module

In this study, enhanced auto-calibration was applied in the study watershed to evaluate effect of improved module in flow estimation. In the SWAT model, there are lots of parameters to be calibrated for fits between simulated and observed flow. Among parameters, five parameters that were ranked high in the sensitive analysis were used in this study (table 1).

Table 1. The five parameters used in auto-calibration.

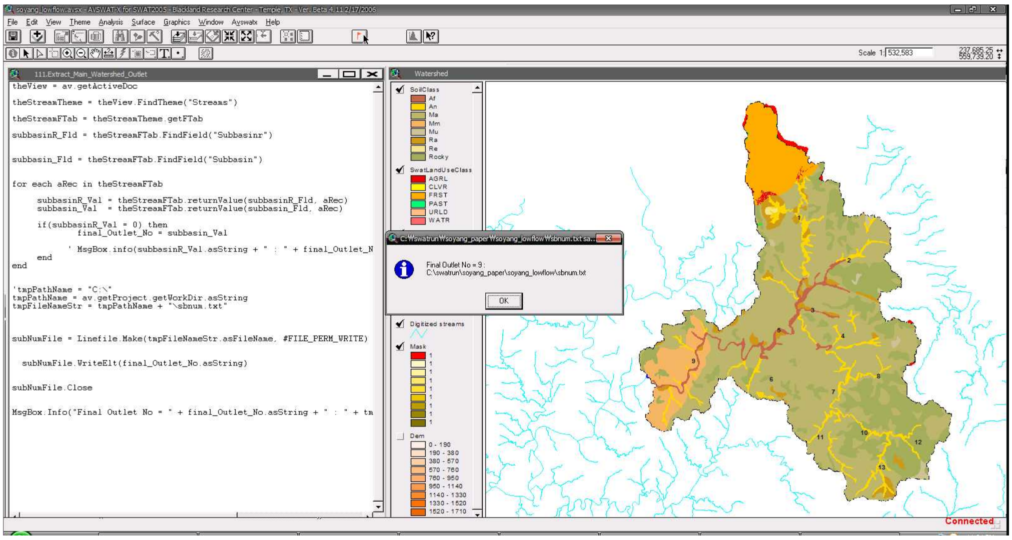
Parameter	Description	Range
CN2	SCS runoff curve number for Moisture condition II	35 ~ 98
AHPAH_BF	Baseflow alpha factor	0 ~ 1
SURLAG	Surface runoff lag time	1 ~ 24
CH_N	Manning's "n" value for the main channel	-0.01 ~ 0.3
CH_K2	Effective hydraulic conductivity in main channel alluvium	-0.01 ~ 150

The enhanced auto-calibration using K-means algorithm and previous auto-calibration were simulated under the same condition, and the each result from two different auto-calibration were compared using daily total flow data at Soyanggang-dam watershed in 2000.

Results

Enhancement of K-means Auto-Calibration

Figure 5 shows the simple interface to extract the main outlet information. As shown in Figure 4, the greatest subwatershed number is not always for main outlet. With this simple interface written in Avenue, the enhanced auto-calibration using K-means can be used by other SWAT users easily.



```
theView = av.getActiveDoc

theStreamTheme = theView.FindTheme("Streams")

theStreamFTab = theStreamTheme.getFTab

subbasinR_Fld = theStreamFTab.FindField("Subbasinr")


subbasin_Fld = theStreamFTab.FindField("Subbasin")


for each aRec in theStreamFTab

     subbasinR_Val = theStreamFTab.returnValue(subbasinR_Fld, aRec)
     subbasin_Val  = theStreamFTab.returnValue(subbasin_Fld, aRec)

     if(subbasinR_Val = 0) then
             final_Outlet_No = subbasin_Val

           ' MsgBox.info(subbasinR_Val.asString + " : " + final_Outlet_N
     end
end


'tmpPathName = "C:\"
tmpPathName = av.getProject.getWorkDir.asString
tmpFileNameStr = tmpPathName + "\sbnum.txt"



subNumFile = Linefile.Make(tmpFileNameStr.asFileName, #FILE_PERM_WRITE)


  subNumFile.WriteElt(final_Outlet_No.asString)


subNumFile.Close


MsgBox.Info("Final Outlet No = " + final_Outlet_No.asString + " : " + tm
```

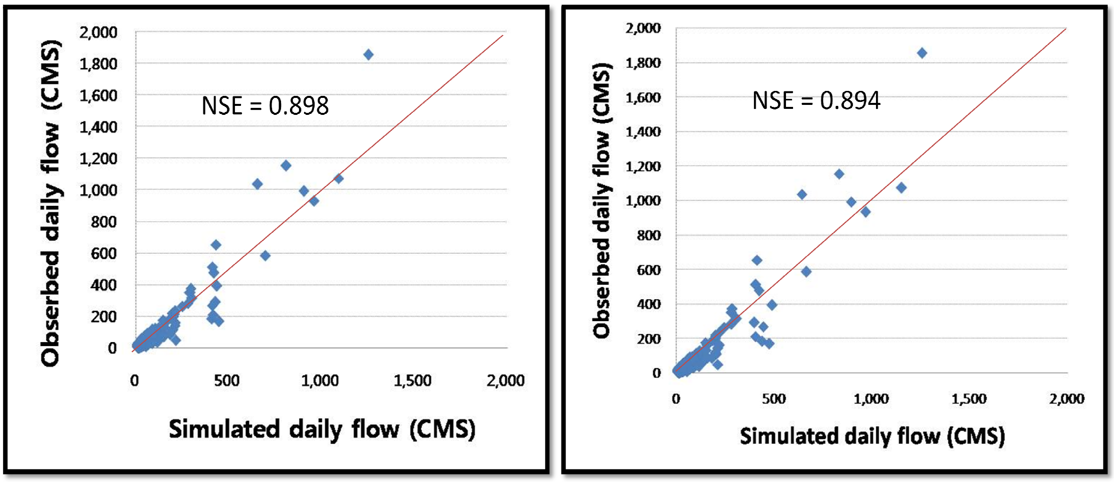
C:₩swatrun₩soyang_paper₩soyang_lowflow₩sbnum.txt sa...

Final Outlet No = 9 :
C:\swatrun\soyang_paper\soyang_lowflow\sbnum.txt

OK

Comparison of SWAT auto-calibration and one with K-means clustering

As shown in Figure 6 and Table 2, the NSE values of total stream flow are similar, However the NSE values for flow group I and flow group II are over 0.60 or close to it, indicating the SWAT auto-calibration using K-means clustering would be an efficient tool by securing accuracies in high and low flow regime. In case of calibration using SWAT auto-calibration tool, which uses flow data for all flow regime (the NSE value of 0.898 for all stream flow comparison), the NSE value for high flow group is 0.336, which is poor calibration result.



SWAT auto-calibration

(b) Enhanced SWAT auto-calibration w/ K-means clustering algorithm

Figure 4. Comparison of daily flow data w/ or w/o enhanced auto-calibration.

Table 2. Comparison of the NSE values for high, low and total flow

Type of Auto Calibration	NSE - Total Flow	NSE - Low Flow	NSE - High Flow
Auto-calibration using K-means algorithm	0.894	0.665	0.592
SWAT auto-calibration	0.898	0.780	0.336

According to the research paper of Donigan and Love (2003)(Table 3), we can say poor calibration if NSE value with daily simulation is less than 0.60. So the NSE_ High flow using SWAT auto-calibration can be thought to be poor calibration (NSE value of 0.336). These results indicate that SWAT calibration using enhanced auto-calibration using K-means clustering could provide better estimation for all flow regimes.

Table 3. Criteria for evaluating model performance (Donign and Love, 2003).

	Poor	Fair	Good	Very Good
Daily flows	< 0.60	0.60 ~ 0.70	0.70 ~ 0.80	> 0.80
Monthly flows	< 0.65	0.65 ~ 0.75	0.75 ~ 0.85	> 0.85

Conclusions

The NSE values from enhanced auto calibration using clustering based on K-means algorithm are 0.665 and 0.592 for low and high flow regimes with the NSE value of 0.894 for all flow data. However the NSE vale for total flow are 0.898 and NSE value for high flow regime using SWAT auto calibration is 0.336 (poor calibration result). This indicates that there could be potential errors in corresponding sediment and pollutant estimation during low flow periods. This is because auto-calibration uses the NSE value, which could be affected by bigger number in entire flow regime, as an objective function. The best parameters estimated by SWAT auto-calibration are obtained when the NSE value reaches the greatest among simulations. For areas such as Korea, flow in streams or rivers changed dramatically because of intensive precipitation during summer, thus the coefficient of flow regime is very high. Thus the enhanced SWAT auto-calibration using K-means clustering algorithm, developed in this study, would provide better estimation for all flow regimes.

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A1-2

Application of SWAT to estimate inflow to bays from ungaged large watersheds

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SWAT (Soil and Water Assessment Tool) model was applied to estimate inflow to the bays from Galveston and Matagorda Bay Watershed, Texas, US over previously used model, TXRR (Texas Rainfall Runoff Model). Two watersheds, Galveston and Matagorda Bay, were selected as a pilot study, one representing urbanized watershed (Galveston Bay) and the other representing rural watershed (Matagorda Bay).

Two separate projects were set up for each watershed. The flow calibration was conducted by two separated area within each watershed; 1) using flow data from available USGS gage stations (gauged subbasins) and 2) using inflow estimation to the bays by TWDB (Texas Water Development Board) (ungaged subbasins). The flow estimation in daily at each gage station showed from acceptable to good correlation coefficient (r^2) ranging from 0.42 to 0.71 with NSME (Nash-Sutcliffe Model Efficiency) ranging from 0.25 to 0.56. The monthly statistics of the total inflow to each bay showed good performance of SWAT model compared to the TXRR. The annual average inflow to the bay was estimated at 516m^3/s by SWAT and at 521m^3/s by TWDB for Galveston Bay. The correlation coefficient between two estimations was 0.930. For Matagorda Bay, the annual average inflow was at 163m^3/s by SWAT and at 162m^3/s by TWDB. The correlation coefficient was 0.899.

A1-3

A Relational Data Paradigm to Manage SWAT Simulations on the GRID for the Black Sea Catchment Observation and Assessment System

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Abstract

The EnviroGRIDS (http://www.envirogrids.net/) project, funded within the EU FP 7 Program and coordinated by the Université de Genève, aims at building capacity for a Black Sea Catchment observation and assessment system supporting sustainable development. The ambition of the project is to improve transnational cooperation, develop and apply innovative, state of the art ICT technologies for monitoring states of the environment.

One objective within the EnviroGRIDS project is to develop a Collaborative Working Environment (CWE) integrating the watershed scale SWAT (Soil and Water Assessment Tool) model within a web based technological framework optimized for data management and report production. The portal will exploit a GRID based Spatial Data Infrastructure (SDI), complex server side technologies (such as Relational DataBase Management System for data management, Mapserver as the GIS rendering engine, etc.) and client side applications. Our approach is founded on centralizing all the model-related data into complex Relational DB infrastructures. Shifting environmental application from the desktop oriented approach to the web based paradigm enhances flexibility in the whole system, extends the use of data and the sharing of experiences, fostering end user and citizen participation.

We present a preliminary application of the system and the challenges we are facing to design and develop a efficient management tool for the whole Black Sea basin.

Keywords: EnviroGRIDS, modeling, SWAT, decision support system, web based interface.

Introduction

The Black Sea Catchment has gone in the last decades through a ecologically unsustainable development and inadequate resource management, which is leading to severe environmental, social and economic problems. First signs of recovery to the Black Sea are now visible thanks to national efforts and regional - international cooperation in the framework of the Convention on the Protection of the Black Sea Against Pollution. The complexity of water resources management in such a complex basin represents an increasing challenge to policy makers of the region, where an interdisciplinary approach is needed to design effective management strategies.

More and more attention is being paid on the development and the use of models and technological ICT tools in order to help decision makers to estimate states of the environment and trends due to anthropogenic pressure such as of land use practices or climate change scenarios.

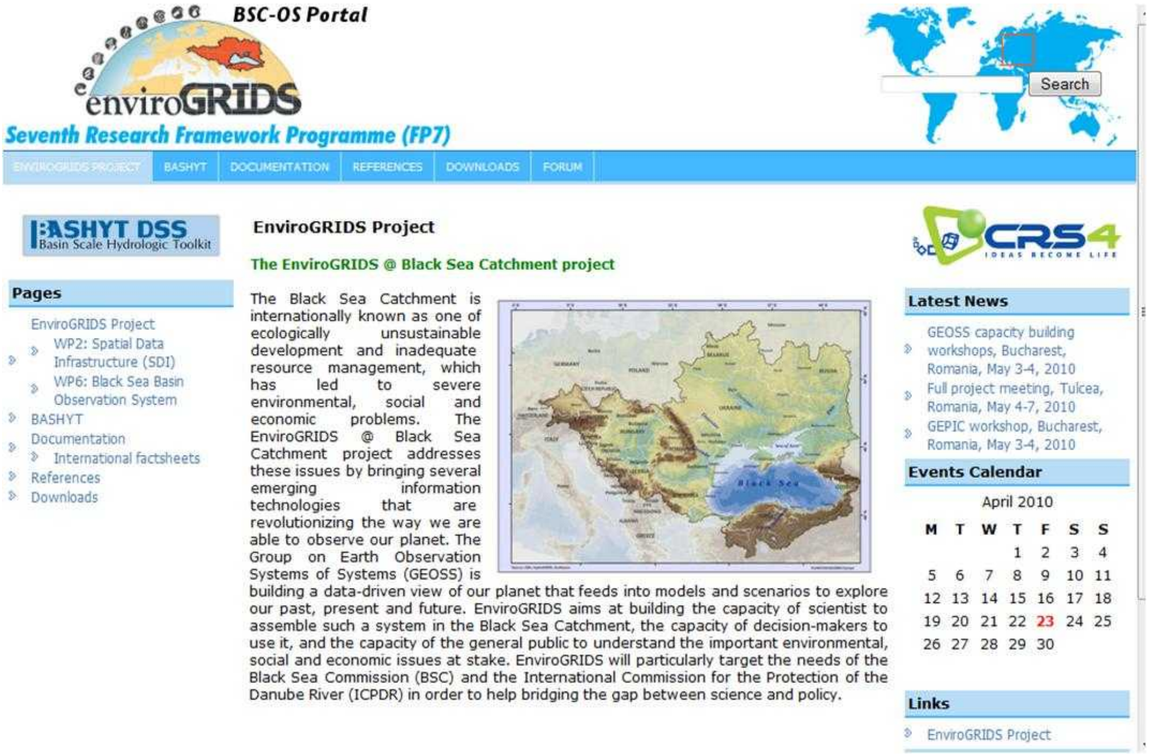
The EnviroGRIDS project, funded in 2009 by the European Commission within the FP VII Program, addresses these issues by bringing several emerging information technologies that can improve the way we observe our planet. The aim is building a data-driven vision of the earth that feeds into models and scenarios to explore our past, present and future. In this regards EnviroGRIDS aims at building the capacity of scientist to assemble such a system in the Black Sea Catchment, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. The development of the CWE portal will particularly target the needs of the Black Sea Commission (BSC - *http://www.blacksea-commission.org/*) and the International Commission for the Protection of the Danube River (ICPDR - *www.icpdr.org/*) in order to help bridging the gap between science and policy.

The Black Sea Basin

The Black Sea catchments is located in the eastern of Europe and drains its waters in the most isolated sea from the World Ocean. It is, in fact, connected to the Oceans via the Mediterranean Sea through Istanbul channel, Canakkale (Turk Straits) and Gibraltar straits and with the Sea of Azov in the northeast through the Kerch Strait.

The catchments draining area exceeds 2 000 000 km^2 with a total shoreline of approximately 4340 km, where the ratio of the catchment draining area versus the Black Sea surface is higher then 4.5. Because of this, even without any additional analysis,

Differently from the Oceans, the Black Sea is comparably smaller than the catchments draining on it, and for this reason it can be considered highly vulnerable to pressure from land based human activity such as land use, industrial activities, urban settlements, etc. and its health is equally dependent from the coastal and non-coastal states of its basin.



EnviroGRIDS Project

The EnviroGRIDS @ Black Sea Catchment project

The Black Sea Catchment is internationally known as one of ecologically unsustainable development and inadequate resource management, which has led to severe environmental, social and economic problems. The EnviroGRIDS @ Black Sea Catchment project addresses these issues by bringing several emerging information technologies that are revolutionizing the way we are able to observe our planet. The Group on Earth Observation Systems of Systems (GEOSS) is building a data-driven view of our planet that feeds into models and scenarios to explore our past, present and future. EnviroGRIDS aims at building the capacity of scientist to assemble such a system in the Black Sea Catchment, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. EnviroGRIDS will particularly target the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR) in order to help bridging the gap between science and policy.

Latest News

- GEOSS capacity building workshops, Bucharest, Romania, May 3-4, 2010
- Full project meeting, Tulcea, Romania, May 4-7, 2010
- GEPIC workshop, Bucharest, Romania, May 3-4, 2010

Events Calendar

April 2010

M	T	W	T	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

Figure 1. First Layout of the CWE environment.

The largest rivers within the basin are the Danube, the Dnieper and the Don. Other main rivers are named Rioni, Kodori and Inguri Chorokh, Kyzyl-Irmak, Eshil-Irmak, Sakarya, and Southern Bug. The connection between the Black Sea and the Mediterranean is guaranteed through the Bosphorus Strait. This is essentially a narrow elongated shallow channel approximately 31 km long, with a width varying between 0.7-3.5 km and a depth which range between 39 and 100 m.

The Black Sea ecosystems are endangered by to eutrophication, pollution, and irresponsible exploitation of natural resources which resulted in an steadily decline of biological diversity in ecosystems and in a degradation of landscapes. As a matter of fact point and diffuse pollution (from priority sources such as oil spills, or insufficiently treated waters) is decreasing. Nutrient loads routed to the Sea are also decreasing and in marine waters, phosphorus concentrations is found to be slowly decreasing, reaching the levels of 1960s, while nitrogen concentration is still increasing and is higher than in 1960s (http://www.blacksea-commission.org/_environment.asp).

Within the projects, 2 different approaches will be followed for:

large scale model: the Black Sea as a whole will be modeled as a unique basin in order to analyze the effect of climate, land use or demographic changes with a low spatial and temporal resolution

small scale model: a series of pilot catchments will be modeled with a high spatial and temporal resolution

The BSC-OS Portal and the GRID Infrastructure

The BSC-OS portal is a set of loosely coupled interoperable WEB applications, (Collaborative Web Environment, Tool for the Citizens and Decision Makers, etc.) developed by the different partners of the Consortium. By this, it is meant that at the actual state of the project, each web application can work on its own independently from the others and from the GRID. The interoperability property is referring to the ability of the diverse systems and organizations to work together (inter-operate) exploiting the same physical and network resources in a controlled and harmonized way.

The CWE will be devoted to visualize SWAT based scenarios run on the GRID or on local machines and then deployed and the CWE infrastructure to analyze pressures on the environment and climate from natural and anthropogenic emissions and improve our understanding of the complex climate system of the Black Sea region. The software infrastructure will digest a large number of watersheds and scenarios.

The interoperability between the CWE and the GRID is of paramount importance. In order to make each piece of the infrastructure self consistent, communication is designed to be one way only: from the GRID to the CWE portal. This permits to overcome problems related to authentication and authorization, maintaining a high degree of security on the GRID side.

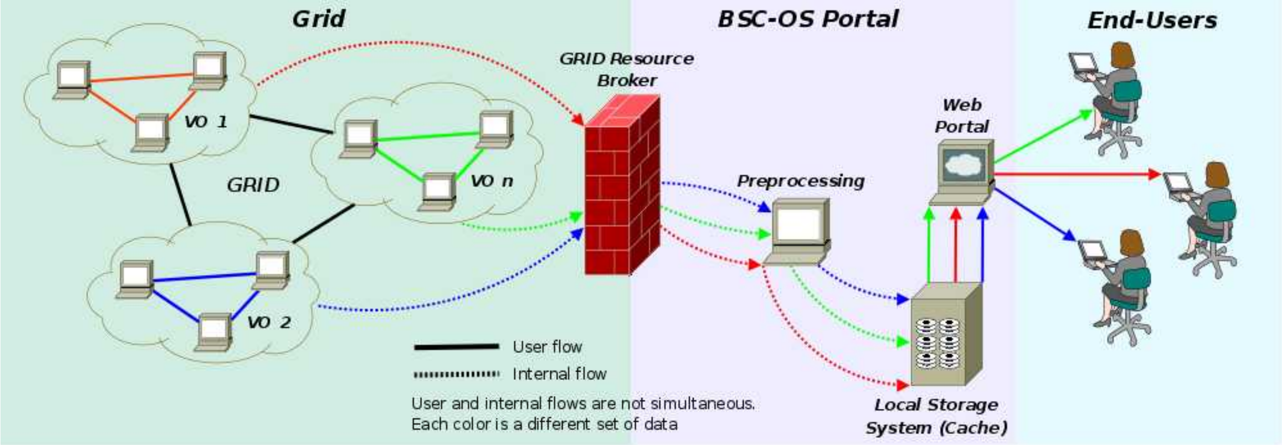


Figure 2. The BSC-OS portal general architecture.

The GRID based Spatial Data Infrastructure (SDI) will expose catalogs of environmental data sets (e.g. land use, hydrology, and climate) that will be gathered and used to perform distributed spatially-explicit simulations to build scenarios of key environmental changes.

The Grid layer is expected to offer many advantages by which the management of computing and data storage resource, data and processing distribution, security, are just the most important [Gorgan et al., 2010].

The authentication layer is being harmonized between the applications of the BSC-OS portal taking into account the following requirements:

self consistency of each web environment

unique user authentication mechanism for all web application and the GRID.

Currently different authentication mechanism and technologies are being evaluated (LDAP, OpenID, Shebolet, the EGEE GRID authentication). OpenID is a decentralized authentication protocol that makes possible for people to sign up and access web accounts using a unique‟ global username‟. It makes use of URLs or XRIs as user identifiers. It enables the auto-discovery of Identity Providers. It is becoming an authentication standard “de facto” in web environments. OpenID can provide a shared uniform access to all the web based applications.

The CWE Environment and the Data Archiving Mechanism

The CWE is expected to enable to store, manage, query data collections; visualize data, (maps, graphs, texts, tables) and digest SWAT simulations to produce reports on the environment.

In particular, it will:

work in tandem with the AVSWAT [Di Luzio et al, 1995] or ArcSWAT [Francisco et al, 2006] (desktop preprocessor for the SWAT [Jayakrishnan et al., 2005] hydrological model to manage data input/output;

design scenarios and run real time applications (small case model) based on the SWAT model and evaluate their effectiveness using a standardized framework (DPSIR model);

create reports (graphs, maps, etc.) optimized for hydrology specialist, end users and citezens exploiting RDBM functionality and server side technology. Data will be fed to relational DB files through automatic standardized procedures;

digest SWAT runs performed on the GRID (large scale scenarios),

expose catalogs and web services (WMS, WFS, etc.) to the internet.

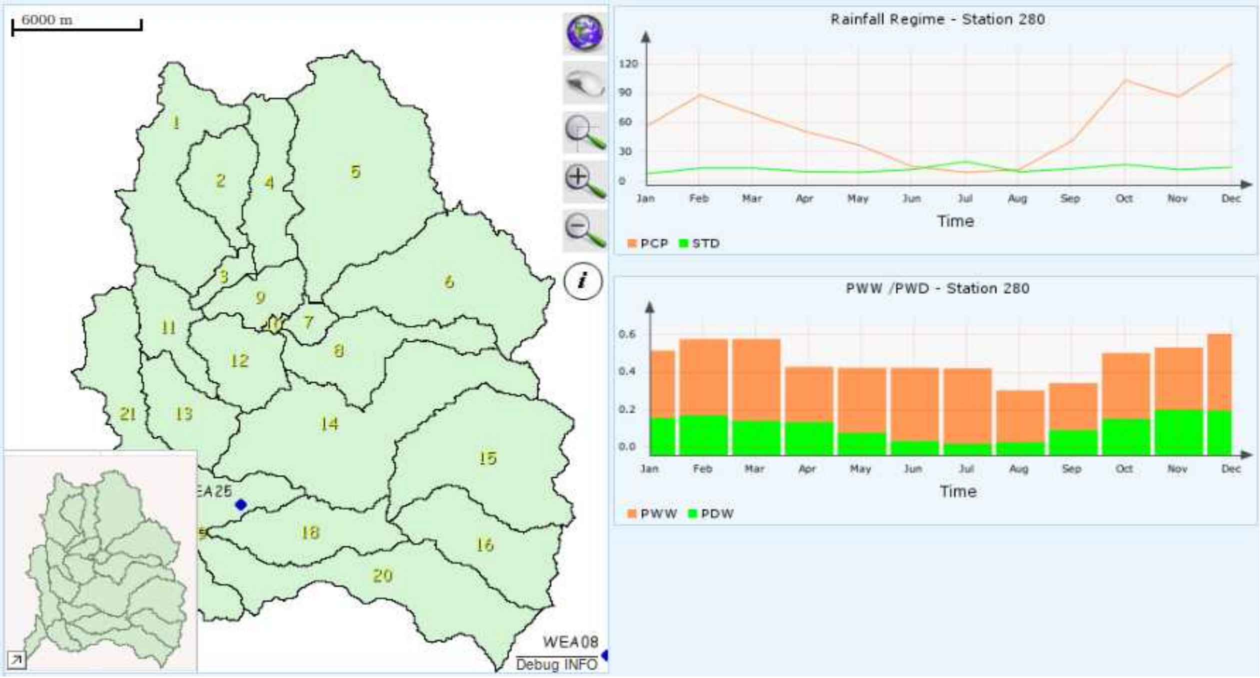
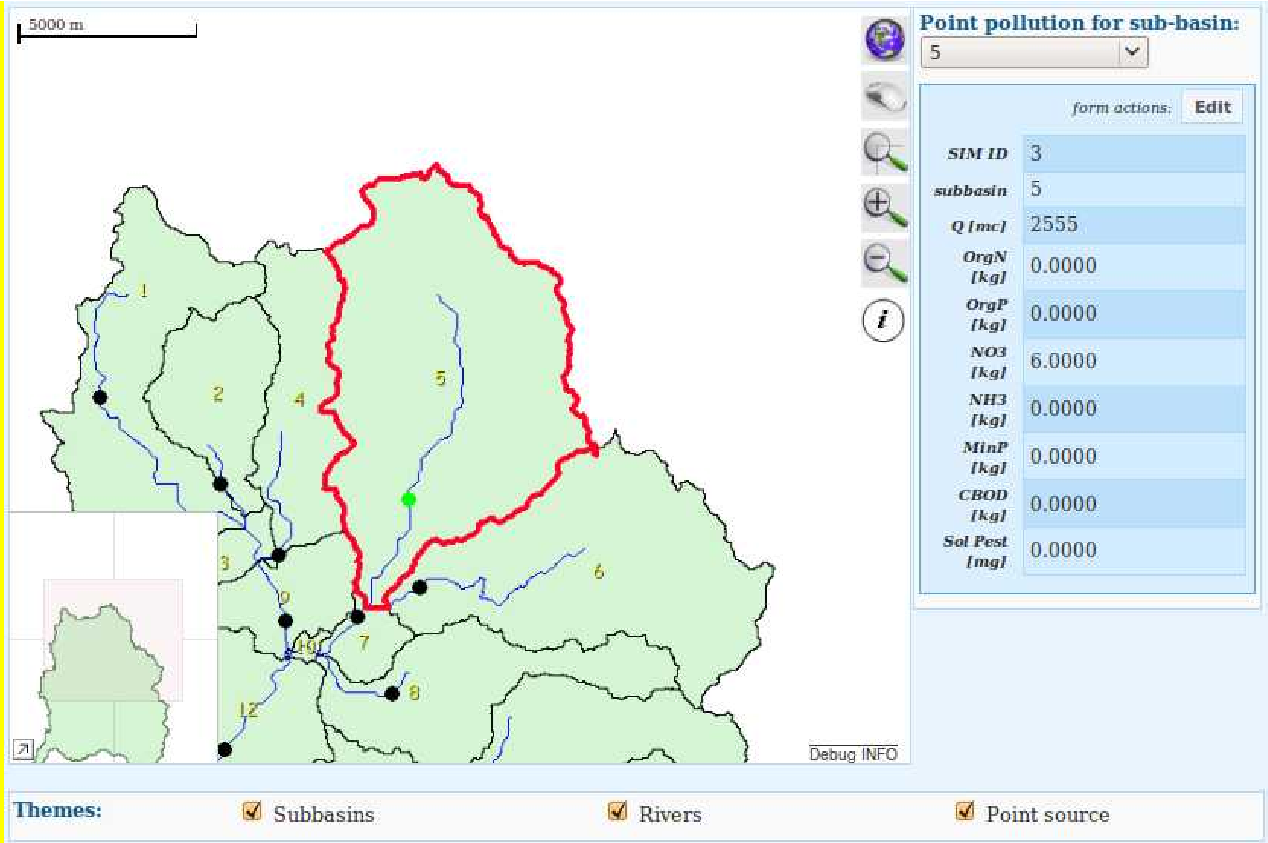


Figure 3. The CWE environment is optimized for the report production mechanism.

The CWE front end, based on the BASHYT framework [Manca et al., 2009], will exploit the Model View Controller (MVC) architectural pattern, isolating "domain logic" (the application logic for the user) from input and presentation (GUI).



Point pollution for sub-basin: 5

SIM ID	3
subbasin	5
Q [mc]	2555
OrgN [kg]	0.0000
OrgP [kg]	0.0000
NO3 [kg]	6.0000
NH3 [kg]	0.0000
MinP [kg]	0.0000
CBOD [kg]	0.0000
Sol Pest [mg]	0.0000

Themes: ☑ Subbasins ☑ Rivers ☑ Point source

Figure 4. GIS, tables, charts, forms and contents are fused within the software to expose reports on the environment.

The CWE environment will exploit massively the WEB templating feature of the MVC architecture, combining GIS capabilities and modules for the production of contents and reports (charts, forms, tables, etc.) in a highly performing web environment. The GIS rendering is exploited using the Open Source MapServer technology accessing the MapServer CGI and OGC (WMS, WFS) interfaces. The server side MapServer is a map engine that provides a spatial context where it is required. The AJAX msCross (http://datacrossing.crs4.it/) interface developed by CRS4 [Manca et al., 2006] will be further developed to meet the requirements of the project.

The approach used for the data archiving mechanism is founded on centralizing all the model-related data into complex Relational DB infrastructures. A flexible relational database architecture is being developed to meet such requirements. The innovative Spatialite RDBMS engine is being used to store all geo-referenced and alphanumeric information. An extensible data models have been developed to keep the highest level of generalization. The well known PostgreSQL/PostGIS technology could not be flexible enough to meet the requirements of scalability of a regional/continental context, like the Black Sea, where virtually hundreds of basins need to be simulated. The serverless nature of this engine assures high scalable scenarios, since all operations work as common read/write filesystem calls. This architecture does not need added configuration or administration charges. Linking our application to libsqlite results in gaining the power of a complete transactional RDBMS, without the need of external server process to query and with a useful portability freedom. SQLite offers the capability to load personal or third party extensions (shared libraries), written in C or other languages. This mechanism can be used to straighten the SQL functionalities of the engine or override its functions.

All SWAT simulations will be accessed on the Internet both by users (developers, decision makers, scientists) and software applications using the provided automatic procedures or direct queries.

The authorization logic of the CWE is coded on the application side and will be based on 2 control levels: Tickets and Tokens. Tickets are used to enable users to browse web pages and applications, while tokens control each object accessibility within each page. The CWE portal will be accessed by different users that can be grouped in the following roles described as follow:

read only role: (*public citizens* interested in the research – *Decicion makers* such as public and government agencies - stakeholders - private companies that want to use the results and the research - end users that are part of the Consortium)

development role (development role from both the server and client side, such users can write pieces of codes and exploit the Velocity Template to write applications and add contents)

insert role (these users, such as *Earth Science (ES) specialist* can upload SWAT scenarios, data, and run small scale scenarios)

administrator role (such role manages user accounts, creates new users, updates information on the Web Portal, manages data resources)

For each role (point 1, 2 and 3) different groups can be assigned with different degree of freedom within the Portal. To each group related to a role, tickets and tokens will control access to the WEB interfaces and the usability of each object/functionality within each HTML page respectively.

Conclusions and Future Work

Shifting environmental application from the desktop oriented approach to the CWE paradigm for the Black Sea region will enhance flexibility in the whole system, possibly will extend the use of data and the sharing of experiences, fostering end user and citizen participation. This is expected to improve the level of comprehension on the dynamics at different time and spatial scale of the complex Black Sea Catchment.

The demand of Web-based human interaction in a lot of situations, scenarios and applications is still unsupported. The CWE will sustain user and group awareness, and communication facilities. This feature will be enhanced and further investigated by effectively working on cooperation support for structured activities and by investigating more generic group building mechanisms. The CWE framework, through the web template framework and the script programming, can also permit to design new applications, the easy assessment, customization and exploitation of services (wiki like) directly on the web browser.

The enviroGRIDS Consortium counts 27 Partners for 15 countries involved. At an advanced stage of the project, each beneficiary of the consortium and regional/national water agencies within the Black Sea area will be enabled to contribute to the deployment of new environmental applications and analysis tools. The web portal is expected to be deeply improved, benefiting from this enlarged collaboration group, exposing even more innovative and useful environmental applications.

Acknowledgments

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A1-4

Applications of Modeling and Web Technologies for Soil Erosion Assessment in North Western Region of Vietnam

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Abstract

Quantification of soil loss over a large area is a significant issue for soil and water conservation practitioners and policy makers but to disseminate that detailed soil erosion loss information to the public is also considered very important. Information and Communication Technology (ICT) has created opportunity to provide modeling results by using a number of online applications. In the present study, application of the SWAT (Soil and Water Assessment Tools) model was used to assess soil erosion over a 38,739 sq. km area of the Black (Da) river basin, North of Vietnam. The SWAT model was calibrated and validated in accordance with the observed daily streamflows at selected gauging stations. Subsequently, the calibrated model was used to examine changes of water and sediment yields as a result of the extreme weather conditions as well as impact of land use. Furthermore, a website and updating tools were designed to send most up-to-date simulated soil erosion information to internet. The purpose of this web application is to provide erosion information to relevant people including the farmers who are in remote area of Northwestern region of Vietnam. To develop this system, PHP, HTML, and Flash graphic applications were utilized. The results of this study are important for future extended SWAT modelling studies and dissemination of this results in other regions in Vietnam.

Keywords: soil erosion, dynamic web, modelling, information dissemination.

Introduction

Erosion on hillslopes within catchments contributes to a decline in agricultural productivity and produce pollutants that adversely affects the quality of water in rivers, reservoirs and lakes. Models that calculate erosion through a year and over many years which called continuous models, proved to be essential tools for soil erosion analysis and assessment especially for large area. In addition o conducting studies and publishing related results in scientific journals and conferences, the issue of dissemination these conclusions in a convincing way to society is also of the utmost importance. Dissemination of research results to society, especially to people in remote areas, can be realized by using many methods.

Recent information technology developments permit information to be available in computers or even possibly in every mobile phone in a very near future.

Dynamic Website now allows remote users to easily access modeling results, provide/modify input data, and get new model's responses by activating model runs. There are on the internet many of such websites (Institute of Water Research with RUSLE, 2002; and Department of Geography, 2008), but to our best knowledge, there is no website related to Soil and Water Assessment Tool (SWAT, Neitsch et al., 2005) which allows users to access modeling results and/or to make assessment of climate change effect on water resources and soil erosion.

SWAT has been being used extensively over the last 30 years all over the world including in Asia and has proven to be an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental conditions. (Gassman et al., 2007). Many of the recent studies showed that SWAT is capable to simulate flow, water quality and soil erosion in large areas, even with limited data which is important for modelers in developing countries: Mekonnen et al. (2009) applied SWAT to simulate hydrological regimes in the two Ethiopian catchments. Quyang et al. (2010) investigated soil erosion dynamics in the upper watershed of the Yellow River, China. The Mekong River Commission (MRC) have been using SWAT since 2000 to to facilitate the joint planning and management of the Mekong River Basin as reported by Rossi et al., (2009).

In SWAT, the watershed is discretized into sub-basins and these sub-basins are typically further discretized into Hydrologic Response Units (HRUs). Chen and Mackay (2004) highlight the inconsistency in SWAT2005 caused by the integration of the HRU concept with the Modified Universal Soil Loss Equation (MUSLE) for predicting sediment erosion on HRUs.

The ultimate goal of this study is to develop a Soil and Water Assessment Tool version 2005 (SWAT2005) model (Neitsch et al., 2005) of the Northwestern region of Vietnam (see Figure 1) which comprises part of the Black (Da in Vietnamese) river basin and upper part of the Horse (Ma) river basin. This paper outlines the model input development, calibration and then multi-period validation of the model. Common approaches in SWAT for input and model setup development are applied considering the large area of the study region. Although SWAT were applied in many other large areas all over the world, the quantity and quality of the spatially variable model inputs as well as the flow and sediment monitoring data for the NW region of Vietnam create a unique opportunity in which we can derive useful experience and technique to be possibly applied to other river basins in the whole of Vietnam. The study was also an additional test case for the efficacy of the SWAT2005 model to represent and simulate spatially variable watershed processes on a large scale watershed in developing countries where data reliability is often a big issue.

The purpose of our study are: (a) application of SWAT model to the Nothwestern region of Vietnam for estimation of soil erosion potentials; and (b) set-up a website using dynamic web technology to display modeling results and to allow users not only to access in details soil erosion data but also to change climate data (rainfall, temperature, solar radiation and air humidity) and to activate SWAT model running. The later will hopefully helps in dissemination of modeling results to public. We think that such kind of study is important for future extended SWAT modelling studies.

Material and Methods

Study area: North Western Region of Vietnam

The major land uses in the 38,739 km^2 Northwestern region are forests (59% of the land area), agricultural grasses (26% of land area) and crops land (10%). Paddy rice accounts for 1% of the land area while urban areas comprise less than 0.5% of the area. Mean annual precipitation at the climate stations is about 1700 mm/yr. The elevation of the watershed ranges from approximately 856 m above mean sea level in the lowland areas to approximately 3000 m in the mountains while the average land-surface slope is 19%. The area water drains mainly into Back (Da) and Horse (Ma) rivers (Figure 1). There are other notable streams flow through the area, such as Nam Ngum as an tributary of the great Mekong, and Day river which ultimately flows into the Red river delta.

SWAT2005 model description

SWAT2005 (Neitsch et al., 2005) is a distributed-parameter model designed to compute long-term runoff and nutrient export from rural watersheds, especially those dominated by agriculture (Arnold et al., 1998). The model is maintained by the Agricultural Research Service of the United States Department of Agriculture (USDA). The base model inputs for SWAT2005 are developed with the aid of the SWAT2005 ArcGIS Interface (ArcSWAT2005) program (Winchell et al., 2009) that automatically assigns default model parameter values and creates input files based on various GIS map layers provided to the interface.

Model input development

The SWAT2005 model of Northwestern region described in this study was derived from a preliminary model version for flow and sediment transport (no phosphorus) developed for a research project carried out in 2009 - 2010 and was sponsored by the Vietnam Ministry of Education and Training (MOET). Details of the substantial input development effort for this version of the model are described in the following sections. Unless otherwise noted below, all model inputs are assumed constant over the modelling simulation time period considered (1997–2008).

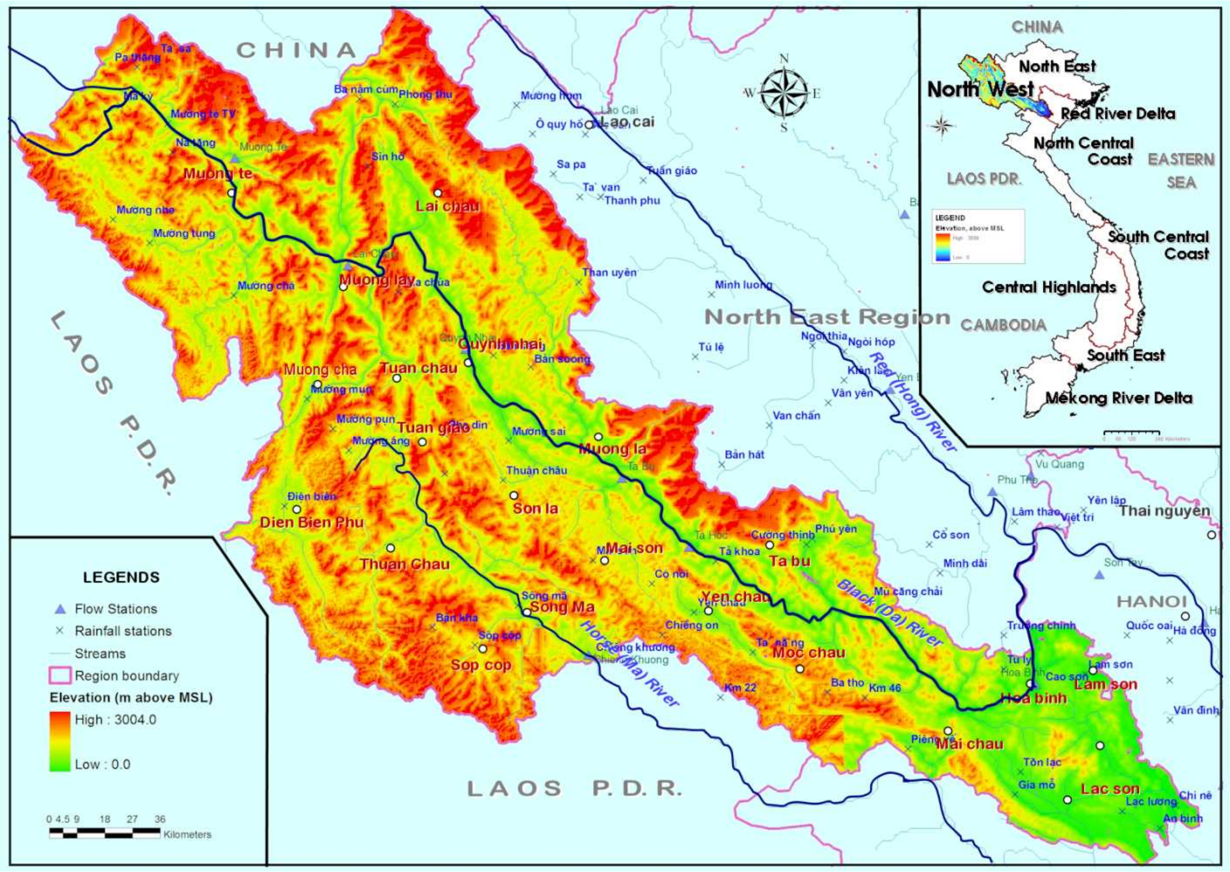


Figure 1. Map of the Vietnam North-Western region.

Watershed configuration

SWAT divides the entire watershed into sub-basins and the sub-basins can be further subdivided into HRUs. A digital elevation map (DEM), soil, land use and stream network coverage were input to ArcSWAT2005 in order to create base SWAT2005 model inputs. Five additional sub-basins were defined along the mainstream of the Black River in order to match more closely the available water flow monitoring stations (Muong Te, Lai Chau, Quynh Nhai, Ta Bu, and Hoa Binh). A total 133 sub-basins were delineated in ArcSWAT2005 using a 30 m DEM provided by Vietnam Ministry of Natural Resources and Environment (MONRE).

Within each sub-basin, HRUs in ArcSWAT2005 are formed as unique soil and land use combinations that are not necessarily contiguous land parcels. ArcSWAT2005 thresholds for defining HRUs within a sub-basin were set at 5% for soils and 10% for land use.

Soil property inputs

SWAT2005 by default uses the State Soils Geographic Database (STATSGO) to describe the physical characteristics of soils. The default ArcSWAT2005 approach assigns soil properties to model HRUs based on the most common soil component (or soil series) within each map unit. In the present study, the soil data obtained from MONRE's soil map was used to create soil input for SWATmodel.

In order to assign more representative Northwestern region specific soil properties while minimizing the number of HRUs modelled, the areas of each MONRE soil map unit were tabulated and soil properties were derived by comparison with soil units of the Mekong River Commission (MRC) (Rossi et al., 2009; Binh et al., 2005). The result of this approach was to estimate soil properties that were consistent with average Northwestern region soil properties (Table 1 and Figure 2).

Table 1. Soil classes in North West of Vietnam according to MONRE.

Soil ID	Abreviation	FAO Name	Soil ID	Abreviation	FAO Name
1	ALh	Humic Alisols	24	FLsg / SCg	Gleyic Salic Fluvisols / Gley Solonchaks
2	Alu-C	Histric Alisols	25	FLsh / SCh	Hapli Salic Fluvisols / Haplic Solonchaks
3	NTh	Haplic Nitisols	26	FRu	Humic Ferralsols
4	ARh	Haplic Arenosols	27	FLd-h	H- Dystric Fluvisols
5	ARb	Cambic Arenosols	28	FLe-h	H- Eutric Fluvisols
6	ARl	Luvic Arenosols	29	FLd	Dystric Fluvisols
7	ARg	Gley Arenosols	30	FLe	Eutric Fluvisols
8	FLe	Eutric Fluvisols	31	FLg	Gley Fluvisols
9	ACha	Albic Haplic Acrisols	32	FLj	Stagni Fluvisols
10	LPq	Lithic Leptosols	33	FLu	Humic Fluvisols
11	ANm	Mollic Andosols	34	LV	Luvisols
12	FRx	Xanthic Ferralsols	35	LVk-h	Hapli Calcic Luvisols
13	ANm	Mollic Andosols	36	LVx	Chromic Luvisols
14	FRp	Plinthic Ferralsols	37	CHk	Calcic Cherozems
15	FRr-c	Calcaric Rhodic Ferralsols	38	LVk	Calcic Luvisols
16	ACf	Ferralic Acrisols	39	FLto	Orthi-Thionic Fluvisols
17	FRx	Xanthic Ferralsols	40	FLto-z	Solonetz Orthi-Thionic Fluvisols
18	FRk	Calcic Ferralsols	41	GLtp	Proto-Thionic Gleysols
19	Fru	Humic Ferralsols	42	GLtp-z	Solonetz Proto-Thionic Gleysols
20	ALh	Humic Alisols	43	FLj	Stagni Fluvisols
21	SLdj	Stagni-Dystric Gleysols	44	ACh	Haplic Acrisols
22	CLh	Calcisols	45	ACg	Gleyic Acrisols
23	FLsm / SCm	Molli Salic Fluvisols / Mollic Solonchaks	46	LPq	Lithic Leptosols

Source: Center of Land Planning and Management, MONRE, 2008.

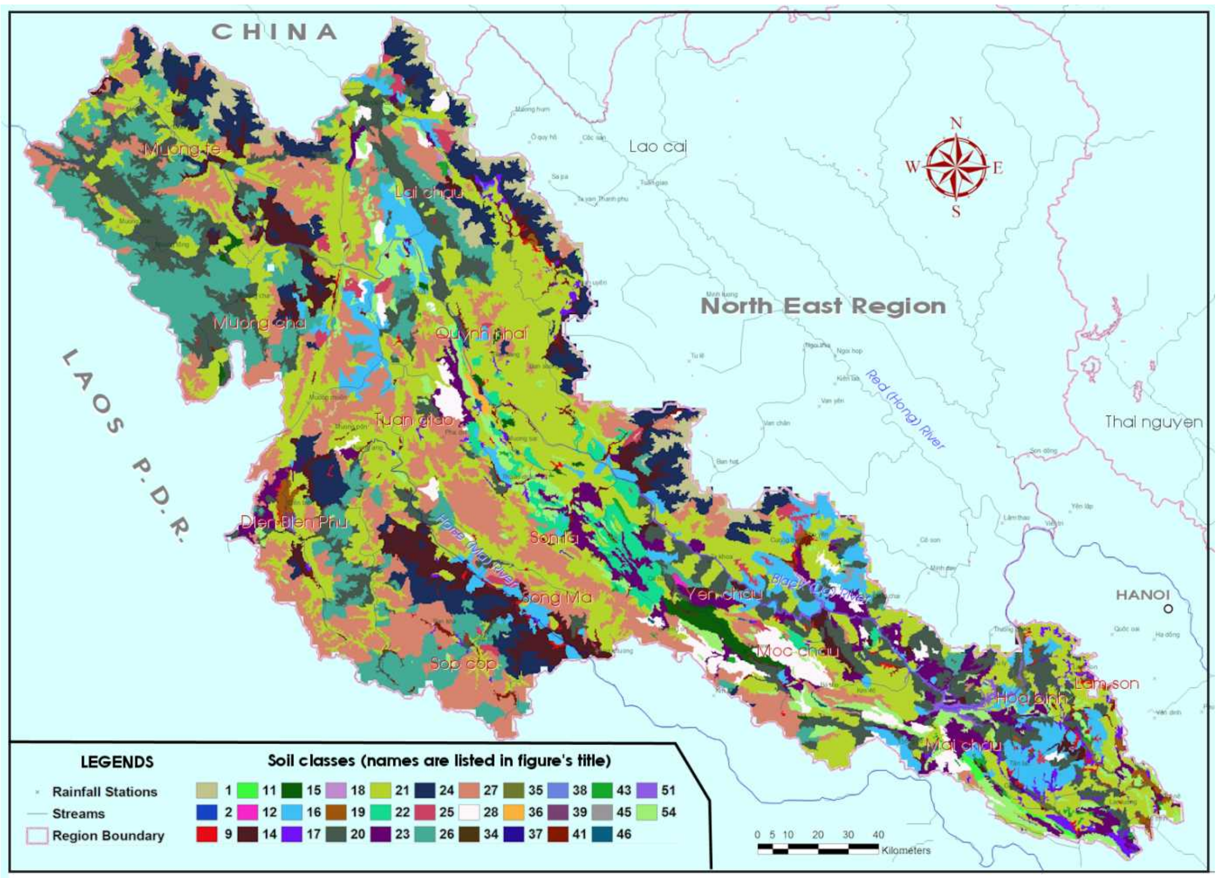


Figure 2 Soil map indicates 54 soil classes as named in Table 1 .

Land use

MONRE provided the land use data (250 m grid) that were derived by supervised classification of 2005 thematic mapper satellite imagery. There are 51 types of landuse in the study area with the most common agricultural land uses in the basin are known to be continuous forest, pasture, perenial and agricultural land. Values of land use parameters for all land use classes were derived from MRC database (Binh et al., 2005). The land use input data can be described similarly to Table 1 and Figure 2. but for the sake of space, that data as well as DEM, climate and agricultural management data were not included in the present paper. Interested reader may contact the author for more detailed explanations.

Climate data

Climate inputs utilized in this SWAT2005 model application were rainfall, minimum and maximum temperature, solar radiation, relative humidity and wind speed. All of these inputs were based completely on measured data within or close to the Northwestern region. Data sources were obtained from the National Climatic Data Center of Vietnam. Daily air temperature and daily precipitation data from 78 stations closed/within the area were available. Solar radiation, wind speed and air relative humidity inputs were based on available climate station data.

Agricultural management representation

All agricultural management and activities input to the model were derived from information provided by multiple local farm planners and agricultural researchers as described by MONRE.

Hydrological data

The locations of the measured flow stations supplying calibration and validation data are provided in Figure 1. Up to a total of 10 years of daily flow data from five hydrological stations were utilized for flow calibration and validation. Figure 3 shows part of daily rainfall, discharge and sediment flow at Hoa Binh hydrological station.

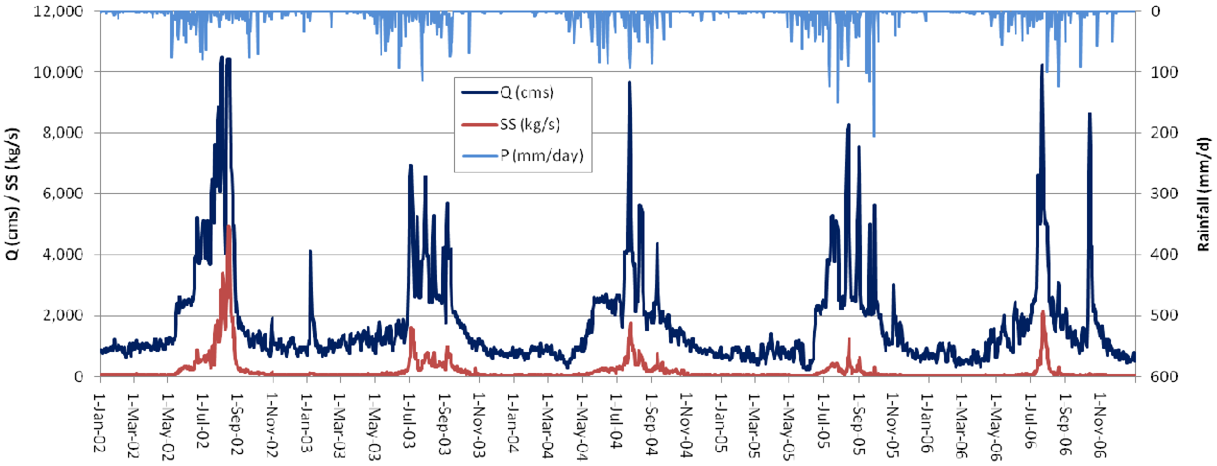


Figure 3 Monitored daily flow, suspended solid and rainfall obtained from Hoa Binh hydrological station (Source : Center for Hydrometeorological Data Management, MONRE, Vietnam).

Data for soil erosion parameters

In addition to soil properties, the most important parameter for soil erosion and sedimentation yield estimation in SWAT is the soil erodibility (K) factor, USLE_K. In the present study, data from various soil experiments conducted in the region, especially from a 9-years hillslope experiment (Ziegler et al., 2007), was examined to derive appropriate value of USLE_K.

Model Calibration and Validation

Model calibration is the adjustment of model parameters, within recommended ranges, to optimize the agreement between measured data and model simulation results. Validation is taken to mean 'model testing' and by no means do we consider our validated model to be a perfect predictor. Rather, good validation (model testing) results are simply stronger evidence that the calibrated model is a good simulator of the measured data and does not over-fit the measured data in the calibration period. In the present study, we used flow monitoring data of 1998-2002 for calibration and of 2003-2008 for verification of the model.

Calibration efforts focused on improving model predictions at the five hydrological monitoring stations (Muong Te, Lai Chau, Quynh Nhai, Ta Bu and Hoa Binh). The coefficient of determination (r^2) and the Nash–Suttcliffe coefficient (ENS) (Nash and Suttcliffe, 1970) were used to quantitatively assess the ability of the model to replicate temporal trends (daily and monthly) in measured data. The %Bias is defined as the relative percentage difference between the average simulation and measured data time series over n time steps and is given in Eq. (1):

$$\%\text{Bias} = \frac{100 \times \left(\sum_{j=1}^{n} \text{Simulated}_j - \sum_{j=1}^{n} \text{Measured}_j\right)}{\sum_{j=1}^{n} \text{Measured}_j} \qquad (1)$$

The calibration objective for each constituent of interest was to maximize the ENS coefficient while simultaneously attempting to reduce the absolute value of %Bias to values ideally less than 10%. In general, the model was calibrated only for flow. Further calibration and validation works for sediment yields will be followed with available monitoring data of sediment yield at a number of stations (i.e. Hoa Binh station as shown in Figure 3). Similar to numerous SWAT studies, we found that the most important parameter adjustments were the uniform reduction of all base runoff curve numbers by 20% of their base value and the reduction of the surface runoff lag coefficient (SURLAG) to 1.0. These two modifications respectively functioned to reduce surface runoff volumes and increase the delay in the delivery of surface runoff to the channel.

Modelling and Web interaction systems

A website and updating tools were designed to send most up-to-date simulated soil erosion information to internet. The purpose of this web application is to provide erosion information to relevant people including the farmers who are in remote area of Northwestern region of Vietnam. Figure 4 shows structure of the modeling and web systems with their associate computer components.

For displaying erosion data and results, the Flash approach of Jin and Xin (2009) was adopted which allows development of a dynamic mapping system with minimum of software costs. The user's interactions with the system includes brower components (a) for user's investigation of soil erosion status of his/her interest and (b) for user's input modifications, run the

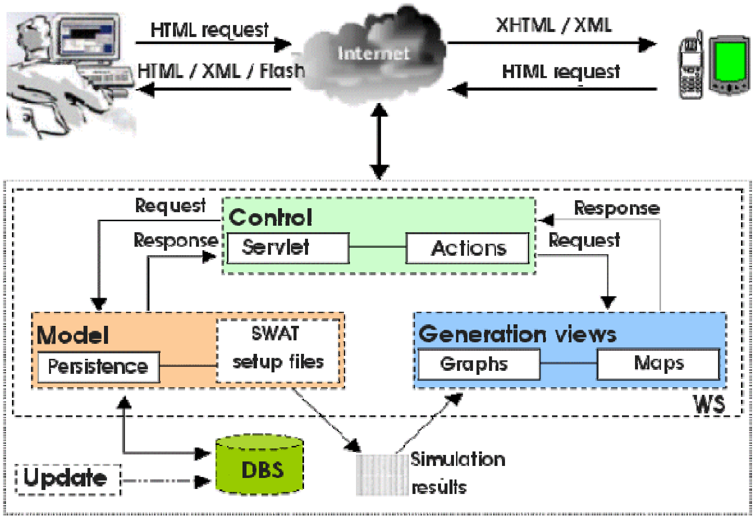


Figure 4 Structure of the modeling and web systems (adapted from Pavan et al., 2009).

SWAT models , and consequently display impacts of that modifications on water regimes and soil erosion.

During developing our dynamic mapping/modeling system, several factors should be taken into consideration: 1) interaction with users, 2) dynamic data retrieving, 3) dynamic activation model run, 4) browser independence, and 5) cost-effectiveness. With that criteria, we design the procedure for implementation of the web-based modeling systems for the North West Region of Vietnam as shown in Figure 5. There are three groups of implementation steps. The first group includes input data preparations, set-up, calibration and validation of SWAT model of the whole region. Due to limitation of the present-day internet communication speed, we found that it was necessary to further develop setups SWAT model separately for each sub-basin in the area. The second group of work comprises of preparations for integrated dynamic mapping and XML (eXtensible Markup Language) data files. For dynamic spatial data retrieving, Geographic Information System (GIS) provides a rich means of data representation and data layer analysis. However, GIS software is usually heavy weighted and software license could be expensive. In our system, we only utilize the map as a data visualization tool, which is only a small portion of GIS's rich features. Other methods for displaying maps on the web include Adobe Flash and APIs, like Google Maps (http://code.google.com/), JFreeChart (http://www.jfree.org/jfreechart/) and AJAX (Asynchronous JavaScript and XML) (Jin and Xin, 2009). We selected Adobe Flash based on the fact that (a) Flash posses rich animation and interactivity features; (b) Most of today's browsers and small electronic devices like cell phones fully support Adobe Flash; (c) Flash has a special scripting language called ActionScript, through which users can manipulate Flash movies dynamically; and furthermore (d) dynamic data retrieving is also available in Flash via XML data format. Clearly, Flash is an attractive solution for dynamic data presentation and visualization on the Internet. The third group is to develop a web interface which allows user interactions for edit data, model run activation and result analysis. The latter group certainly has many common features relating strongly with the first and second groups and relies heavily on the programming language PHP (Hypertext Preprocessor).

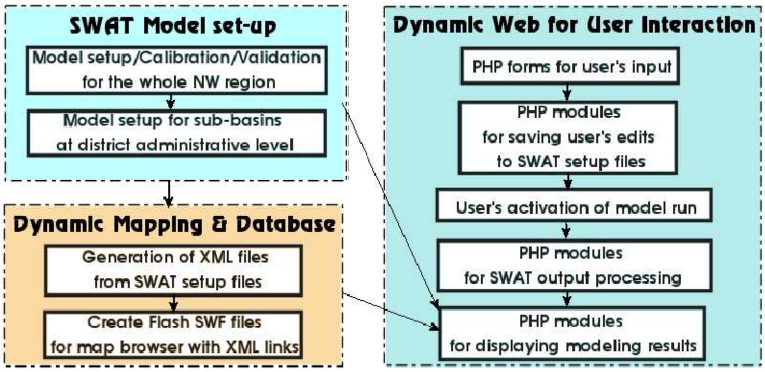


Figure 5 Procedure for implementation of the dynamic web-based modelling system for North West region of Vietnam.

The web development of the system was based mainly on PHP that is especially suited for Web development and can be embedded into HTML. PHP is mainly focused on server-side scripting, such as collect form data, generate dynamic page content, or send and receive cookies. One of the strongest and most significant features in PHP is its support for a wide range of databases.

As in any web-based system, there are server and clients in our implementation. In the server side, different model set-ups for sub-basins are stored to provide internet access. In the client side, data display and visualization were implemented using HTML (Hypertext Markup Language), JavaScript and Adobe Flash.

Results and Discussions

The essential input data of the SWAT model for the Northwestern region of Vietnam: (a) topography as a Digital Elevation Model (DEM); (b) land use map; (c) soil map; and (d) location of meteorological and hydrological monitoring stations and associate time series of monitoring daily rainfall, air temperature, air humidity, solar radiation and wind speeds.

After model calibration and validation were calibrated and validated satisfactorily, soil erosion simulations were carried out for the 1997 – 2002 period which resulted in yearly potential erosion maps. The average soil erosion map is presented in Figure 6. An attempt of accuracy assessment on simulated soil erosion was carried out using available experimental data (i.e. Ban Tat hillslope project, Zigler et al., 2007).

The website comprises pages for project descriptions, common knowledge on soil erosion and related models, browser facilities for user access to details of soil erosion down to district level (Figure 7), and interfaces which allow user to modify and investigate climate change conditions (precipitation, solar radiation, air temperature and wind speed) impacts on flow and sedimentation, as shown in Figure 8.

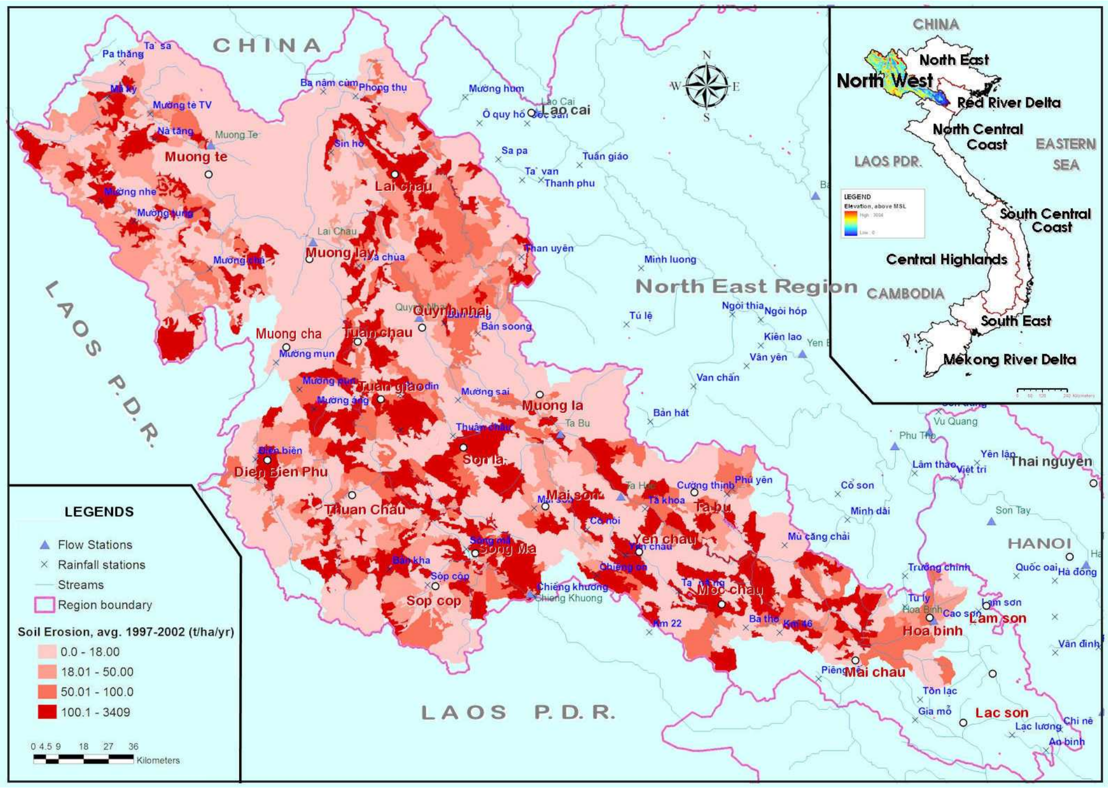


Figure 6. The simulated soil erosion map for Northwestern region of Vietnam, here as averaged values for 1997-2002 periods.

Modelling

Applications of SWAT (Soil and Water Assessment Tools) for North Eastern Region of Vietnam

The following are descriptions of a research project currently conductd by Faculty of Information Technology and Faculty of Natural Resources and Environment.

nt study uses a Soil and Water Assessment Tool version 2005 t al., 2005) to set-up an hydrological and sedimentation in the m which comprises part of the Black (Da in Vietnamese) river orse (Ma) river basin.

(DEM), soil, land use, climate and agricultural management data. Click here to view input data for the NW region.

3. Calibration and Verification: Model calibration is the adjustment of model parameters, within recommended ranges, to optimize the agreement between measured data and model simulation results. Validation is taken to mean 'model testing' and by no means do we consider our validated model to be a perfect predictor.

4. Modelling results: flow regimes, sediment flows and soil erosion estimates. Click here to access the results for the NW region of Vietnam.

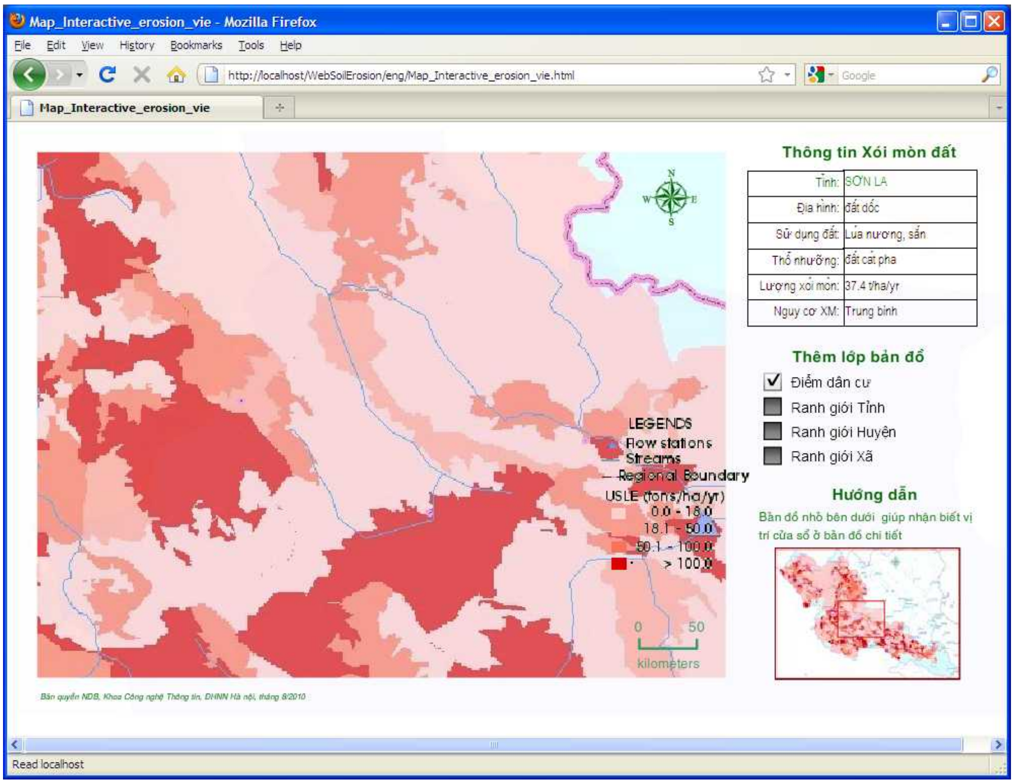
4. Interactive Modeling for Climate Change Assessment: Web tools were designed and implemented to send most up-to-date simulated soil erosion information to internet. The purpose of this web application is to provide erosion information to relevant people including the farmers who are in remote area of Northwestern region of Vietnam. Click here to access the Interface.

Related Links

- Research Team
- Organization Structure

Registration for our Newsletter: Please type your e-mail address below

Figure 7 Main page of the website on soil erosion research.



Thông tin Xói mòn đất

Tỉnh:	SƠN LA
Địa hình:	đất dốc
Sử dụng đất:	Lúa nương, sắn
Thổ nhưỡng:	đất cát pha
Lượng xói mòn:	37.4 t/ha/yr
Nguy cơ XM:	Trung bình

Thêm lớp bản đồ

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☐ Ranh giới Tỉnh
☐ Ranh giới Huyện
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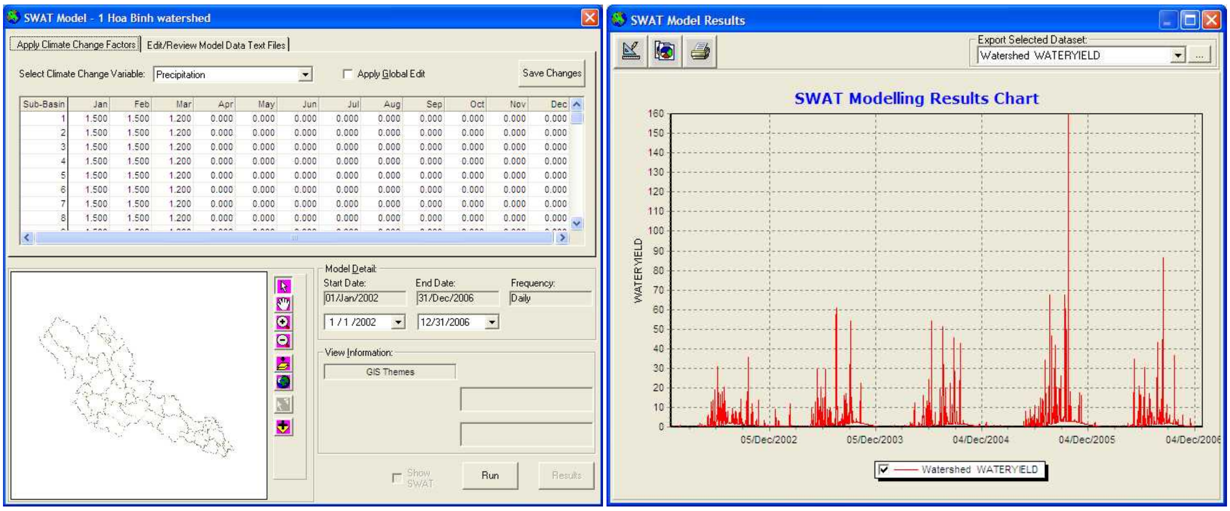
Hướng dẫn

Bản đồ nhỏ bên dưới giúp nhận biết vị trí cửa sổ ở bản đồ chi tiết

Bản quyền NDB, Khoa Công nghệ Thông tin, ĐHNN Hà nội, tháng 8/2010

Figure 8 Map browser for user's access to detailed erosion information.

The later component is designed so that modifications of climate data can be increased/decreased by percentage of global data or by modifications of individual climate value at specified location and time (Figure 9).



Select Climate Change Variable: Precipitation

☐ Apply Global Edit

Sub-Basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	1.500	1.500	1.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Start Date: 01/Jan/2002
End Date: 31/Dec/2006
Frequency: Daily
1 / 1 /2002
12/31/2006

Export Selected Dataset: Watershed WATERYIELD

Figure 9 Sample of interface for modification of climate input data, activation of model run, and displaying model results as climate impact on water flows.

Conclusions

SWAT model was applied to estimate effect of climate conditions on soil erosion and water regimes in North Estern part of Vietnam. More than that, an attempt using web technology to disseminate that modeling results to public has been implemented. Although the study have not been completed satisfactorily but a number of conclusions can be derived: (a) SWAT can be used to evaluate climate change impacts over time on soil erosion and on water availability which are of prime importance for agriculture productions in upland regions; (b) Application of distributed models like SWAT require considerable amount of detailed data which is not readily available and not possible to evaluate data accuracy/reliability of a certain amount of data; (c) The study demonstrates that SWAT can be integrated with Web technology and Adobe Flash which can present details of modeling data and results, and even can allow users to investigate climate change impacts by modification of climate data, running models and displaying modeling results, is expected to raise climate change awareness among the public.

When implementing a modelling and dynamic mapping system, modeling, website and GIS components are to be combined. This paper presents a solution for setting up SWATmodels, dynamic mapping and model activation using Adobe Flash, XML, and PHP. That Web's usage in allowing users to investigate climate change impacts is not only restricted to soil erosion analysis, but also can be extended to other areas in water resources and agriculture.

Our study produced a Flash-based tool for dynamic soil erosion mapping. Future applications could be to provide a generalized Flash map service for users to customize their own maps.

Acknowledgements

This paper is partially based on the on-going modeling project which was originally sponsored by Vietnam Ministry of Education and Training (MOET) and Hanoi University of Agriculture (HUA). The authors are especially thankful for the MOET and HUA for giving us the opportunity to work on that project. Thanks to Prof. Dr. T.D. Vien who has been continuously encouraged the modelling work in HUA as well as Prof. Dr. R. Srinivasan from the Texas A&M University who provided training and advice throughout the modelling effort.

Other people that provided critical data and assistance included T.T. Trang and many other members at the Vietnam Ministry of Natural Resources and Environment (MONRE).

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A1-5

Hydrological Modeling of the Black Sea Catchment using SWAT

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Abstract

The Black Sea Catchment (BSC) is internationally recognized for its ecologically unsustainable development and inadequate resource management leading to severe environmental, social and economical problems. This work is part of the 7th Framework European project entitled EnviroGrid (Building Capacity for a Black Sea Basin Observation and Assessment System supporting Sustainable Development). The main objective of this project is to use SWAT to build a hydrologic model of the BSC and to study the impact of climate and landuse change on all components of the water balance at subbasin level with monthly time steps. In a preliminary attempt, the 2 million km^2 drainage basin was discretized into 1629 subbasins. Based on the initial run, river discharge results were quite satisfactory for 33 stations distributed across the region and unsatisfactory for another set of 31 stations. We will investigate the problems with these stations and build a second and more detailed model of BSC with finer DEM, landuse, and climate information. The refined model will be calibrated using the SWAT-CUP calibration and uncertainty analysis package, which will be made to run on grid computing using the facilities of CERN. The calibrated hydrologic model will be used to study the impact of climate and landuse changes.

Keywords: Large-scale application, SWAT, SWAT-CUP, EnviroGrids

Introduction

The Black Sea Catchment (BSC) is internationally recognized for its ecologically unsustainable development and inadequate resource management leading to severe environmental, social and economical problems. The European Community is addressing the crucial problem of water quality and quantity by adopting the Water Framework Directive (CEC 2000) that promotes water management based on watersheds rather than administrative or political boundaries. The EnviroGrids project (Building Capacity for a Black Sea Basin Observation and Assessment System supporting Sustainable Development), which is defined in the 7th European Framework, aims at building capacities in the Black Sea region on new international standard to gather, store, distribute, analyze, visualize and disseminate crucial information on past, present and future states of this region in order to assess its sustainability and vulnerability.

First, a gap analysis identifies areas where most efforts are needed to reinforce existing observation systems in this region. Then, spatially explicit scenarios of key drivers of changes such as climate, demography, and land cover will be created. These scenarios will feed into the hydrological model that we are building, calibrating, and validating for the entire Black Sea Basin. EnviroGrids will rely on the largest GRID computing infrastructure in the world (European Organization of Nuclear Research, CERN) for storing, calibrating, and running different scenarios. The combined impacts of expected climatic, demographic, land cover, and hydrological changes will be measured against Group on Earth Observation (GEO, http://www.earthobservations.org/) Societal Benefit Areas. Specific outcomes will be analyzed and made accessible to both the expert and non-expert public through a state-of-the-art web interface providing advance warning to target audiences about risks.

Climatic change is becoming a worldwide concern that will affect many areas of human activities. The last report of the Intergovernmental Panel on Climate Change (IPCC 2007c, a, b) predicts important changes in the coming decades that will not only modify climate patterns in terms of temperature and rainfall, but will also drastically change freshwater resources qualitatively and quantitatively. This is expected to lead to more floods or droughts in different regions, lowering of drinking water quality, increased risk of water-borne diseases, and irrigation problems. These changes may trigger socio-economic crises across the globe that need to be addressed well in advance of the events in order to reduce the associated risks.

There are many studies concerning the increasing threat of water scarcity and vulnerability of water resources at regional and global scales (Yang and Zehnder 2007; Oki and Kanae 2006; Cosgrove and Rijsberman 2000; Vörösmarty et al. 2000; Postel et al. 1996). There is, however, a lack of information with adequate spatial and temporal resolution concerning the hydrological components affecting the availability of water resources in the Black Sea Catchment.

Against this background, the main objective of this study is to build a calibrated hydrologic model of Black Sea Catchment. This model will be capable of estimating water resources availability at the sub-basin level on a monthly time step and explicitly quantifying hydrological components of water resources, e.g. surface runoff, deep aquifer recharge (blue-water flow), soil water(green-water storage), and actual evapotranspiration (green-water flow). Furthermore, this work is intended to provide a basis for future scenario analyses of land use and climate change impact on water resources in BSC.

Calibration of large-scale models is, however, not straight forward. Important issues to address are how to deal with the availability of input data, watershed parameterization, and uncertainties associated with input data accuracy and scarcity (especially rainfall), model uncertainty and parameter non-uniqueness. To satisfy the objectives of this study, the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) was used to model the hydrology of Black Sea basin. For calibration and uncertainty analysis as a first run in this study, we used the Sequential Uncertainty Fitting program SUFI-2 (Abbaspour et al., 2007). SUFI-2 is a tool for sensitivity analysis, multi-site calibration and uncertainty analysis. SUFI-2 is linked to SWAT in the SWAT-CUP software (Abbaspour, 2010).

Materials and Methods

Description of the study area

Black Sea is located between the continents of Europe and Asia (Figure 1). It connects the Atlantic Ocean via Mediterranean Sea. BSC with the total area of around 2 million km^2, five times the surface of the Black Sea, is located between 38^o and 56^o north latitude and 8^o to 46^o east longitude. It contains 19 European and Asian countries. Some of Europe's longest and largest rivers flow into the Black Sea and into the Sea of Azov, including the Danube, the Dnieper, the Southern Bug, the Dniester and the Don. The area is inhabited by a total population of around 160 million people (BSEI, 2005)

The area is mountainous in the east and south, in the Caucasus and in Anatolia, and to the north west, with the Carpathians in the Ukraine and Romania. Most of the rest of the Black Sea's western and northern neighborhood is low lying. Mean annual air temperature shows a distinct north-south gradient from < -3^{o}C to > 15^{o}C. Precipitation pattern is characterized by a west-east gradient that is decreasing precipitation with distance from the Atlantic Ocean. Areas of high precipitation (> 300 cm y^{-1}) are in the west and areas of low precipitation (< 19 cm y^{-1}) are in the north and east (Tockner et al., 2009).

The region's natural ecosystems include forests in the west, south and east, steppes to the north, and Alpine ecosystems at higher altitudes in the Carpathians, in Anatolia and in the Caucasus. Both the Caucasus and parts of Anatolia are considered by the European Environmental Agency as "biodiversity hotspots", because they combine a particularly rich biodiversity and an alarming rate of habitat loss (EEA, 2007).

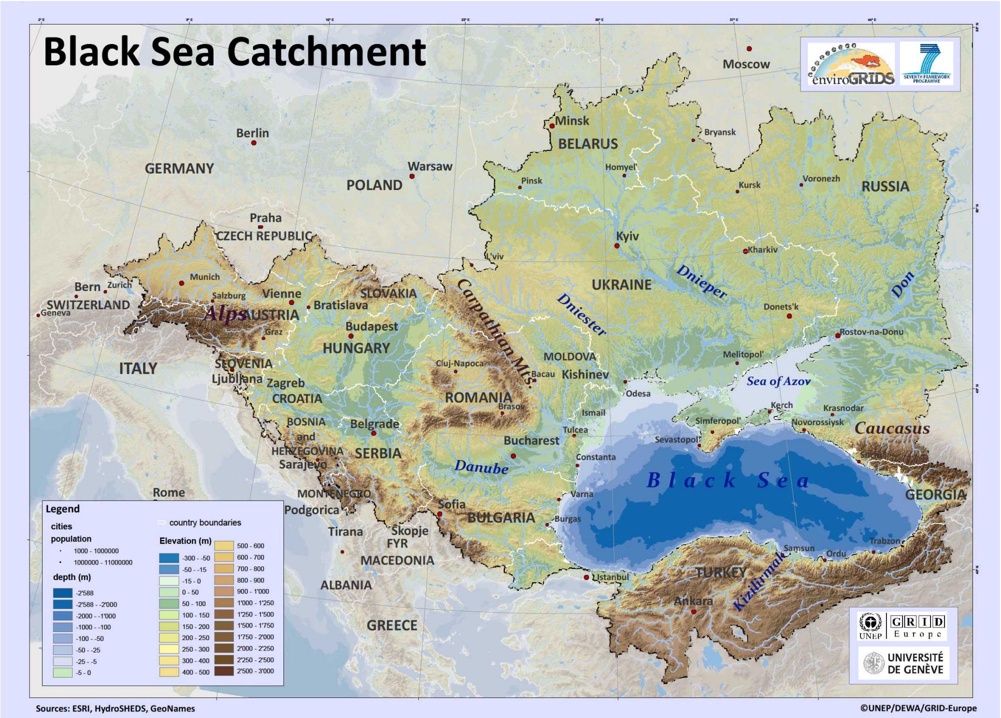

Figure 1. Map of Black Sea Catchment showing major cities, rivers, and elevation

Model inputs and model set up

Data required for this study were compiled from different sources. They include:

- Digital Elevation Model (DEM) extracted from the Global US Geological Survey (USGS, 1993) public domain geographic database HYDRO1k with a spatial resolution of 1 km (http://edc. usgs.gov/products/elevation/gtopo30/hydro/index.html).

- Land use map from the USGS Global Land Use/Land Cover Characterization (GLCC) database with a spatial resolution of 1 km and distinguishing 24 land use/land cover classes was used for the eastern part of the Black Sea Catchment (http://edcsns17.cr.usgs.go/glcc/glc.html), and CORINE land cover map (CLC1990) with 100 m spatial resolution, which provides information for all EU countries that covers the western part of the catchment (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster). The CORINE land cover map contains 43 different classes. These two maps are combined and resized so that the final map with spatial resolution of 100 m covers the whole catchment.

- Soil map obtained from the global soil map of the Food and Agriculture Organization of the United Nations (FAO, 1995), which provides data for 5000 soil types comprising two layers (0–30 cm and 30–100 cm depth) at a spatial resolution of 10 km.

- Information about the digital stream network (DCW, http://www.maproom.psu.edu/dcw) and BSC boundaries (http://www.envirogrids.net).

- Weather input data (daily precipitation, maximum and minimum temperature, Figure 2a,b) mostly from the National Climatic Data Centre (NCDC, http://www.climate.gov/#dataServices/dataLibrary) and the European Climate Assessment & Dataset (ECAD, http://eca.knmi.nl/dailydata/predefinedseries.php). Periods covered by the available data were from 1970 to 2008. The WXGEN weather generator model (Sharpley and Williams, 1990), which is incorporated in SWAT, was used to fill gaps in the measured records.

- River discharge monthly data (Figure 2c,d) required for calibration-validation were obtained from Global Runoff Data Center(GRDC, http://grdc.bafg.de) for 63 hydrometric stations for the period 1970–2008.

The preliminary model was set up using a drainage area of 1000 km^2 as the threshold for the delineation of watersheds. This resulted in 1629 sub-basins which were characterized by dominant soil, land use, and slope (Figure 3). The initial run period was 1970–2008, considering 3 years as the warm-up period.

A first run on sensitivity analysis, calibration and uncertainty analysis were performed for the hydrology using river discharge. Initially 22 parameters sensitive to discharge were selected based on the literature (Table 1).

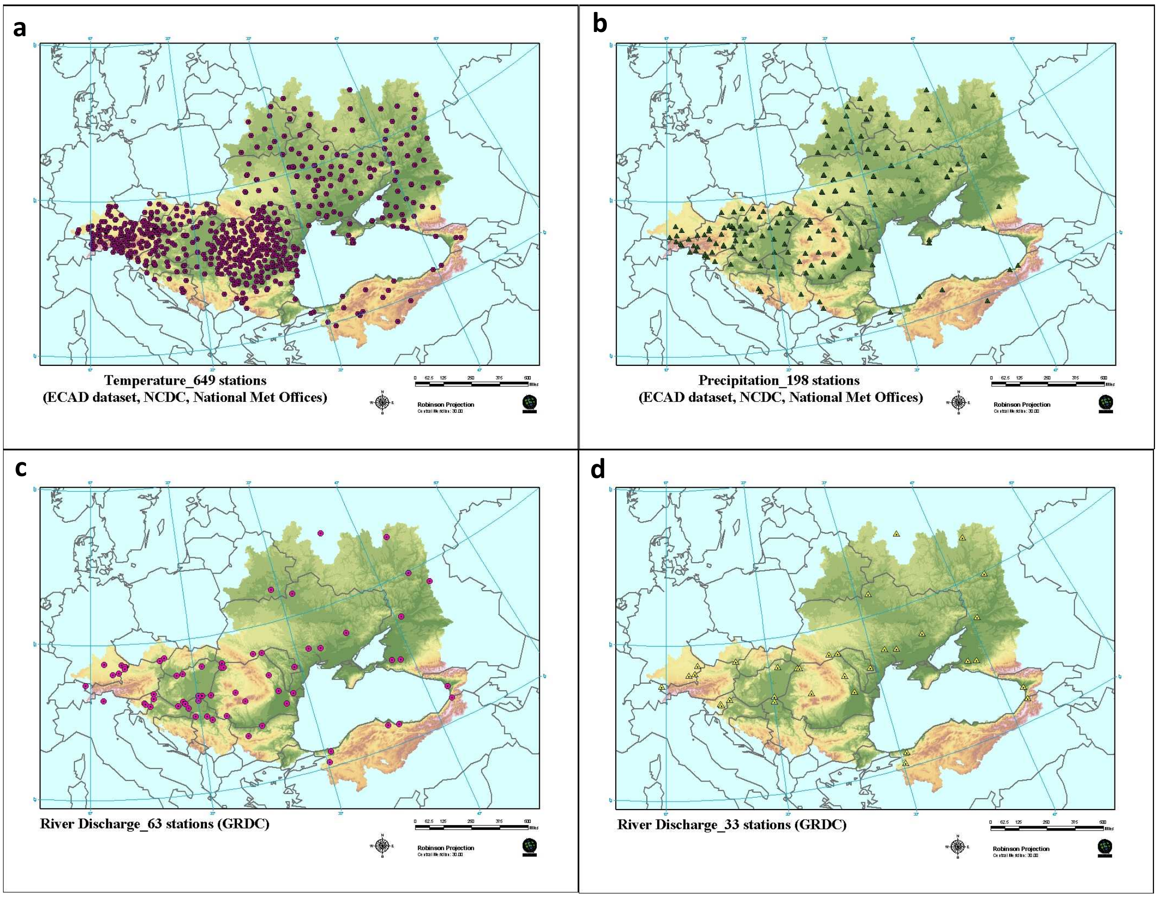

Figure 2. Showing a) temperature station distribution, b) rainfall gauges, c) all discharge stations, d) discharge stations with promising results

Table 1. Parameters used for the preliminary run and their initial ranges

Parameter	**Range**	**Parameter**	**Range**
v__SURLAG.bsn	1-24	v__GWQMN.gw	0-5
v__SMTMP.bsn	-5-5	v__RCHRG_DP.gw	0.01-1
v__SFTMP.bsn	-5-5	v__ESCO.hru	0.5-1
v__SMFMX.bsn	0-10	v__EPCO.hru	0.01-1
v__SMFMN.bsn	0-10	r__OV_N.hru	-0.6-0.6
v__TIMP.bsn	0.01-1	r__SOL_AWC(1).sol	0-0.6
r__CN2.mgt	0-0.5	r__SOL_K(1).sol	-0.8-0.8
v__ALPHA_BF.gw	0-0.1	r__SOL_BD(1).sol	-0.5-0.5
v__REVAPMN.gw	50-100	r__SOL_ALB(1).sol	-0.5-0.5
v__GW_DELAY.gw	0-500	v__CH_N2.rte	0-0.3
v__GW_REVAP.gw	0.05-0.2	v__CH_K2.rte	0-100

The SUFI-2 (Abbaspour et al., 2007) algorithm was used for a preliminary run. In this algorithm all uncertainties (parameter, conceptual model, input, etc.) are mapped onto the parameter ranges, which are calibrated to bracket most of the measured data in the 95% prediction uncertainty (Abbaspour et al., 2007). The overall uncertainty in the output is quantified by the 95% prediction uncertainty (95PPU) calculated at the 2.5% and 97.5%

levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. In order to compare the measured and simulated monthly discharges we used bR^2 as the objective function (Faramarzi et al., 2009). In SUFI-2 as a measured discharge signal is compared against a simulation band represented by 95PPU, two statistics are defined for assessing the goodness of fit and degree of uncertainty captured by the model. These statistics are referred to as *P-factor*, which is the percentage of observed data bracketed by the 95PPU and the *R-factor*, which is the average thickness of 95PPU divided by the standard deviation of the observed data. Ideally, *P-factor* should tend towards 1 (e.g., 100% of observed data captured by the 95PPU band), and *R-factor* should tend towards zero (e.g., uncertainties should be small). Observed data not captured by the 95PPU band are indicative of errors or processes not captured by the model.

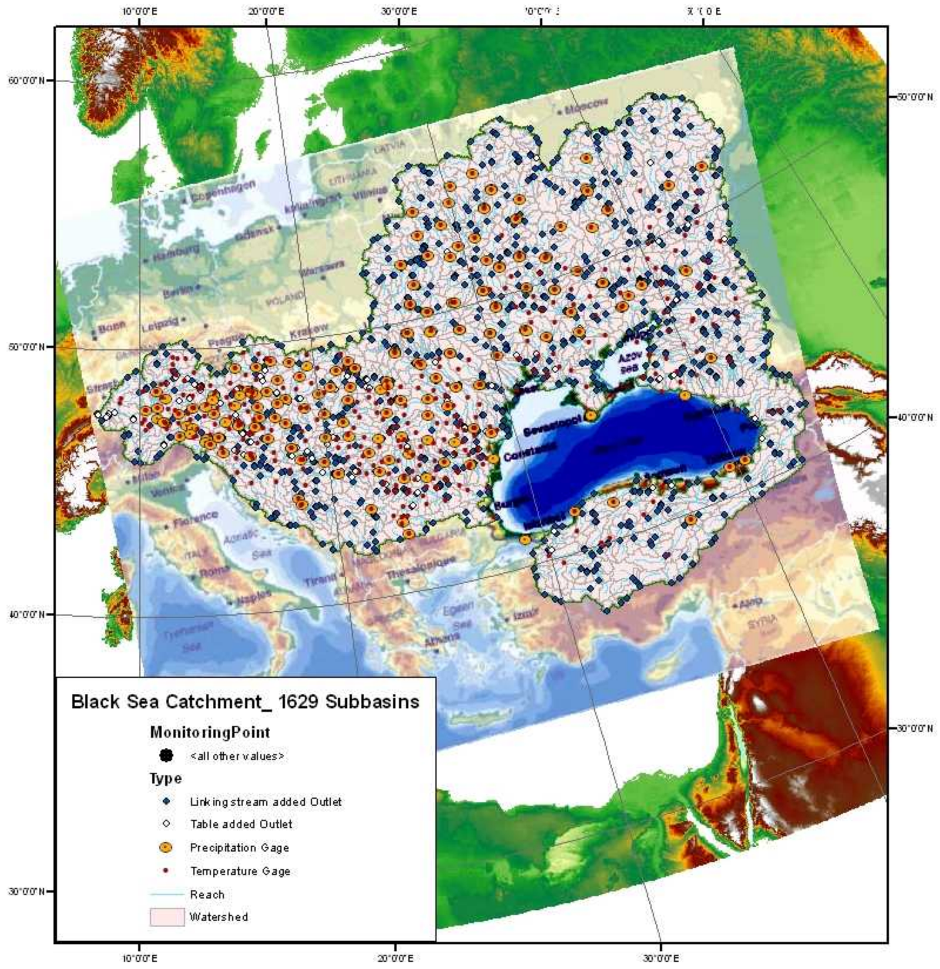

Figure 3. Black Sea Catchment as delineated by SWAT showing subbasins, weather stations, outlets, and the river system.

Results and Discussions

So far we have only performed preliminary calibration of Black sea hydrologic model. Figure 4 illustrates the *NS* statistics for all the outlet stations. It is seen that about 30 stations located in the Danube River Basin have quite small *NS* coefficient. These stations need to be further studied, but our initial guess is that the intense management of this river may not allow calibration of these outlets unless they are naturalized or detail management information is available. Quiet a few stations have *NS* coefficient larger than -1, which is quite promising as an initial run. With calibration, better results could be obtained.

Figure 5 shows the 95PPU for two good (Figure 5a, b) and a poor (Figure 5c) discharge simulations. In the DRAGESTI station 81% of the measured data is bracketed by the 95PPU band (*P-factor* = 0.81), with a relatively small *R-factor* (1.24), which represents a small level of uncertainty in the prediction. In the LUNGOCI station *R-factor* is larger (1.58) while *P-factor* is smaller (0.74) indicating a larger model uncertainty. Both stations show a good representation of the discharge dynamics indicating calibration could significantly improve model performance. The SENTA station, however, shows a large discrepancy between the measured and modeled results. Although the dynamics of predicted results is quite good (R^2 = 0.29), the large *P-factor* (3.43) here indicates quite large model uncertainty. Clearly different processes are at work here as compared with the other two stations. In further analysis we need to investigate these processes in more detail.

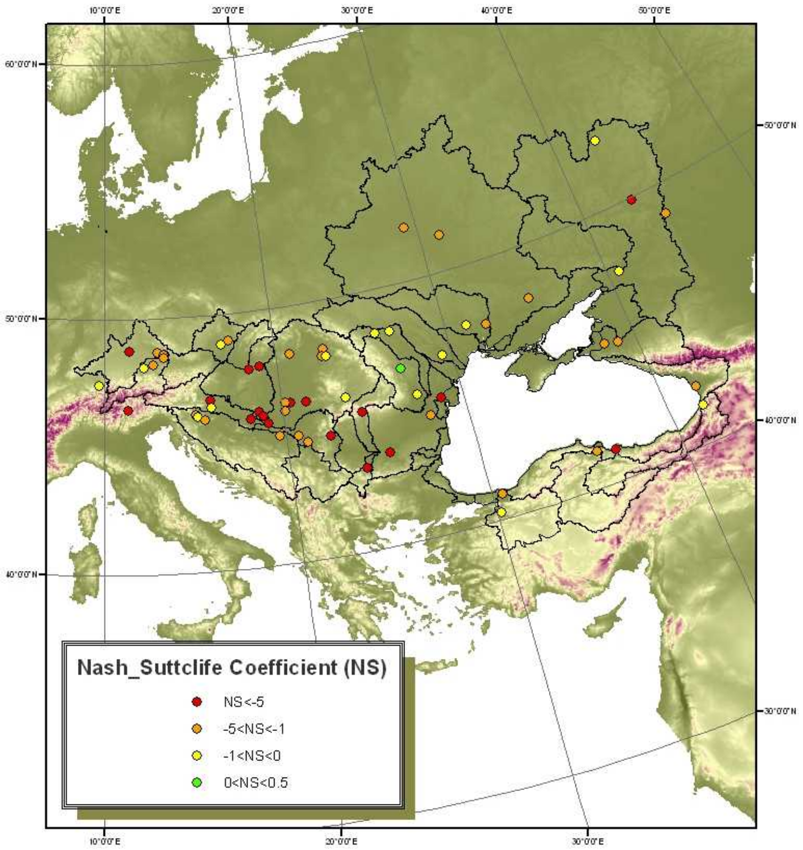

Figure 4. Nash-Sutcliffe (NS) coefficient for 63 discharge stations across the study region.

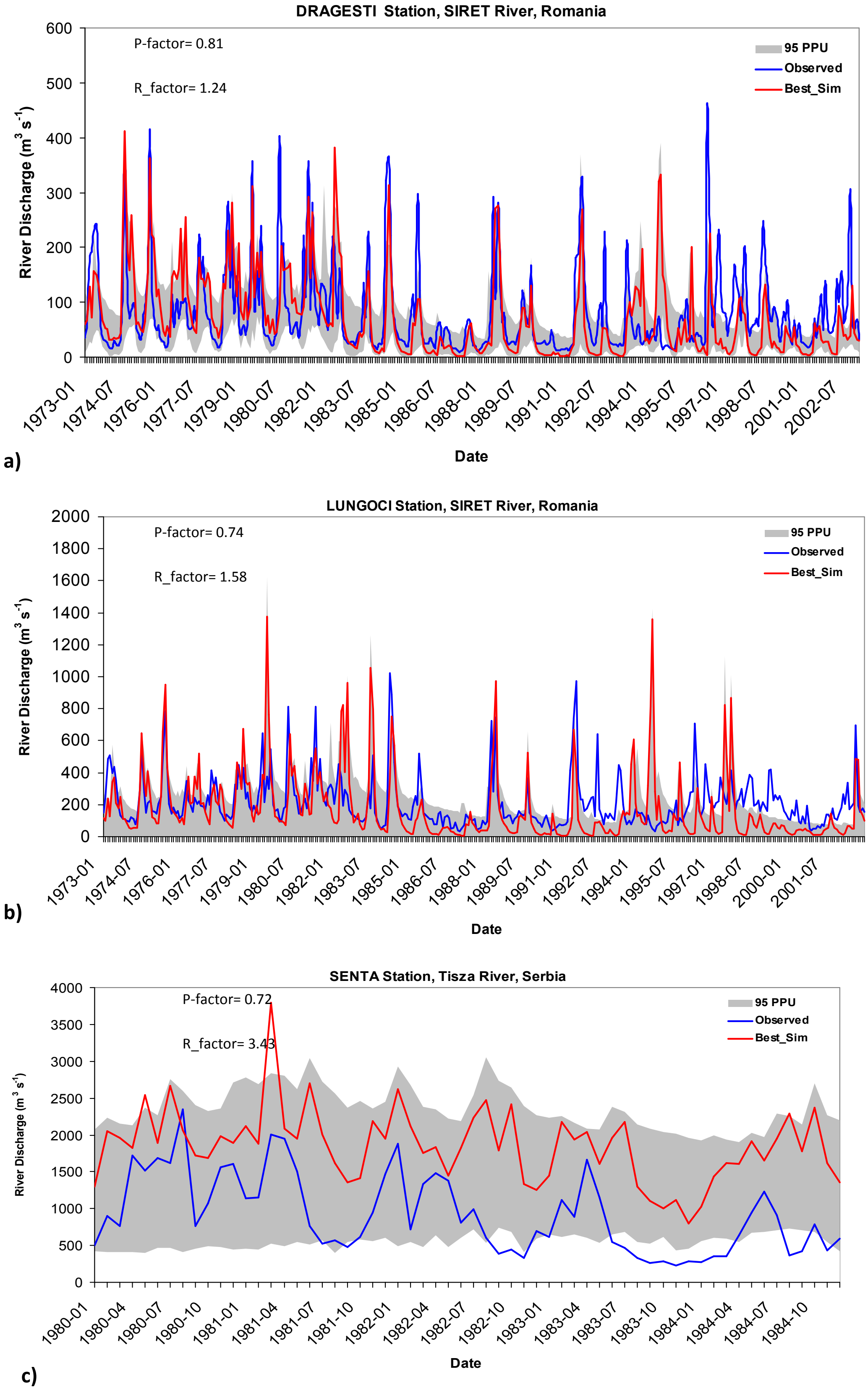

Figure 5. Time series graph of discharge at three stations showing the 95PPU (shaded region), best simulation, and observed data.

As part of information dissemination, we created a visual platform using GeoServer (http://geoserver.org/display/GEOS/Welcome), where calibrated SWAT outputs are projected on the Google Earth for ease of referencing (Figure 6). All the information layers in the ArcGIS rasters are accessible in this platform. This tool could be very useful during the calibration procedure as some management operations around the outlets could be detected such as existence of reservoirs, dams, and intensive agricultural sites. Furthermore, one could examine the correctness of the location of the outlets as they are placed by the ArcSWAT interface.

To speed up the process of calibration and future scenario analyses we gridify the running of SWAT on the CERN computing grid. To accomplish this, SUFI-2 was used in parallel processing by distributing the number of runs as separate jobs on several computers. A Linux version of SWAT and SUFI-2 is created for gridification where after distribution of runs the outputs are collected and compiled for post processing, e,g, objective function calculation and calculation of the 95PPU. This system enables running, for example 1000 runs, in parallel so that the total length of execution time equals the time needed for one SWAT run.

A similar approach is being developed for PCs with many CPUs where several jobs are automatically assigned to each CPU and the final outputs are collected for post processing. This grid computing and visualization on Google Earth will soon be available to users in the SWAT-CUP package.

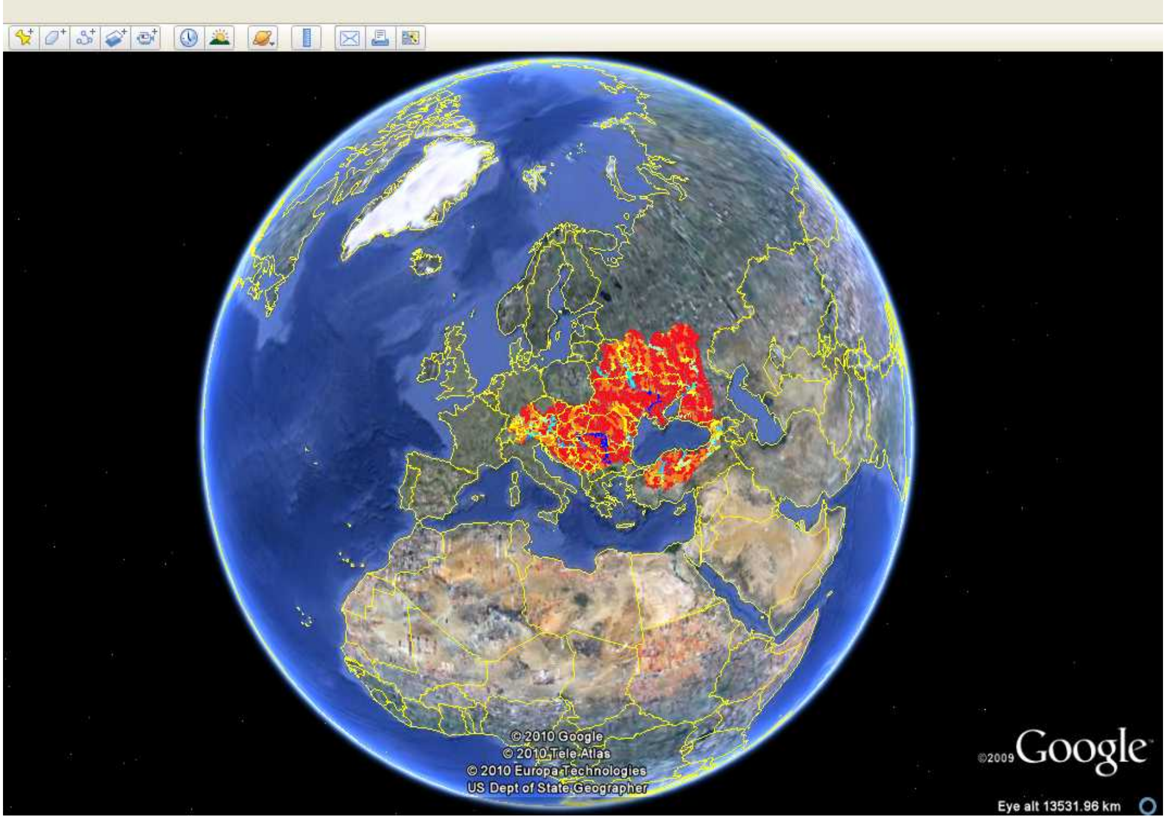

Figure 6. Black Sea Catchment long-term discharge map visualized on Google Earth via GeoServer infrastructure.

Conclusion

A preliminary SWAT model of the BSC was built and tested. We concluded that many stations in the region could be quite well calibrated while some may not be due to intense management. Building of a more detailed model incorporating major dams and agricultural processes is underway. We also found that the use of calibration and uncertainty analysis program SWAT-CUP is indispensible for the calibration of the BSC model. The use of a platform for visualizing SWAT outputs on Google Earth was found to be extremely useful for model calibration as well as running SWAT-CUP on grids, which speeds up the running of calibration and scenario analyses.

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A1-6

Preliminary Results of the Application and Calibration of a Hydrological Model in Europe

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Abstract

Previous studies have shown that SWAT is applicable to large scales , but with an increasing scale, the data collection and preparation becomes more challenging and time consuming. Hence a first main goal of the project is to set up a European Database. Spatial maps such as elevation information, soil and landuse were obtained from global datasets (USGS) or from European projects (CORINE Land Cover Project). An extensive effort was made in setting up a European climate database which consists now of over 2000 climate records containing good quality data. For calibration purpose, a discharge dataset obtained from GRDC (Global Runoff Data Centre) is available containing around 150 monthly discharge observations. After a successful model setup, first calibration results using the SUFI-2 algorithm are promising but also outline the main problems to solve. Extreme climatic regimes such as those encountered in north-eastern Europe require special treatment in the calibration process. In the first results, a trend of underestimating runoff can be observed, independent of the location of the watershed. This leads to the conclusion that the climate station network may not lead to satisfying results as precipitation input is unreliable.

Keywords: SWAT, large scale application, Europe, hydrological modeling

Introduction

The use of large scale hydrological models allows us to generate estimates of freshwater resources, river discharge or pollutant concentration in water balance components for an entire continental scale. The significance of this type of information, not only on a river basin scale but on an inter-country level has been perceived in various publications (Jackson et al., 2001; Döll et al. 2003; Alcamo et al., 2008,). Large-scale watershed models could also be used as independent tools to support decision makers. With this type of modeling, impact of issues such as climate change, land cover change and demographic changes on water availability could be assessed, leading to a better base for water management decisions.

Until now, large scale applications have focused on global assessments (Vörösmarty et al., 2000; Shiklomanov, 2000; Alcamo et al., 2003; Döll et al., 2003), on the African continent (Schuol et al., 2008a,b), on the Indian subcontinent (Gosain et al., 2006), and on Iran (Faramarzi et al., 2009). The program SWAT (Arnold et al., 1998) was used on the last three applications. In our project, the aim is to model the European continent using the SWAT model with a special focus on the blue and green water concept (Falkenmark and Rockström, 2006). In the European project, relevant climate and landuse scenarios will be included to assess their impact on water resources availability. When it comes to freshwater issues, Europe is generally not known as a hot spot of water shortage. However, at present some countries at the Mediterranean Coast are already experiencing water shortage during the summer months which will not ease according to future climate scenarios (Vörösmarty et al. 2000). This may either be due to a high water withdrawal rate or low water availability. When looking at the spatial differences in Europe regarding population density, water demand and water supply, it can no longer be avoided to have a serious assessment and discussion about water politics in Europe. Population density and water availability varies highly throughout the continent and water storage or transfer is since long part of the solution in order to meet the water demand all over the continent. European countries are in general highly industrialized and maintain at the same time a large part of the land resources as agricultural farmland. This inevitably leads to water quality problems as the results of an excessive use of pesticides and fertilizers, making the supply of high quality water in many regions a challenging task.

On the European continent, on a rather small area (around 10 Mio km2), different kinds of climatic and geomorphologic conditions or land cover classes can be found. Rivers are widely used for energy production or water storage; population density varies from very low to highly urbanized areas. These factors make a successful model application to the European continent a challenge.

In this paper we are presenting the results of a preliminary setup and calibration effort of the European model. Due to the high variety of characteristics in the study area, we are expecting to take a step by step regional calibration approach towards a good model performance. In this paper, it is also a goal to come up with suggestions on how to overcome some of the problems encountered, which may help other users in the modeling community when dealing with similar complications.

Data sources

Successful modeling requires input data of good quality. On a large scale the required amount of data is large and should thus be freely available. Data sources used in this project are free of charge and mostly available on the internet. The following datasets have been used:

- *Digital elevation model* (DEM) was constructed from the US Geological Survey's (USGS) public domain geographic database HYDRO1k (http://edc.usgs.gov/products/elevation/gtopo30/hydro/index.html), which is derived from their 3000 digital elevation model of the world GTOPO30. HYDRO1k has a consistent coverage of topography at a resolution of 1 km.
- The *land use map* is a product of the European Environmental Agency, the CORINE Land Cover project (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster) provides land use information for all EU countries on a resolution of 100 m. To cover the non-EU countries, the CORINE map was combined with the U.S. Geological Survey's public domain land use map with an original resolution of 1 km (http://edcsns17.cr.usgs.go/glcc/glc.html).
- The *soil map* was published by the Food and Agriculture Organization of the United Nations (FAO, 1995). It holds around 5'000 soil types at a spatial resolution of 10 km.
- *Climate data* stems from various sources. Most climate records are part of the 'Global surface summary of the day' of the National Climatic Data Centre (NCDC, http://www.climate.gov/#dataServices/dataLibrary), available on their homepage. A second main source for climate data is the European Climate Assessment & Dataset (ECAD, http://eca.knmi.nl/dailydata/predefinedseries.php) which covers some additional climate stations. Some national meteorological services provide daily climate records free of charge and were also added to the climate database. Due to the different sources of climate data and

to ensure good data quality, a thorough quality check was applied. The temporal and spatial resolution of the raw climate records is highly variable. But as the number of records is too high to allow an individual quality check, a routine was written which is applicable to all stations. Records with more than 10 years of data have been included, which led to a total number of around 2000 temperature and 1200 precipitation records.

- The *stream network* from the Digital Chart of the World (DCW, http://www.maproom.psu.edu/dcw) homepage was used for the project.
- *Discharge measurements* for calibration purposes were provided by the Global Runoff Data Centre (GRDC, http://grdc.bafg.de) on a monthly resolution.

Model Setup

The European model setup was carried out using the ArcSwat interface in ArcGIS (Winchell et al., 2007). Europe has an area of around 10 Mio m^2, using a threshold area of 150 km^2 led to approximately 3000 subbasins, which were then manually edited to 2186.

In order to include as many discharge measurements as possible, some changes to the outlet table needed to be done by hand during the delineation process. For the HRU generation, only the dominant landuse and soil type were used to keep the computational time down.

The final setup including the streams, the watershed outlines and the climate stations is shown in Figure 1. Climate information has a high spatial density in Mid-Europe, but is rather scarce on the Iberian Peninsula, in France, Greece, the former Yugoslavian countries, and in Eastern Europe.

Calibration techniques

The first setup of the European project does not include any reservoirs, lakes or wetlands. Hence good calibration results are only expected for more or less pristine rivers. To get preliminary ideas of where additional information needs to be applied a first calibration round was carried out nonetheless. For this purpose, the SUFI-2 (Abbaspour et al., 2007) algorithm of SWAT-CUP (Abbaspour et al., 2010) was used choosing the Nash-Sutcliffe efficiency as the objective function.

Results

The results of an original model setup are shown in Figure 2. Nash-Sutcliffe (NS) efficiencies of river discharge simulations are plotted on the respective locations on the streams. Considering the performance of a model with a NS value of zero being as good as the observation average, the results are not satisfying. NS values for a selection of rivers are listed in Table 1.

Figure 3: Setup of European Project, stream reaches in blue, watershed outlines in pink, precipitation stations in green and temperature stations in yellow.

However, at first glance the region in north Russia exhibits a pattern of similar, rather high, NS values. Figure 3 illustrates the calibration results at two stations at Kolva and Pechora rivers. The regularity in the occurrences of the peak flow leads to the assumption, that yearly discharge fluctuations are governed by the annual snow melt period. This theory is supported by the fact that climate in north east Europe is described with long cold winters and short hot summers. This leads to a short but intense snow melt period at the beginning of the summer season. This pattern is rather nicely captured by the model while the discharge volume at peak time is underestimated. For the discharge stations in north east Europe, a calibration approach will be an increase in snow water accumulation to increase the water storage volume in the watershed.

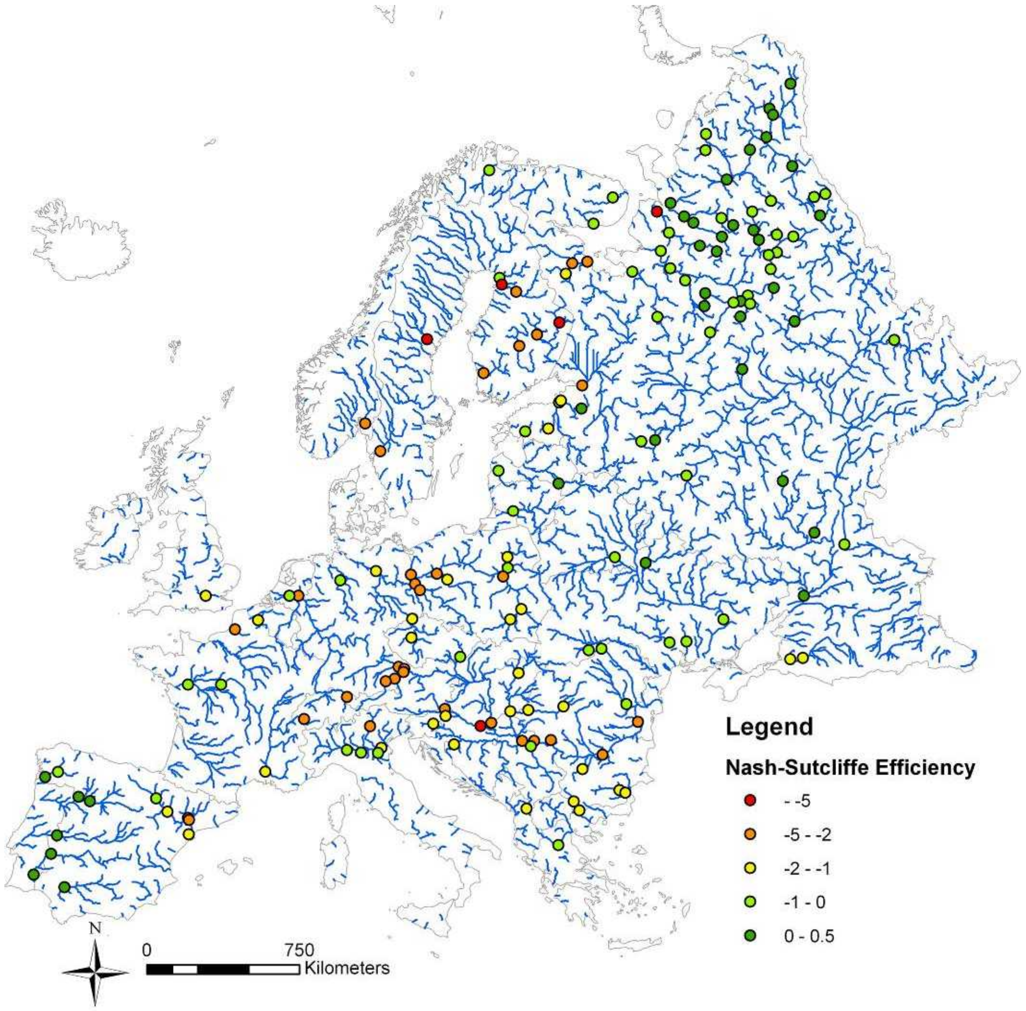

Figure 4: River streams and calibration results for the European Continent.

A second cluster of stations with promising calibration results is located on the western side of the Iberian Peninsula. As an illustration example, discharges at Duero and Guadalquivir rivers with a NS value of 0.41 and 0.31, respectively, are shown in Figure 4. These results promise a successful calibration, as the discharge volume and the pattern are already well represented. At Guadalquivir river, baseflow is in general too low in the model output, hence infiltration and soil storage parameters will be included for further calibration efforts.

Figure 5 shows the Danube river at two exemplary stations, at Hofkirchen, which is the upstream station and at Harsova, the downstream gauge. At both locations, the discharge volume is highly underestimated, not only the best simulation but also the 95PPU band does not fit the discharge peaks. This underestimation of discharge is even more pronounced for the downstream station. The Danube is the largest river in Europe and is highly influenced by human management hence it is not surprising that calibration is not successful at the first approach. On the other hand, the systematic underestimation of discharge leads to the conclusion that the water input in the model may be too low. This effect is accumulating along the stream and thus the lack of discharge is more distinct downstream. A look at two other major European rivers supports this idea. In Figure 6 the Rhine river and the Po river at one station each are displayed. While at the Po station in Portelagoscuro, the model captures the timing and the amount of some peaks rather well, at Lobith, the Rhine discharge is continuously underestimated.

Table 2. Nash-Sutcliffe Efficiencies for a selection of rivers at the respective stations.

Location (Lat / Lon)		River	Station	Observed discharge [m3/s]	Simulated discharge [m3/s]	NS value
44.68	27.94	Danube	Harsova	5998	2725	-2.46
48.68	13.12	Danube	Hofkirchen	640	320	-3.07
47.92	35.15	Dnepr	Dnepr Power Plant	1492	2130	-0.14
41.58	-6.19	Duero	Puente Pino	275	268	0.41
42.18	-1.69	Ebro	Zaragoza	620	121	-1.05
50.79	14.23	Elbe	Decin	303	66	-1.67
37.82	-7.63	Guadiana	Pulo do Lobo	156	150	0.31
65.97	57.37	Kolva	Kolva	161	120	0.42
47.38	-0.83	Loire	Montjean	838	537	-0.65
65.03	45.62	Mezen	Malonisogorskaya	642	195	0.06
52.77	14.32	Oder	Gozdowice	530	199	-2.42
67.60	52.20	Pechora	Oksino	4444	1465	-0.02
44.88	11.60	Po	Pontelagoscuro	1513	897	-0.35
51.84	6.11	Rhine	Lobith	2227	1055	-2.29
43.2	4.67	Rhone	Beaucaire	1709	1004	-1.50
46.25	20.17	Tisza	Szeged	828	368	-1.16
66.55	59.42	Usa	Adzva	943	264	0.03
52.25	21.03	Vistula	Warsaw	561	245	-2.05
56.51	34.93	Volga	Staritsa	153	119	0.16
52.42	16.97	Warta	Poznan	114	36	-1.97
52.59	9.11	Weser	Liebenau	194	156	-0.05

At this time overall model uncertainty is high but after a second calibration effort parameter uncertainty is expected to decrease substantially. Remaining uncertainty will be mostly accounted as input uncertainty which is not affected by calibration.

Climate input is a driving force of a hydrological model; hence, it is inevitable to use reliable climate information. Modeling on a large scale entails that no data can be produced on suited locations inside the study area but that the existing data must be used to the best outcomes. The approach in SWAT allows only one value for each time step per subbasin as climate information. This leads to situations where one climate station determines the input for more than 15 subbasins due to a coarse station network. Although Europe has probably the densest freely available climate station network globally, it is interesting to test the use of a gridded interpolated climate product. Schuol et al., 2008a,b successfully modeled the African continent using monthly gridded climate data (CRU dataset, Mitchell and Jones (2005)) on a 0.5° grid. Combined with a daily weather generator (dGen, Schuol and

Abbaspour (2007)) gridded monthly data can be brought into SWAT climate input format. The CRU gridded data will be used in our next model to test the impact of input (rainfall) uncertainty on the discharge simulation.

Conclusions

The first setup of SWAT on a European scale has successfully been completed, however, the result of initial model setup pinpointed a few regions with special situations that would need a more detail model evaluation. Main problems to overcome include handling of different climatic regimes and the highly managed river systems. The question of the input uncertainty may be examined by using gridded interpolated climate data and comparing the results to the climate network stations used at this point.

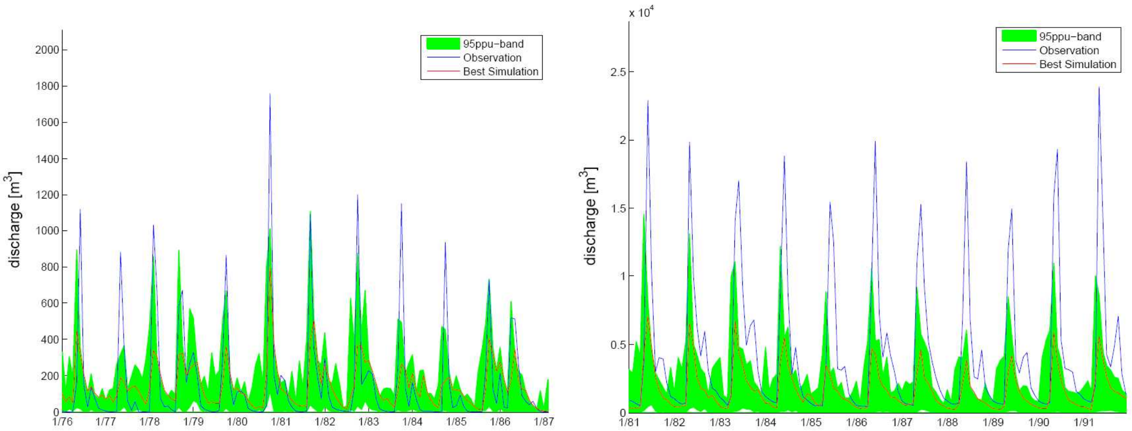

Figure 5: Observed and modeled streamflow at Kola River (Kolva) on the left side and at Pechora River (Oksino) on the right side.

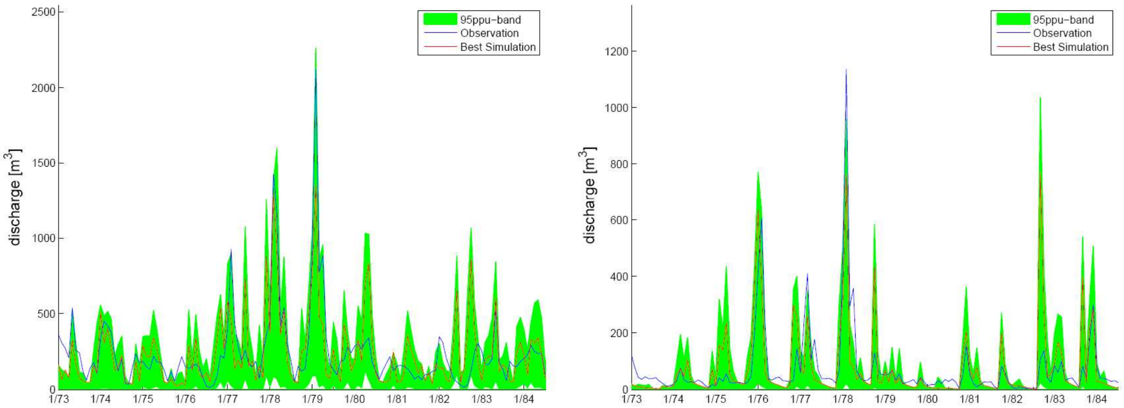

Figure 6: Observed and modeled streamflow at Duero river (Puente Pino) on the left side and at Guadalquivir river (Cantillada) on the right side.

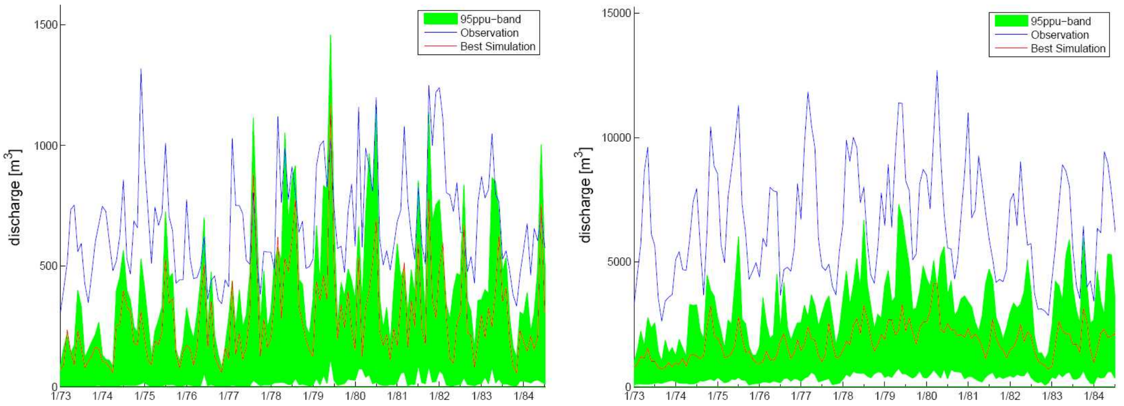

Figure 7: Observed and modeled streamflow at Danube river at the upstream station Hofkirchen on the left side and the downstream station Harsova on the right side.

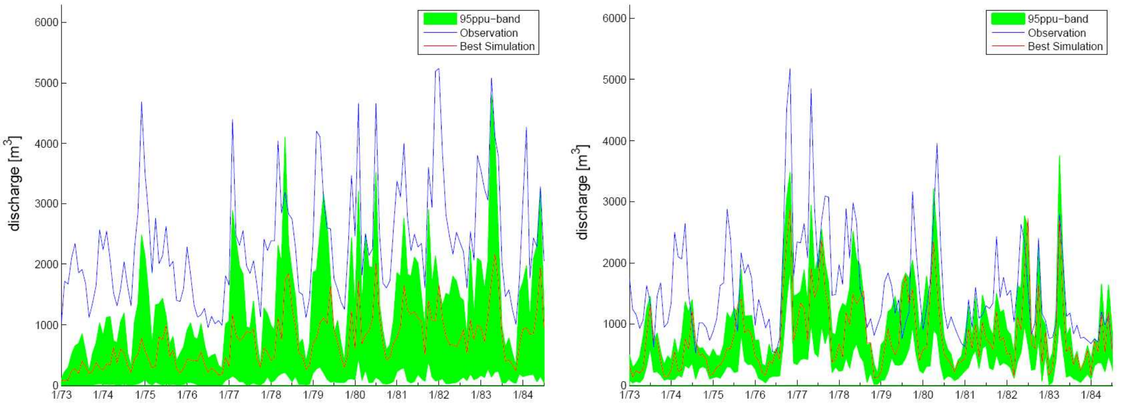

Figure 8: Observed and modeled streamflow at Rhine river (Lobith) on the left side and Po river at Pontelagoscuro on the right side.

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Hydrologic Calibration of the SWAT Model for African River Basins using GRACE data

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Abstract

The Soil and Water Assessment Tool (SWAT) is a well-known river basin model with a proven track record of successful applications at smaller scales. In recent years the SWAT model has also shown potential for watershed studies at larger scales. In this presentation, we report on a study calibrating the SWAT model using total water storage variation data derived from the Gravity Recovery and Climate Experiment (GRACE) in an endeavor to develop large-scale SWAT applications to model the water budget of sub-Saharan Africa. Conventionally, the hydrologic calibration of SWAT relies solely on river discharge data. The use of the GRACE data provides additional constraints for SWAT model conditioning and offers the opportunity to evaluate and improve the SWAT model in regions where the river system is poorly monitored. However, incorporating the GRACE data into the SWAT model calibration is nontrivial due to the inherent uncertainties introduced in GRACE data processing. In our study, we chose to sample the SWAT output on a 0.5° latitude by 0.5° longitude grid and filter the grid-based SWAT estimates of total water storage variation to correct the filter-induced bias arising from the GRACE data processing. The methodology and preliminary results will be presented, and other data issues for developing large-scale SWAT application will also be discussed.

Keywords: SWAT, GRACE, Hydrologic calibration, sub-Saharan Africa

Introduction

Soil moisture is an important hydrologic component of water balance, and it would be ideal to use soil moisture for model calibration if measured data are available at study area. It is a state variable to affect the plant and crop actual evapotranspiration (ET), storage capacity for surface runoff and subsurface flow, and recharge to groundwater. However usually due to the lack of measured soil moisture data to represent the spatial soil moisture distribution for an interesting area, we need a pseudo indicator of soil moisture condition.

The soil moisture is highly dependent on the surface temperature and its vegetation vitality under the spatial land cover condition. Recently, researches to evaluate the watershed scale soil moisture have been attempted by using satellite products to overcome the limited information of field scale soil moisture. The monitoring and modelling of land surface and/or vegetation processes by using satellite images viz. NOAA AVHRR (Advanced Very High Resolution Radiometer) and Terra MODIS (Moderate Resolution Imaging Spectroradiometer) is now popular for the assessment of hydrologic behaviour. Many studies to couple the land surface or vegetation condition with soil moisture have been tried. The trace of subsurface soil moisture via surface vegetation condition is useful to prepare data as the initial condition of moisture information for a hydrologic model run and can be used for the warning level of forest fire. Meanwhile, soil temperature is one of the key variables in the physics of land surface processes, which influences energy and water cycles of land–atmosphere system, and largely depends on soil moisture and fractional vegetation cover. Furthermore, soil moisture is a function of soil temperature, so subsurface temperature influences soil moisture transfer in different soil layers (Huang et al. 2007).

A number of studies (Sandholt et al., 2002; Carlson, 2007; Nemani et al., 1993) have suggested that the information from LST and NDVI (Normalized Difference Vegetation Index) can provide better information on vegetation stress and moisture conditions at the surface. Farrar et al. (1994) found that soil moisture and NDVI are well correlated in the plant growing periods. Hutchinson et al. (2006) generated spatially-distributed near surface soil moisture conditions using readily available NOAA AVHRR products on a repetitive basis for Fort Riley, Kansas, and Narasimhan et al. (2005) analyzed the correlation between soil moisture and NDVI in pasture. NDVI also has been used to estimate evapotranspiration (ET) that is strongly related to soil moisture. Ann (2003) calculated soil moisture using ET estimated by NDVI with weather data. Hwang et al. (2006) estimated soil moisture using SWAT model and performed a drought monitoring. Hence, NDVI and LST can be a useful indicator to analyze the soil moisture during the active growing of crop or plant, and to determine the soil moisture condition for drought monitoring (Narasimhan et al., 2005). Thus, this study is to identify how much MODIS NDVI and LST products can explain soil moisture of forest area by using SWAT simulated soil moisture results. The 9 years (2000-2008) monthly MODIS NDVIs and LSTs were prepared, and the spatial analyses were conducted the SWAT simulated forest soil moistures for a 2,694.4 km^2 mountainous watershed of South Korea.

Materials and Methods

Study watershed

A 2,694.4 km^2 forest-dominant watershed located in the northeast of South Korea was adopted. It lies between 127° 45’ E - 128° 32’ E and 37° 39’ N - 38°33’ N. The watershed has 18.9 % deciduous, 53.1 % evergreen, and 21.0 % mixed forests respectively. The Soyanggang Dam at the watershed outlet has important roles to supply municipal water of Seoul metropolitan city and protect flood attack from storms and Typhoons, and is the only multipurpose dam in Bukhan-river basin. The dam of 2.7 billion m^3 of water storage capacity has been operated by K-water (Korea Water Resources Corporation) since 1973. For the proper reservoir water level management especially in case of drought and flood conditions, the dam inflow estimation from the watershed is very important and the accurate estimation largely depends on the soil moisture information of the time. For the dry spring, the forest fires by the spontaneous combustion have been occurred in connection with dryness of soil moisture at first, litters secondly.

The annual average precipitation is 1,359.5 mm, the mean temperature is 9.4 ℃, the relative humidity is 71.0 %, the wind speed is 2.17 m/sec, and the solar radiation is 13.42 MJ/m^2 over the last 30 years (1977-2006). For the analysis, the watershed was subdivided into 3 sub-watersheds, which the division locations are Wontong, Naerincheon, and SoyanggangDam water level gauging stations.

SWAT model and input data

The Soil and Water Assessment Tool (SWAT) is a physical bases and continuous, long-term, distributed-parameter model designed to predict land management practices on the hydrology, sediment and contaminant transport in agricultural watersheds with varying soils, land use, and management conditions (Arnold et al., 1998). SWAT is based on the concept of hydrologic response units (HRUs) which are portions of a subbasin that possess unique land use/management/soil attributes. The runoff, sediment, and nutrient loadings from each HRU are calculated separately using input data about weather, soil properties, topography, vegetation, and land management practices, and then summed together to determine the total loadings from the subbasin.

The model uses spatially distributed data on elevation, soil, land use, and weather data for hydrologic modelling and operates on a daily time step (Narasimhan et al., 2005). For the elevation, 30 m DEM (Digital Elevation Model) was produced from 1:5,000 vector maps supplied by the Korea National Geography Institute. The 30 m land use data were prepared by 2000 Landsat TM (Thematic Mapper) supervised classification with NOAA NDVI. The 1:25,000 soil data were obtained from Korea Rural Development Administration. Loam and loamy sand dominate, covering 52.4 % and 42.4 % of the watershed, respectively.

Weather data of SWAT are precipitation, maximum and minimum air temperatures, wind velocity, relative humidity, and solar radiation. For this study, 11 years (1998-2008) daily precipitation from 18 automatic weather stations (AWS), and other meteorological data at 5 weather stations were obtained from Korea Meteorological Administration.

In the pre-processing of model run, the study watershed was divided into 20 subbasins. In turn, the subbasins were subdivided into 348 HRUs (Hydrological Response Unit). The SWAT model creates input parameters, and performs simulation through HRU.

SWAT soil water routing

The SWAT model runs on a daily time-step. The hydrological component is based on the soil water balance equation as Eq. (1).

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - w_{seep} - E_a - Q_{gw}) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of returnflow on day i (mm H_2O).

Terra MODIS NDVI and LST data

NDVI is a distributed vegetation condition index, using difference of reflectivity in near infrared light. NDVI not only maps the presence of vegetation on a pixel basis, but also provides measures of the amount or condition of vegetation within a pixel (Wan et al., 2004). The NDVI value is calculated by Eq. 2 for each grid cell.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where *NDVI* is Normalized Difference Vegetation Index, *NIR* is Near Infrared Ray (MODIS band 2), *RED* is Red band (MODIS band 1).

The MODIS produces the NDVI at 16 days temporal and 250, 500, 1000 m spatial resolutions. To obtain the MODIS NDVI data among the products, the MODIS 250 m NDVI 16-days composite scenes (MOD13Q1) from 2000 to 2008 were downloaded at the Earth Observing System Data Gateway. The 16-days temporal resolution means a composite image using MVC (Maximum Value Composite) during that period. The MVC minimizes the influence of the clouds atmosphere (air molecules, water vapour and aerosols).

LST can be obtained from satellite sensors such as MODIS thermal infrared (TIR) sensors on board the Terra and Aqua satellites. The accuracy of daily MODIS LST products has been validated in more than 20 clear-sky cases with in situ measurement data. The MODIS LST accuracy is better than 1 K in the range from 263 to 322 K (Wan et al., 2002, 2004).

Results and Discussion

SWAT model calibration and validation with streamflow and soil moisture data

The SWAT model was warmed up for 2 years (1998-1999), and calibrated using 5 years (2000-2004) daily streamflow data of three stations (Wontong, Naerincheon, and SoyanggangDam) and 2 years (2003-2004) daily soil moisture data of three locations (Inje, Chuncheon, and Hwacheon).

The model was validated for 4 years (2005-2008) streamflow and soil moisture data. Multisite calibration enhances the calibration results from the viewpoint of spatial variation of the hydrologic response. The calibrated model parameters are shown in Table 1.

Figure 1 shows the comparison of observed and simulated streamflows at Soyanggang Dam of the three stations, and Tables 2 shows the statistical summary of model results. The root mean square error (RMSE) and Nash-Shutcliffe model efficiency (NSE) for validation period were 2.2 mm/day, and 0.7 at Wontong station, 3.0 mm/day, and 0.7 at Naerincheon, and 2.4 mm/day, and 0.7 at Soyanggang Dam station respectively. The NSE value means that the model predicted 70 % better than simply using the average streamflow value during that period. Figure 2 and Table 3 show the comparison of observed and simulated soil moisture at Inje of the three locations, and the statistical summary of model results respectively. The average determination of coefficient (R^2) at Inje, Chuncheon, and Hwacheon were 0.6, 0.5, and 0.6 respectively.

As seen in Figure 1, the error of streamflow in the low flows may come from the uncertainties of forest humus layer function and groundwater parameters during model calibration. Also, the peak runoff errors may be caused by the difference between real and simulated runoff mechanisms in paddy fields. Unlike the unsaturated flow mechanism in a natural environment, paddy has artificial factors such as irrigation scheduling and levee height management that increases the uncertainty of the water budget. During the paddy cultivation periods, farmers control levee heights artificially for their own water management. Irrigating water before rainfall and draining water after rainfall affect the streamflow with significant quantity.

Table 1. The calibrated model parameters at 3 subwatersheds

Parameter	Description	Calibration Range	Wontong Optimal value	Naerincheon Optimal value	Soyanggang Dam Optimal value
CN2	Curve number adjustment ratio	± 20 %	0	10	10
ESCO	Soil evaporation compensation	0.01 ~ 1	0.5	0.3	0.02
SOL_AWC	Available water capacity	± 20 %	10	- 10	5
SFTMP	Snowfall temperature (℃)	-5 ~ 5	1	1	1
SMTMP	Snowmelt base temperature (℃)	-5 ~ 5	0.5	0.5	0.5
SMFMX	Maximum snow melt factor (mm H_2O/ºC-day)	0 ~ 10	4.5	4.5	4.5
SMFMN	Minimum snow melt factor (mm H_2O/ºC-day)	0 ~ 10	4.5	4.5	4.5
TIMP	Snow pack temperature lag factor	0 ~ 1	1	1	1
LAT_TTIME	Lateral flow travel time (days)	-	3	3	2
GW_DELAY	Groundwater delay time (days)	0 ~ 500	180	150	180
CH_K2	Effective hydraulic conductivity of main channel	0 ~ 150	70	20	20

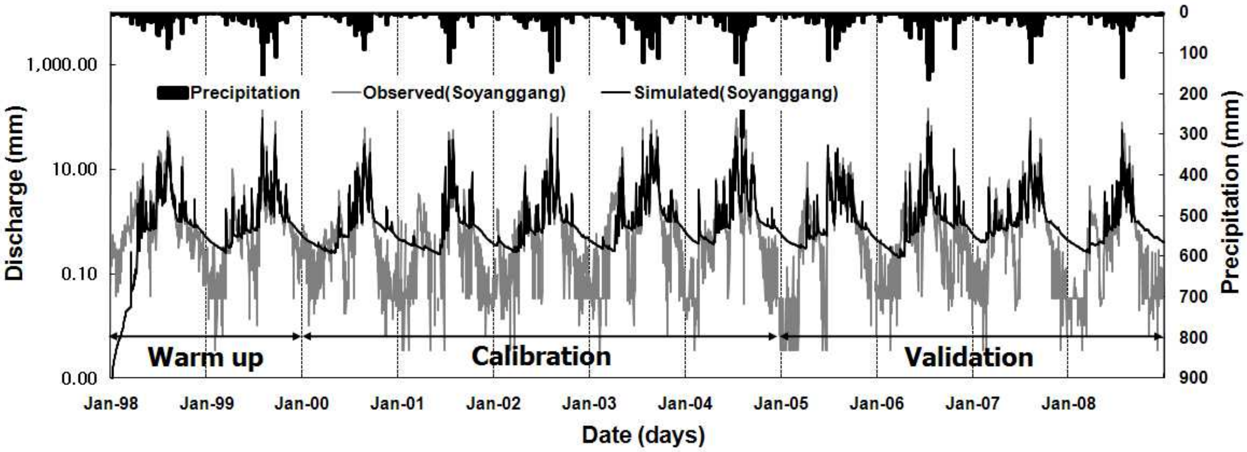

Figure 1. Comparison of observed versus simulated streamflow at Soyanggang Dam

Table 2. The Calibration and verification statistics in Soyanggang Dam station

Period	Year	Precipitation (mm)	Runoff (mm)		Runoff Ratio (%)		R^2	RMSE (mm/day)	NSE
			Obs.	Sim.	Obs.	Sim.			
Calibration	2000	1092.5	676.9	622.9	62.0	57.0	0.89	2.63	0.79
	2001	935.5	515.4	524.5	55.1	56.1	0.92	2.07	0.84
	2002	1280.5	787.7	719.4	61.5	56.2	0.76	3.25	0.69
	2003	1654.7	1276.1	1071.5	77.1	64.8	0.77	2.65	0.72
	2004	1739.0	951.3	1024.2	54.7	58.9	0.62	3.04	0.54
Average		1340.4	841.5	792.5	62.1	58.6	0.79	2.73	0.72
Validation	2005	1149.0	731.8	661.9	63.7	57.6	0.70	1.91	0.68
	2006	1562.2	1125.9	995.1	72.1	63.7	0.86	3.06	0.77
	2007	1336.2	884.6	779.7	66.2	58.4	0.82	2.09	0.70
	2008	1056.1	679.0	594.2	64.3	56.3	0.80	2.72	0.71
Average		1275.9	855.3	757.7	66.6	59.0	0.80	2.45	0.72

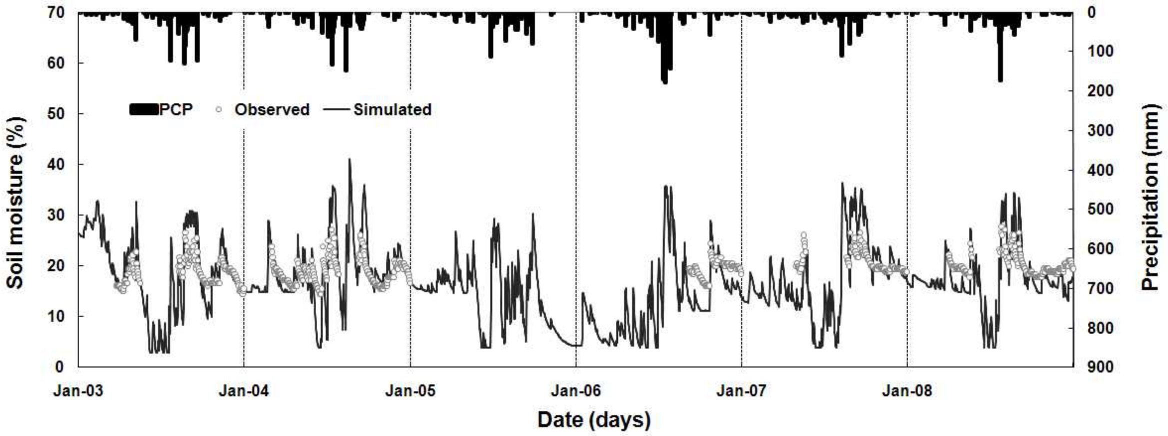

Figure 2. Comparison of the observed versus simulated soil moisture at Inje.

Table 3. The Calibration and verification statistics in three soil moisture station

Period	Year	Inje (%)		Chuncheon (%)		Hwacheon (%)		R^2		
		Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Inje	Chuncheon	Hwacheon
Calibration	2003	17.3	18.7	6.6	17.6	10.6	9.6	0.60	0.55	0.61
	2004	15.6	19.0	12.5	15.3	9.0	9.0	0.60	0.51	0.56
Validation	2005	-	-	11.8	16.1	7.1	9.4	-	0.61	0.62
	2006	14.4	12.8	-	-	-	-	0.72	-	-
	2007	19.8	17.5	-	-	13.4	10.0	0.60	-	0.65
	2008	18.9	17.4	-	-	8.4	8.9	0.64	-	0.56
Average		17.2	17.0	10.3	16.3	9.7	9.4	0.63	0.56	0.60

The correlation analysis between SWAT soil moisture and MODIS NDVI, LST

The temporal correlation analysis was conducted using the 9 years (2000-2008) monthly average data of SWAT simulated soil moisture (SM), MODIS NDVI and LST.

The results show that the soil moisture is in an inverse proportion with NDVI and LST during the leaf growing period. During the leaf growing period of forest, plants need soil water for transpiration. Evaporation from surface also increases because temperature rises from March to June of our country. Therefore the soil moisture is forced to decrease experiencing the wetting and drying process by rainfalls while NDVI and LST increases by the leaf growth. On the other hand, there were little direct proportion between soil moisture and NDVI, and almost no relation between soil moisture and LST during forest leaf falling period.

Tables 4 and 5 show the correlation results of SWAT SM versus MODIS NDVI during forest leaf growing and falling periods of each year respectively. Tables 6 and 7 show the correlation results of SWAT SM versus MODIS LST during forest leaf growing and falling periods of each year respectively.

Looking at the determination of coefficients (R^2) in Tables 4 and 6 of forest leaf growing period, the average R^2 above 0.5 with negative slope for 3 forest types was 4 times between SM and NDVI and 5 times between SM and LST for the 9 years. From Tables 5 and 7 of forest leaf falling period, the average R^2 above 0.5 with positive slope was 3 times each for NDVI and LST respectively.

We could not explain the high R^2 of the years definitely, but we can infer that the values are greatly affected by the rainfall frequency occurred during the period. Soil moisture directly responds to rainfall. Soil moisture increases when rainfall occurs and decreases before the next rainfall. Thus the number of soil moisture fluctuation during the period affected the temporal correlation. The soil moisture continually was decreased by the low rainfall frequency while the air temperature increased. The R^2 of leaf growing period showed the high value with the big inverse slope between two variables among the 9 years. The low R^2 appeared in case of dispersed storms occurred during the period regardless of the leaf growing or falling periods.

Table 4. The temporal correlation between SWAT simulated soil moisture and MODIS NDVI during forest leaf growing period (March-June)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	235.3	13.4	y=-2.1393x+9.7736	y=+0.2865x+8.6856	y=-2.8548x+7.9764	0.21	0.01	0.28
2001	211.5	13.9	y=-25.223x+27.016	y=-20.147x+23.375	y=-17.178x+19.279	0.67	0.58	0.63
2002	286.1	13.7	y=+4.2162x+8.1402	y=+3.0535x+9.7578	y=+0.7755x+7.6458	0.12	0.08	0.01
2003	374.6	12.6	y=-16.213x+28.043	y=-17.309x+28.402	y=-14.574x+22.958	0.76	0.82	0.72
2004	356.6	13.1	y=+6.9717x+7.6368	y=+7.8776x+7.7714	y=+3.9831x+7.2158	0.41	0.51	0.28
2005	383.1	12.8	y=-16.709x+23.950	y=-15.855x+24.347	y=-14.713x+20.488	0.87	0.80	0.78
2006	405.7	12.5	y=+6.0098x+8.5721	y=+5.8201x+8.9483	y=+3.0951x+7.8093	0.68	0.65	0.36
2007	345.4	12.6	y=-23.683x+29.736	y=-21.503x+28.595	y=-21.457x+25.797	0.97	0.97	0.95
2008	290.4	12.6	y=-9.6834x+16.847	y=-3.1432x+13.596	y=-13.221x+16.962	0.42	0.08	0.61
Average	321.0	13.0	y=-4.8919x+17.7461	y=-6.7688x+17.0531	y=-8.4605x+15.1257	0.57	0.50	0.51

Table 5. The temporal correlation between SWAT simulated soil moisture and MODIS NDVI during forest leaf falling period (September-December)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	251.6	8.5	y=+28.532x+2.6753	y=+22.524x+5.0682	y=+28.514x+0.0186	0.53	0.42	0.68
2001	157.4	8.7	y=-7.6178x+18.133	y=-12.189x+21.008	y=-1.522x+11.287	0.09	0.26	0.01
2002	167.9	7.5	y=+18.698x+5.6075	y=+9.1336x+10.486	y=+19.81x+2.7876	0.80	0.43	0.76
2003	452.3	9.0	y=+35.537x-2.2618	y=+29.42x+0.3436	y=+32.665x-2.1686	0.91	0.81	0.92
2004	272.2	9.7	y=+38.851x-5.2091	y=+33.517x-3.1374	y=+36.596x-5.9488	0.92	0.89	0.87
2005	192.6	8.2	y=+18.317x+5.9039	y=+12.434x+8.909	y=+18.333x+2.8593	0.40	0.27	0.46
2006	254.9	9.4	y=-23.788x+29.401	y=-26.003x+30.399	y=-21.302x+26.778	0.69	0.74	0.69
2007	303.2	9.3	y=+38.124x-0.9763	y=+35.385x-1.5646	y=+36.384x-2.5936	0.99	0.99	0.99
2008	142.9	9.4	y=+13.144x+6.031	y=+6.1203x+8.5509	y=+11.297x+5.3715	0.20	0.11	0.16
Average	243.9	8.9	y=+17.755x+6.5894	y=+12.260x+8.8959	y=+17.864x+4.2657	0.61	0.55	0.62

Table 6. The temporal correlation between SWAT simulated soil moisture and MODIS LST during forest leaf growing period (March-June)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	235.3	13.4	y=-0.3067x+98.383	y=-0.259x+85.29	y=-0.3216x+100.42	0.93	0.81	0.94
2001	211.5	13.9	y=-0.9957x+301.32	y=-0.907x+275.08	y=-0.7868x+237.64	0.76	0.72	0.75
2002	286.1	13.7	y=+0.0334x+1.3174	y=+0.0087x+9.3033	y=-0.0446x+21.112	0.01	0.00	0.02
2003	374.6	12.6	y=-0.7597x+239.06	y=-1.036x+319.64	y=-0.8536x+262.53	0.67	0.75	0.60
2004	356.6	13.1	y=+0.2366x-56.321	y=+0.2586x-61.955	y=+0.0517x-5.1168	0.23	0.22	0.02
2005	383.1	12.8	y=-0.3572x+116.13	y=-0.3238x+107.17	y=-0.3257x+104.47	0.97	0.97	0.96
2006	405.7	12.5	y=+0.2779x-68.113	y=+0.2957x-73.039	y=+0.1918x-45.715	0.92	0.96	0.75
2007	345.4	12.6	y=-0.8283x+255.6	y=-0.3016x+101.23	y=-0.217x+73.14	0.77	0.65	0.57
2008	290.4	12.6	y=-0.3577x+115.1	y=-0.2812x+93.117	y=-0.3511x+111.27	0.48	0.55	0.35
Average	321.0	13.0	y=-0.3397x+111.39	y=-0.2828x+95.093	y=-0.2952x+95.528	0.64	0.63	0.55

Table 7. The temporal correlation between SWAT simulated soil moisture and MODIS LST during forest leaf falling period (September-December)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	251.6	8.5	y=+0.1306x-16.047	y=+0.0682x-0.2731	y=+0.182x-33.171	0.09	0.03	0.19
2001	157.4	8.7	y=+0.0839x-10.406	y=+0.0307x+4.7949	y=+0.124x-24.715	0.08	0.01	0.26
2002	167.9	7.5	y=+0.2633x-56.447	y=+0.1246x-18.914	y=+0.3427x-80.932	0.61	0.24	0.69
2003	452.3	9.0	y=+0.5498x-135.77	y=+0.4562x-111	y=+0.5928x-149.76	0.67	0.47	0.75
2004	272.2	9.7	y=+0.6502x-166.73	y=+0.5242x-132.68	y=+0.605x-156.21	0.69	0.42	0.55
2005	192.6	8.2	y=+0.312x-70.637	y=+0.277x-61.737	y=+0.3178x-75.354	0.92	0.90	0.93
2006	254.9	9.4	y=-0.5224x+163.16	y=-0.6088x+187.86	y=-0.5272x+163.28	0.87	0.91	0.93
2007	303.2	9.3	y=+0.2364x-45.102	y=+0.2573x-53.423	y=+0.2633x-55.208	0.12	0.12	0.12
2008	142.9	9.4	y=+0.1296x-23.155	y=+0.0665x-6.7377	y=+0.1592x-33.288	0.13	0.05	0.14
Average	243.9	8.9	y=-0.3397x+111.39	y=-0.2828x+95.093	y=-0.2952x+95.528	0.46	0.35	0.51

Summary and Conclusions

Due to the lack of soil moisture ground data, we need a pseudo indicator of soil moisture condition. This study was tried to investigate the correlations between SWAT simulated soil moisture (SM) and MODIS NDVI and LST how much the NDVI and LST can explain the soil moisture for the forest leaf growing and falling periods respectively.

For the analysis, a 2,694.4 km^2 forest-dominant dam watershed was selected and 9 years (2000-2009) MODIS NDVI and LST were prepared. For soil moisture preparation, the SWAT model was calibrated and verified using the 9 years daily streamflow data at 3 stations and 6 years daily soil moisture data at 3 locations. The average Nash-Shutcliffe model efficiency for validation period was 0.7 and the average determination of coefficient (R^2) was 0.57.

The temporal correlation between the soil moisture and NDVI and LST showed an inverse proportion during the leaf growing period and a little direct proportion in leaf falling period. The correlation of SM with NDVI was on the similar level with LST for the forest leaf growing (March-June) and falling period (September-December). The 9 years average R^2 between SM and NDVI were 0.57, 0.50, and 0.51 for deciduous, evergreen, and mixed forests during the leaf growing period, and 0.61, 0.55, and 0.62 during the leaf falling period respectively. Meanwhile, the 9 years average R^2 between SM and LST were 0.64, 0.63, and 0.55 during the leaf growing period, and 0.46, 0.35, and 0.51 during the leaf falling period respectively. The soil moisture showed high correlation with the big inverse slope for NDVI and LST during the forest leaf growing period among the 9 years. The low correlation appeared in case of dispersed storms occurred during the period regardless of the leaf growing or falling periods.

In this study, we derived the simple relationship between model simulated soil moisture and vegetation index and surface temperature from satellite image. To understand the relationship between the variables, we need spatial correlation analysis and discuss with the soil because the soil moisture is dependent on the soil physical properties. In addition, we can try the multiple regression including rainfall amount or frequency as dependent variables. Other MODIS products such as LAI (leaf area index) can a candidate indicator to be analyzed.

Acknowledgements

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SESSION B1

Model Development

B1-1

Enhancement of the SWAT-REMM System for Simulation of T-N Reduction Efficiency with Riparian Buffer System at a Bonggok watershed

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Abstract

In recent years, riparian buffer system has been known as one of the effective best management practices. However, establishment of riparian buffer system in aspect of plant species and its position in the riparian buffer zone has not been investigated due to lack of efficient evaluation method for the analysis of water quality improvement with established riparian buffer system. To solve this problem, the SWAT-REMM prototype model, which also have several limitations in applying it to other watersheds because many model input parameters are not read from the local input data, was developed by the researchers in Canada. Thus the SWAT-REMM enhanced was developed by improving four major limitations - 1) riparian buffers at designated reaches in the watersheds, 2) riparian buffer using soil properties at riparian buffer zone along reaches, 3) multiple weather stations at large scale watersheds, and 4) NO_3-N loads in baseflow flowing into riparian buffers. This enhanced SWAT-REMM system was applied to the Bonggok watershed in Korea. In this study, 3 riparian buffer scenarios with different widths (10m, 5m, and 1m) of buffer zones with different canopies. It was found that T-N reduction efficiency ranged from 14.8 to 54.0 % in each subwatershed in scenario 1 10m width of established riparian buffer system. Also, T-N reduction efficiency was from 6.9 to 31.6 % in each subwatershed in scenario 3 which has 1m width of established riparian buffer system. The reduction efficiency was not proportional to the width of riparian buffer system. As shown in this study, the SWAT-REMM enhanced system could be used to evaluate the effects of various riparian buffer scenarios on water quality improvement at spatiotemporal aspects. The SWAT-REMM enhanced system interface for ArcGIS should be developed for wide ranges of ArcGIS and SWAT users.

KEYWORDS: Riparian buffer, RBS, SWAT, REMM, Water quality

Introduction

Recently government and several environmental groups have given numerous efforts to improve the water quality at the watershed. A lot of researches have been conducted to manage non-point source pollution at the watershed scale effectively. Various Best Management Practices (BMPs) have been proposed to mitigate adverse impacts on water bodies and ecosystem of non-point source pollution (Jobin et al., 2004; Dwire and Lowrance, 2006). The riparian buffer system (RBS) has been recommended among a lot of researchers studying in this field (Anbumozhi et al., 2005; Li et al., 2009). However, there are few studies about effect of the water quality improvement through riparian buffer system. To solve this problem, the SWAT-REMM prototype model (Liu et al., 2007) was developed by the researchers in Canada. However, the SWAT-REMM prototype model has limitation in that the riparian buffer system should be installed along the reaches at every subwatershed in the study watershed, which is not feasible in most cases, especially for watersheds in Korea where many-human made structures are already installed along the reaches to prevent flooding. The SWAT-REMM prototype model can not reflect soil property at study watershed and it did not consider multiple weather stations in simulating hydrology and water quality at large scale watersheds.

The purpose of this study is to 1) improve the prototype version of the SWAT-REMM system and 2) simulate water quality improvement with riparian buffer system using SWAT-REMM enhanced model.

Study Areas

In this study, the Bonggok watershed at Gonju-si, Chunchungnam-do in South Korea was selected for evaluation of the SWAT-REMM enhanced model. The Bonggok watershed is 90.82 ha in size (figure 1). Forest (81.81%) is the dominant land use at Bonggok watershed and agricultural fields takes 4.37% of the watershed.

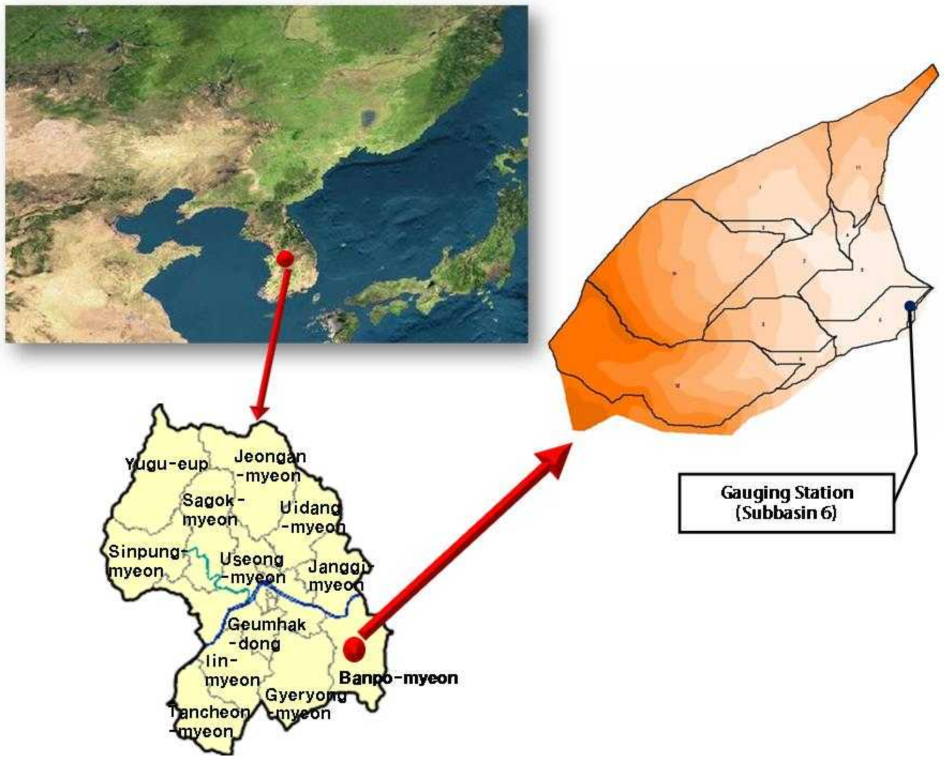


Figure 1. Study watershed, Bonggok watershed, Gonju-Si, South Korea

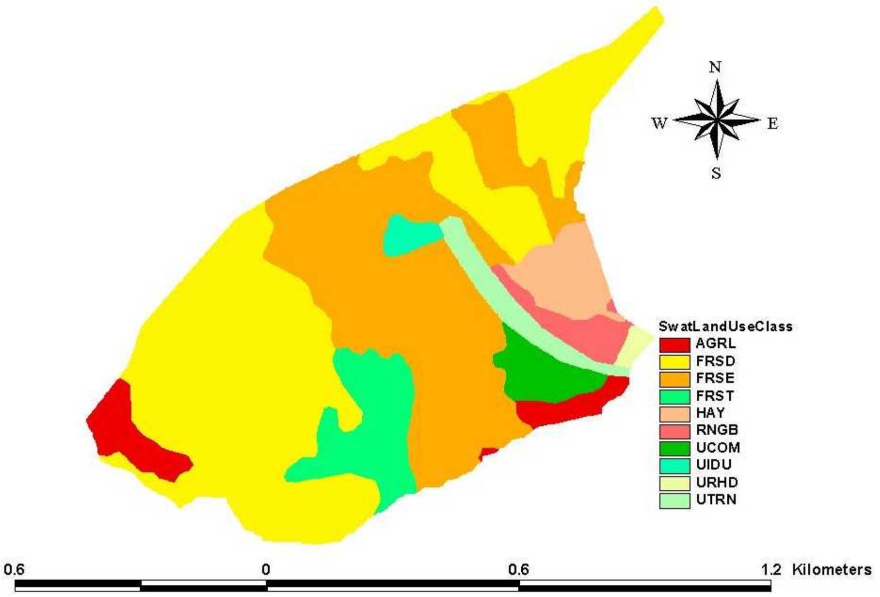


Figure 2. Land Use of Bonggok watershed

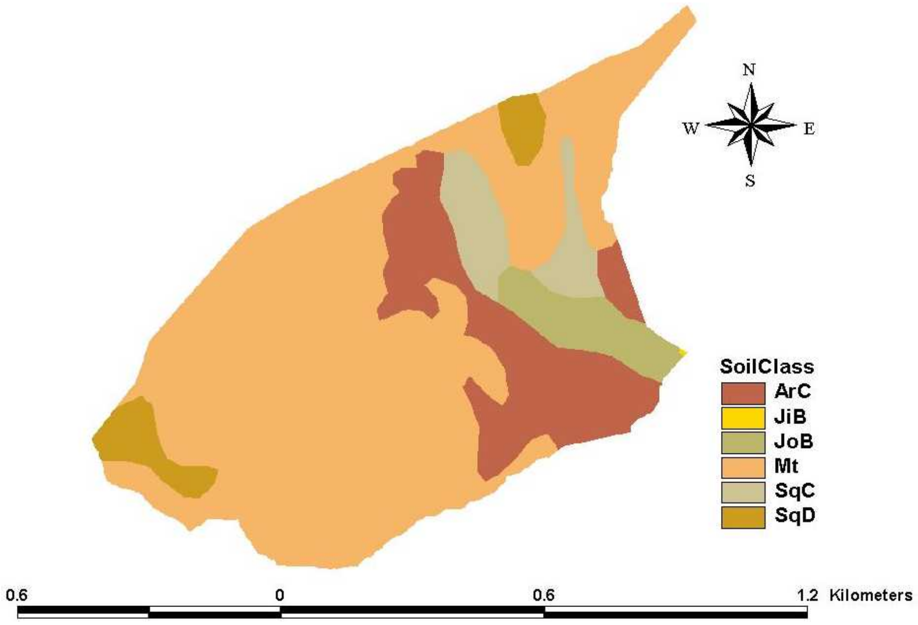


Figure 3. Soil map of Bonggok watershed

Development of SWAT-REMM Enhanced System

As stated earlier, the prototype SWAT-REMM (Liu et al., 2007) has limitations in applying it to other watershed to evaluate the effect of riparian buffer system. Thus, four major improvements were made in this study to simulate 1) riparian buffers at designated reaches in the watersheds, 2) riparian buffer using soil properties at riparian buffer zone along reaches, 3) multiple weather stations at large scale watersheds, and 4) NO_3-N loads in baseflow flowing into riparian buffers.

Simulation of riparian buffer system at designated reaches in watershed

The prototype version of the SWAT-REMM simulates the riparian buffer system established at all reaches in the watershed. However, it is not essentially possible to establish riparian buffer zone at all reaches of the watershed in Korea because of human made retaining or concrete walls installed along the reaches to prevent flooding. Thus new module was developed and integrated with the SWAT-REMM system for simulation of riparian buffer system for partial section of the reaches for practical application of the SWAT-REMM in Korea and other countries. In this new module, users have to provide the riparian buffer reach segment shape file in the input interface to define buffer drainage at each subwatershed. If no reach segment is defined for a certain subwatershed, the SWAT-REMM enhanced system, developed in this study, regards the subwatershed as 100% 'concentrated watershed'. Figure 4 shows the enhanced SWAT-REMM interface and buffer drainage for subwatershed with user-defined riparian buffer reaches. The shaded parts in each subwatershed are the areas contributing flow and pollutant into riparian buffer zone. The rest of areas (concentrated drainage) in the watershed are not affected by riparian buffer zones.

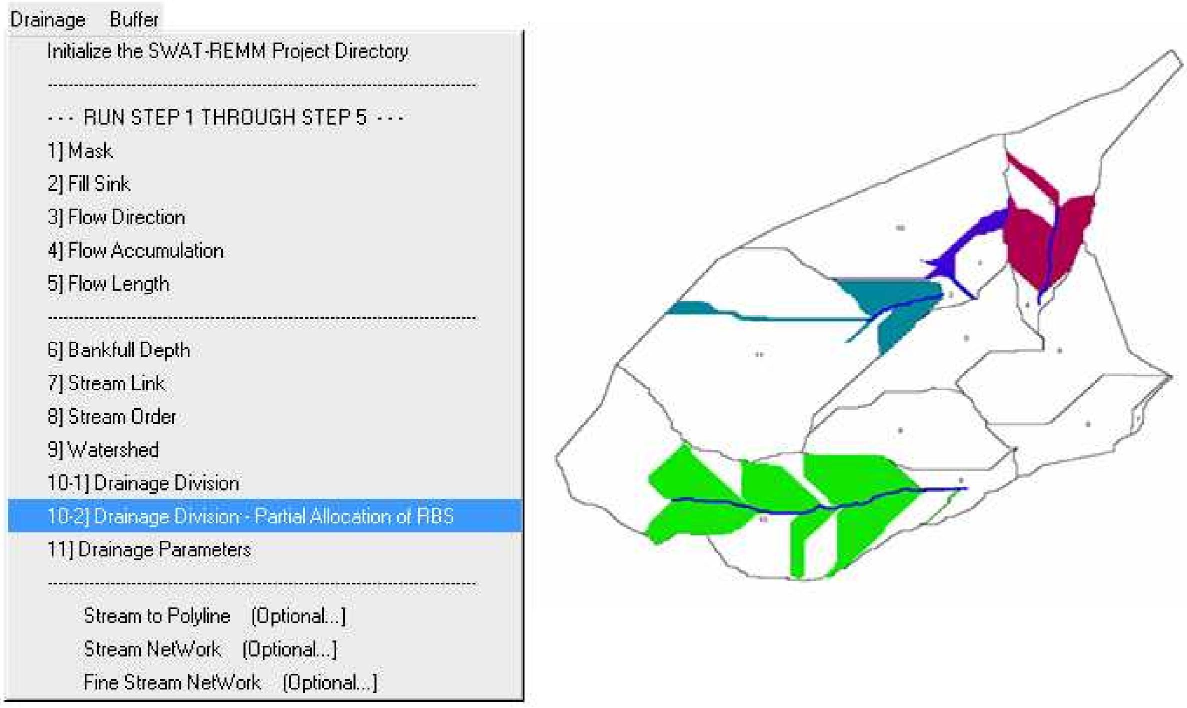
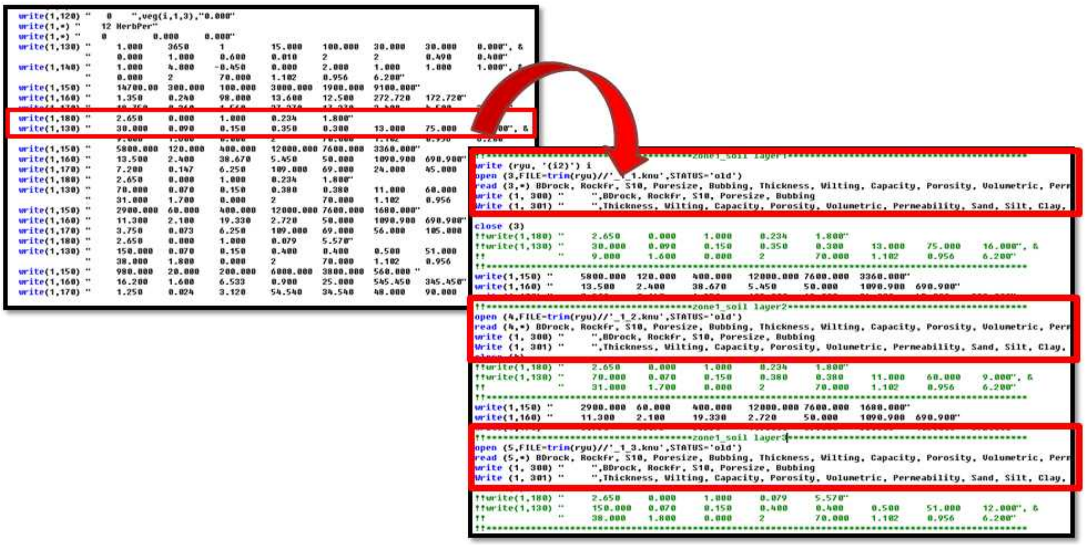


Figure 4. Buffer drainage for several subwatersheds along reaches with SWAT-REMM enhanced system

Reflection soil properties of riparian buffer zone at study watershed

In the prototype SWAT-REMM system, the soil properties at the riparian buffer zone were not directly read from the soil layer. Soil properties of the the Canagagigue Creek watershed used by the Liu et al. (2007) are used in the prototype version of the SWAT-REMM. Thus the soil properties of the riparian buffers are retrieved from local soil map with Avenue and Fortran programming as shown in Figures 5 and 6. In the SWAT-REMM system, representative soil properties of single soil type for each riparian buffer can be simulated. Thus representative soil type is determined with areas of major soil among soil types in riparian buffers after clipping soil grid with riparian zone. The soil properties needed for the

REMM are retrieved from soil database (usersoil.dbf) and written back into REMM input data format.



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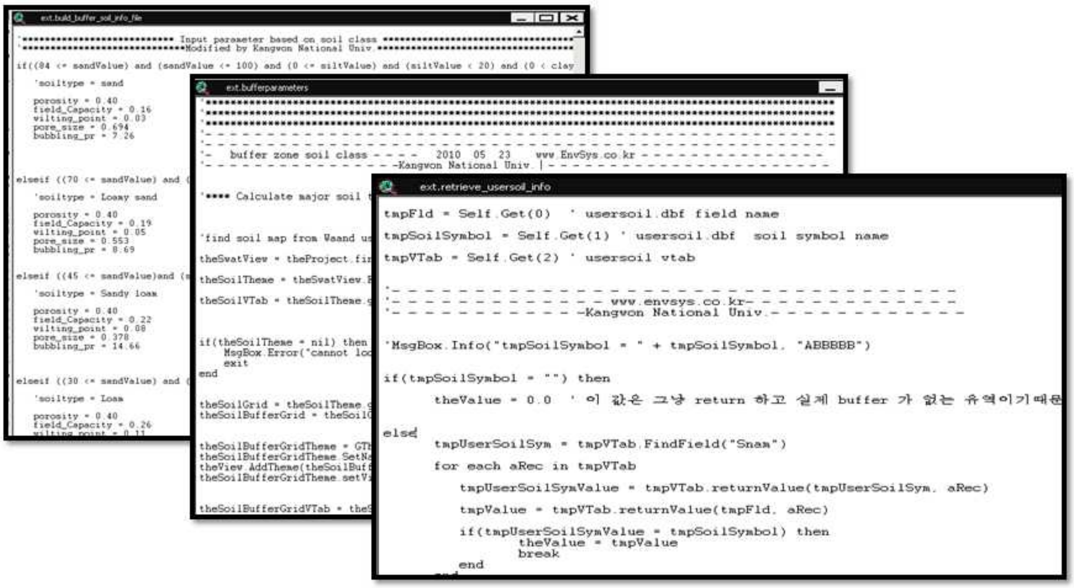
write(1,130) "      150.000   0.070     0.150      0.400     0.400     0.500     51.000
             "      38.000    1.800     0.000      2         70.000    1.102     0.956
write(1,150) "      980.000   20.000    200.000    6000.000  3800.000  560.000 "
write(1,160) "      16.200    1.600     6.533      0.900     25.000    545.450   345.450"
write(1,170) "      1.250     0.024     3.120      54.540    34.540    48.000    90.000
```

```
write (ryu, '(i2)') i
open (3,FILE=trim(ryu)//'_1_1.knu',STATUS='old')
read (3,*) BDrock, Rockfr, S10, Poresize, Bubbing, Thickness, Wilting, Capacity, Porosity, Volumetric, Perm
write (1, 300) "      ",BDrock, Rockfr, S10, Poresize, Bubbing
Write (1, 301) "      ",Thickness, Wilting, Capacity, Porosity, Volumetric, Permeability, Sand, Silt, Clay,
close (3)
!!write(1,180) "      2.650     0.000      1.000     0.234     1.800"
!!write(1,130) "      30.000    0.090      0.150     0.350     0.300     13.000    75.000    16.000", &
!!            "      9.000     1.600      0.000     2         70.000    1.102     0.956     6.200"
!!*****************************************************************************************
write(1,150) "     5800.000  120.000    400.000   12000.000 7600.000  3360.000"
write(1,160) "     13.500    2.400      38.670    5.450     50.000    1090.900  690.900"
!!*********************************zone1_soil layer2**************************************
open (4,FILE=trim(ryu)//'_1_2.knu',STATUS='old')
read (4,*) BDrock, Rockfr, S10, Poresize, Bubbing, Thickness, Wilting, Capacity, Porosity, Volumetric, Perm
write (1, 300) "      ",BDrock, Rockfr, S10, Poresize, Bubbing
Write (1, 301) "      ",Thickness, Wilting, Capacity, Porosity, Volumetric, Permeability, Sand, Silt, Clay,
!!write(1,180) "      2.650     0.000      1.000     0.234     1.800"
!!write(1,130) "      70.000    0.070      0.150     0.380     0.380     11.000    60.000    9.000", &
!!            "      31.000    1.700      0.000     2         70.000    1.102     0.956     6.200"
!!*****************************************************************************************
write(1,150) "     2900.000  60.000     400.000   12000.000 7600.000  1680.000"
write(1,160) "     11.300    2.100      19.330    2.720     50.000    1090.900  690.900"
!!*********************************zone1_soil layer3**************************************
open (5,FILE=trim(ryu)//'_1_3.knu',STATUS='old')
read (5,*) BDrock, Rockfr, S10, Poresize, Bubbing, Thickness, Wilting, Capacity, Porosity, Volumetric, Perm
write (1, 300) "      ",BDrock, Rockfr, S10, Poresize, Bubbing
Write (1, 301) "      ",Thickness, Wilting, Capacity, Porosity, Volumetric, Permeability, Sand, Silt, Clay,
!!write(1,180) "      2.650     0.000      1.000     0.079     5.570"
!!write(1,130) "      150.000   0.070      0.150     0.400     0.400     0.500     51.000    12.000", &
!!            "      38.000    1.800      0.000     2         70.000    1.102     0.956     6.200"
!!*****************************************************************************************
```

Figure 5. Modified Fortran code in SWAT-REMM enhanced system to extract soil properties



```
'*************************** Input parameter based on soil class ****************************
'****************************Modified by Kangwon National Univ.******************************
if((84 <= sandValue) and (sandValue <= 100) and (0 <= siltValue) and (siltValue < 20) and (0 < clay

    'soiltype = sand

    porosity = 0.40
    field_Capacity = 0.16
    wilting_point = 0.03
    pore_size = 0.694
    bubbling_pr = 7.26

elseif ((70 <= sandValue) and (

    'soiltype = Loamy sand

    porosity = 0.40
    field_Capacity = 0.19
    wilting_point = 0.05
    pore_size = 0.553
    bubbling_pr = 8.69

elseif ((45 <= sandValue)and (s

    'soiltype = Sandy loam

    porosity = 0.40
    field_Capacity = 0.22
    wilting_point = 0.08
    pore_size = 0.378
    bubbling_pr = 14.66

elseif ((30 <= sandValue) and (

    'soiltype = Loam

    porosity = 0.40
    field_Capacity = 0.26
```

```
'***********************************************************************************
'***********************************************************************************
'***********************************************************************************
'- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'-   buffer zone soil class - - - -   2010  05  23    www.EnvSys.co.kr - - - - - - - - - - - - - - -
'- - - - - - - - - - - - - - - - - - -Kangwon National Univ. | - - - - - - - - - - - - - - - - - -

'**** Calculate major soil t

'find soil map from Waand us

theSwatView = theProject.fi

theSoilTheme = theSwatView.

theSoilVTab = theSoilTheme.


if(theSoilTheme = nil) then
    MsgBox.Error("cannot lo
    exit
end

theSoilGrid = theSoilTheme.
theSoilBufferGrid = theSoil

theSoilBufferGridTheme = GT
theSoilBufferGridTheme.SetN
theView.AddTheme(theSoilBuf
theSoilBufferGridTheme.setV

theSoilBufferGridVTab = the
```

```
tmpFld = Self.Get(0)   ' usersoil.dbf field name

tmpSoilSymbol = Self.Get(1) ' usersoil.dbf  soil symbol name

tmpVTab = Self.Get(2) ' usersoil vtab

'- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'- - - - - - - - - - - - - - - www.envsys.co.kr- - - - - - - - - - - - -
'- - - - - - - - - - - - - -Kangwon National Univ.- - - - - - - - - - - - -

'MsgBox.Info("tmpSoilSymbol = " + tmpSoilSymbol, "ABBBBB")

if(tmpSoilSymbol = "") then
    theValue = 0.0  ' 이 값은 그냥 return 하고 실제 buffer 가 없는 유역이기때문

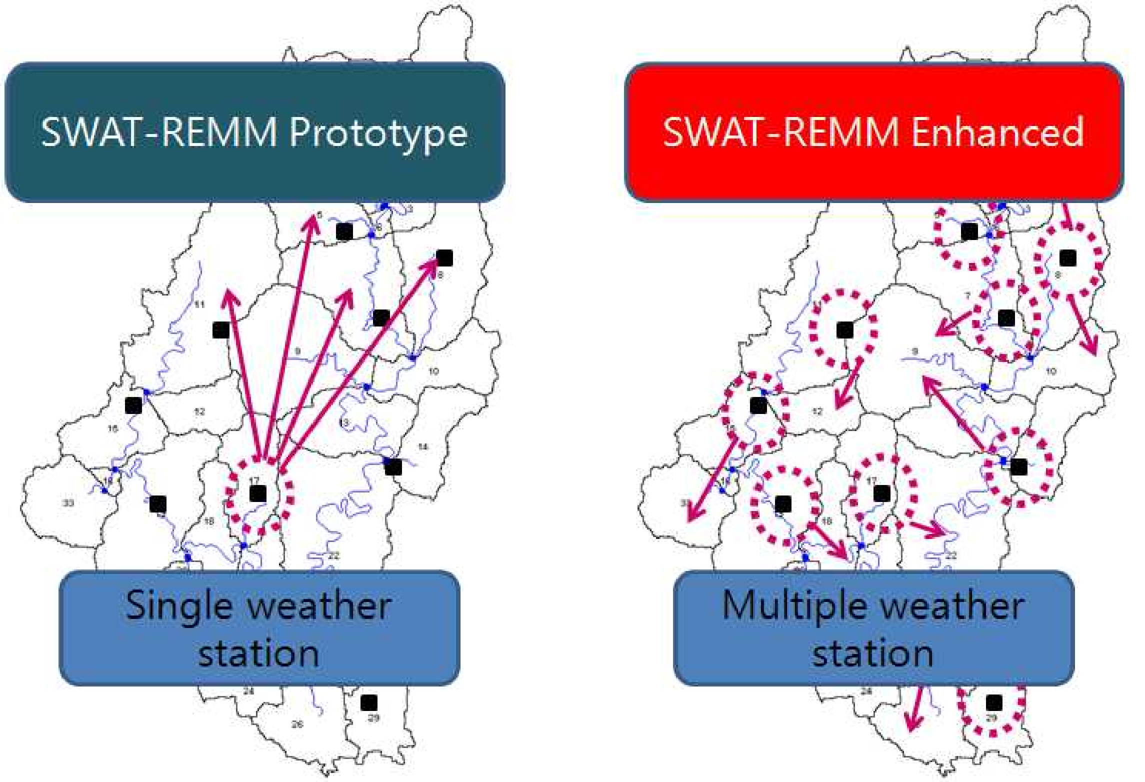
else
    tmpUserSoilSym = tmpVTab.FindField("Snam")
    for each aRec in tmpVTab
        tmpUserSoilSymValue = tmpVTab.returnValue(tmpUserSoilSym, aRec)
        tmpValue = tmpVTab.returnValue(tmpFld, aRec)
        if(tmpUserSoilSymValue = tmpSoilSymbol) then
                theValue = tmpValue
                break
        end
```

Figure 6. Modified Avenue code in SWAT-REMM enhanced system to extract soil properties

Simulation of multiple weather stations at large scale watershed

In the prototype SWAT-REMM system, only one weather station can be simulated as shown in Figure 7 (a). This could be a problem when effects of riparian buffer systems at large scale watersheds are simulated where spatio-temporal variations in precipitation exist, which will affect rainfall-runoff and entailing pollutant generation and transportation at the watershed.

In the SWAT system, the nearest weather station in each subwatershed is selected with computation of distance between centroid of each subwatershed and weather station. Thus this information should be used to keep consistency in SWAT and REMM simulations, respectively. Thus, the weather data for REMM input are generated from SWAT weather data for each riparian buffer zone with Avenue and Fortran programming. With this capability, the SWAT-REMM enhanced system (Figure 7 (b)) can be used at large scale watersheds since it can simulate hydrology and water quality using nearest weather data, instead of one representative single weather station, which was the only option available in SWAT-REMM prototype version.



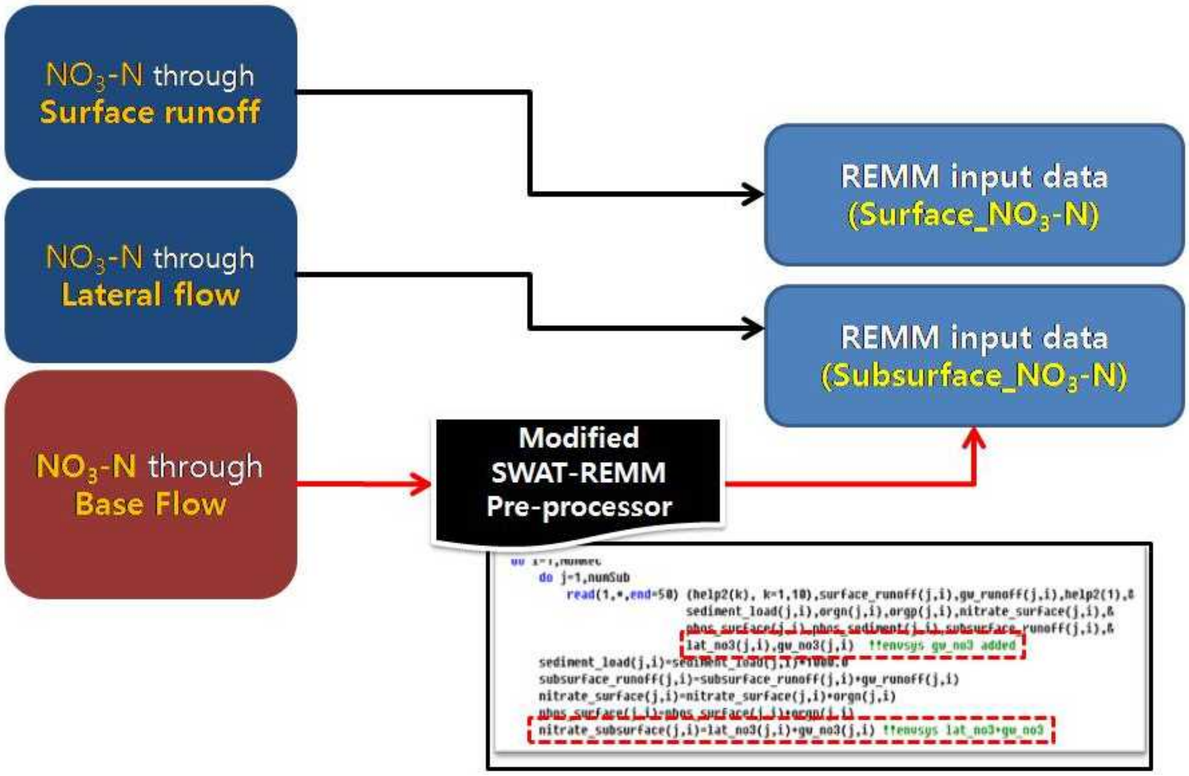
Single weather station in prototype SWAT-REMM **Multiple weather stations in enhanced SWAT-REMM**

Figure 7. Multiple weather stations in SWAT-REMM enhanced systems

Consideration of HRU NO3-N baseflow load flowing into through riparian buffer system

In the SWAT-REMM prototype version, the HRU NO_3-N loads in baseflow are assumed not to flow through riparian buffer zone in subsurface flow. The SWAT system is semi-distributed model, thus simulated values for all HRUs are assumed to enter upper stream areas of stream in each subwatershed directly. For the watersheds with riparian buffers, the simulated values for all HRUs in buffer watershed, not in concentrated watershed, are assumed to enter the riparian buffer in either surface or subsurface flow in the SWAT-REMM prototype system. However, nutrient loads in baseflow for each HUR is not routed to the riparian buffer zone in the SWAT-REMM prototype system. Thus the HRU NO_3-N loads in baseflow are simulated as entering into riparian buffer zone in subsurface flow in the SWAT-

REMM enhanced version with slight modification of pre-processor of the SWAT-REMM (Figure 8).



```
    do j=1,numSub
        read(1,*,end=50) (help2(k), k=1,10),surface_runoff(j,i),gw_runoff(j,i),help2(1),&
                         sediment_load(j,i),orgn(j,i),orgp(j,i),nitrate_surface(j,i),&
                         phos_surface(j,i),phos_sediment(j,i),subsurface_runoff(j,i),&
                         lat_no3(j,i),gw_no3(j,i)  !!envsys gw_no3 added
    sediment_load(j,i)=sediment_load(j,i)*1000.0
    subsurface_runoff(j,i)=subsurface_runoff(j,i)+gw_runoff(j,i)
    nitrate_surface(j,i)=nitrate_surface(j,i)+orgn(j,i)
    phos_surface(j,i)=phos_surface(j,i)+orgp(j,i)
    nitrate_subsurface(j,i)=lat_no3(j,i)+gw_no3(j,i) !!envsys lat_no3+gw_no3
```

Figure 8. Overview of NO_3-N load in baseflow flowing into through riparian buffer system in SWAT-REMM enhanced systems

Calibration and Validation of Flow and T-N at Bonggok Watershed

Before analyzing effects of riparian buffers on water quality improvement, the SWAT model should be calibrated and validated for stream flow and water quality simulations, because the SWAT-REMM system uses the output of SWAT model as an input to the REMM model. Thus, SWAT model was calibrated and validated using observed flow and water quality data at Bonggok watershed (Kim, 2007) in Korea. Flow and T-N calibration period was from Jan. 1st 2005 to Dec. 31st 2005 in daily simulation, and validation period for flow and T-N was from 1st 2006 to Dec. 31st 2006 in daily simulation.

Three Riparian Buffer System Scenarios

To evaluate the effects of riparian buffers on water quality improvement, three riparian buffer system scenarios were made as shown in Figure 9. It was assumed that the same plant types were planted at zone 1, 2, and 3 with different buffer width (10m, 5m, and 1 m at both sides of reaches). In this study, it was assumed that the riparian buffers are installed along the reaches at subwatersheds 10, 11, and 12 (Figure 9).

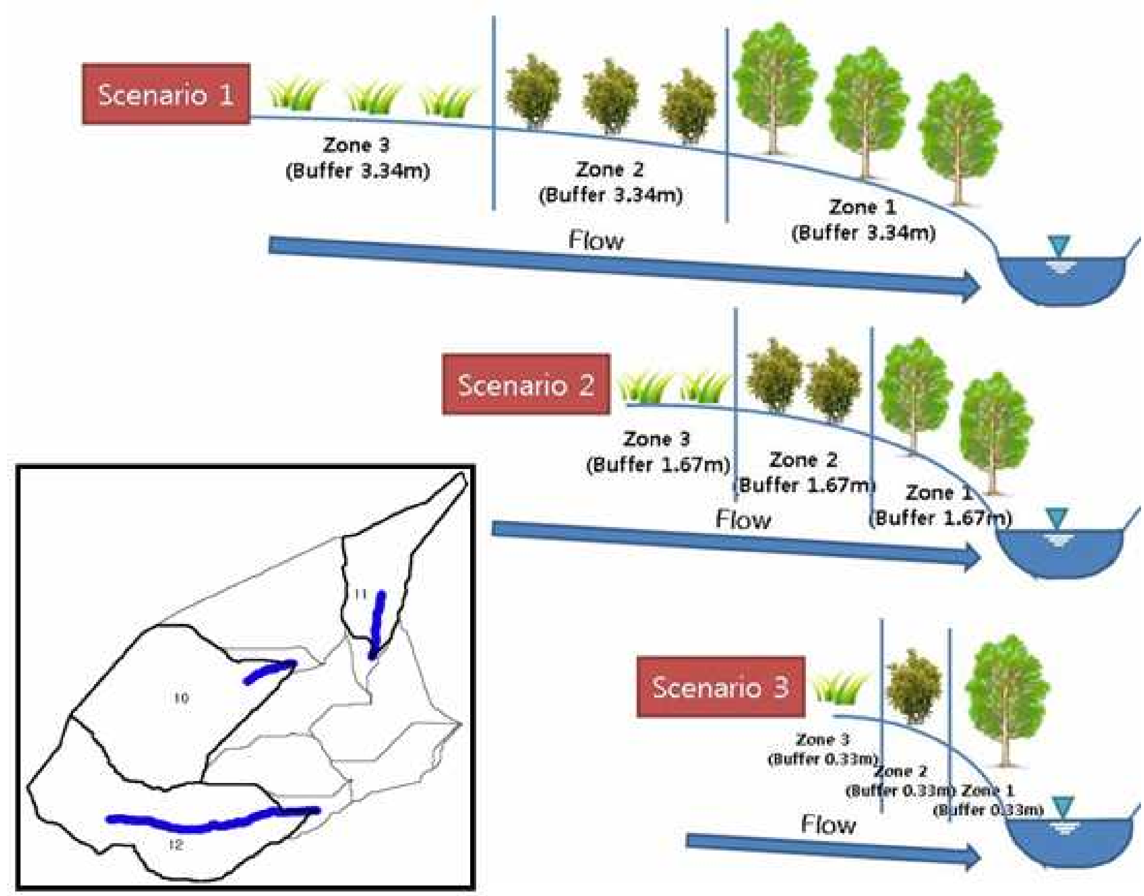
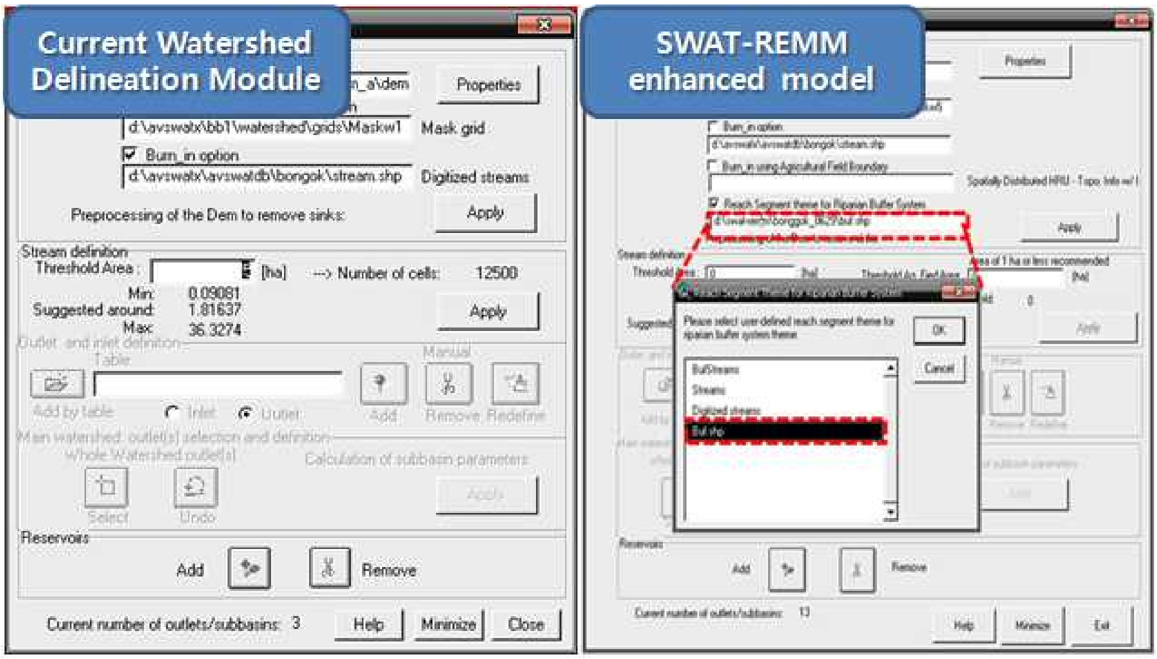


Figure 9. Three riparian buffer system scenarios to evaluate water quality improvement

Result and Discussion

Development of SWAT-REMM enhanced model

In this study, four major improvements were made in SWAT-REMM enhanced system as described below. First, figure 10 shows the modified watershed delineation interface to allow users to specify the location of riparian buffer system within watershed. With this interface, users can provide locations of riparian buffer system for all or several subwatersheds depending on local conditions along the reaches. Figure 11 (a) shows the buffer drainage delineated using user riparian buffer zone data with SWAT-REMM enhanced. The flow and pollutant from all HRUs in buffer drainage are assumed to enter the riparian buffer zone to simulate effects of riparian buffers on water quality improvement, while flow and pollutants from all HURs in concentrated drainage are assumed not to enter the riparian buffer zone. Differentiation of flow and pollutants from buffer drainage and concentrated drainage are key procedures in simulating the riparian buffer zone, especially in case of riparian buffer zones at user designated subwatersheds.



..._a\dem

d:\avswatx\bb1\watershed\grids\Maskw1

☑ Burn_in option

d:\avswatx\avswatdb\bongok\stream.shp

Preprocessing of the Dem to remove sinks:

Number of cells: 12500

Min: 0.09081

Suggested around: 1.81637

Max: 36.3274

Current number of outlets/subbasins: 3

☐ Burn_in option

☐ Burn_in using Agricultural Field Boundary

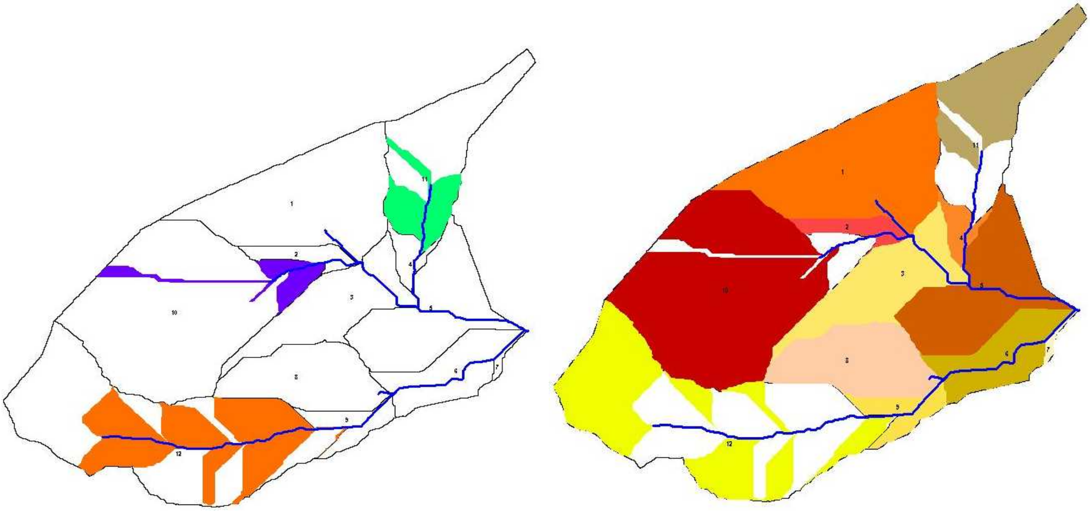
☑ Reach Segment theme for Riparian Buffer System

Please select user-defined reach segment theme for riparian buffer system theme

Buf.shp

Current number of outlets/subbasins: 13

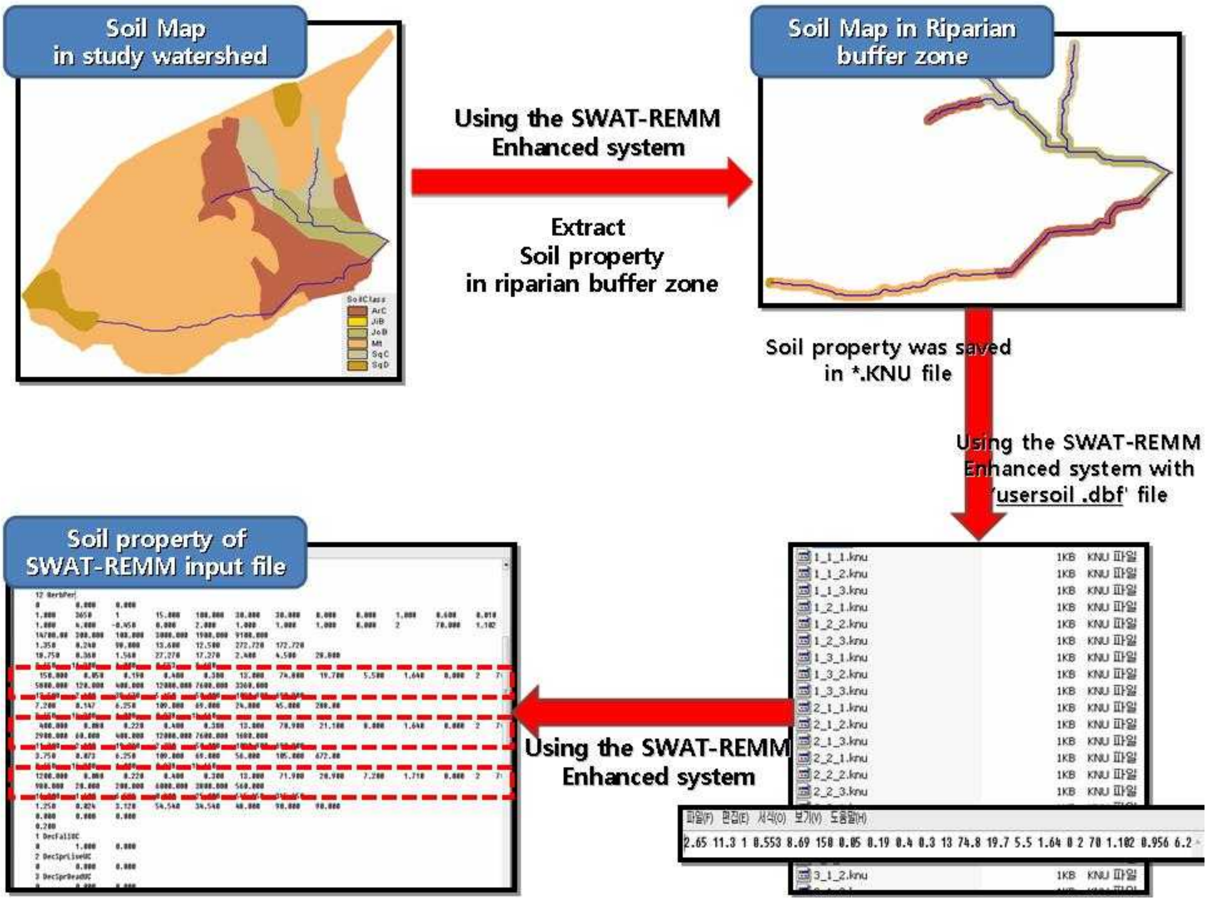
Figure 10. Prototype and SWAT-REMM enhanced watershed delineation interface



(a) **buffer drainage** (b) **concentrated drainage**

Figure 11. Buffer drainage and concentrated drainage delineated using SWAT-REMM enhanced system

Second, the SWAT-REMM enhanced model is now able to read soil properties at riparian buffer zone from soil map. Figure 12 shows how soil property of study watershed was automatically entered into SWAT-REMM input data with the pre-processors developed in this study. In the current SWAT-REMM enhanced system, soil properties of only one representative soil symbol for each riparian buffer zone are used. This could pose potential errors where the soil properties changes over the space.

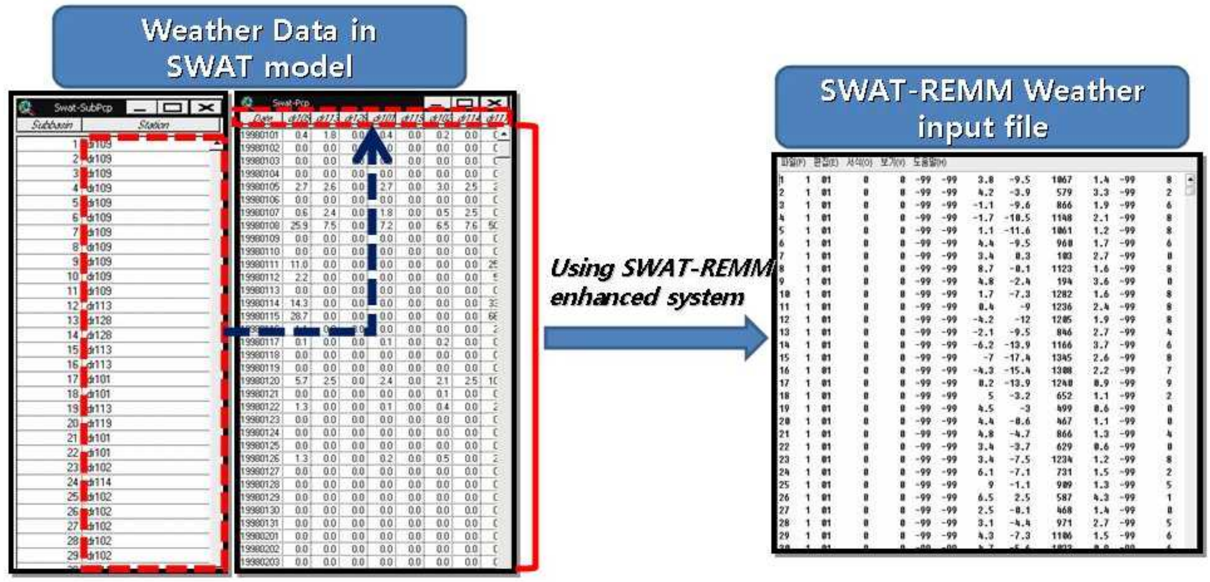


```
1_1_1.knu    1KB  KNU 파일
1_1_2.knu    1KB  KNU 파일
1_1_3.knu    1KB  KNU 파일
1_2_1.knu    1KB  KNU 파일
1_2_2.knu    1KB  KNU 파일
1_2_3.knu    1KB  KNU 파일
1_3_1.knu    1KB  KNU 파일
1_3_2.knu    1KB  KNU 파일
1_3_3.knu    1KB  KNU 파일
2_1_1.knu    1KB  KNU 파일
2_1_2.knu    1KB  KNU 파일
2_1_3.knu    1KB  KNU 파일
2_2_1.knu    1KB  KNU 파일
2_2_2.knu    1KB  KNU 파일
2_2_3.knu    1KB  KNU 파일
3_1_2.knu    1KB  KNU 파일
```

```
2.65 11.3 1 0.553 8.69 150 0.05 0.19 0.4 0.3 13 74.8 19.7 5.5 1.64 0 2 70 1.102 0.956 6.2
```

Figure 12. Extraction of soil properties at riparian buffer zone for REMM simulation

Third, the SWAT-REMM enhanced model is able to consider multiple weather stations at large watershed. Figure 13 shows that weather data for multiple weather stations were considered in SWAT-REMM enhanced model. With this, the SWAT-REMM enhanced system can be used for larger watersheds where measured weather data are available for multiple weather stations for accurate simulation of flow and pollutant generation and transportation.



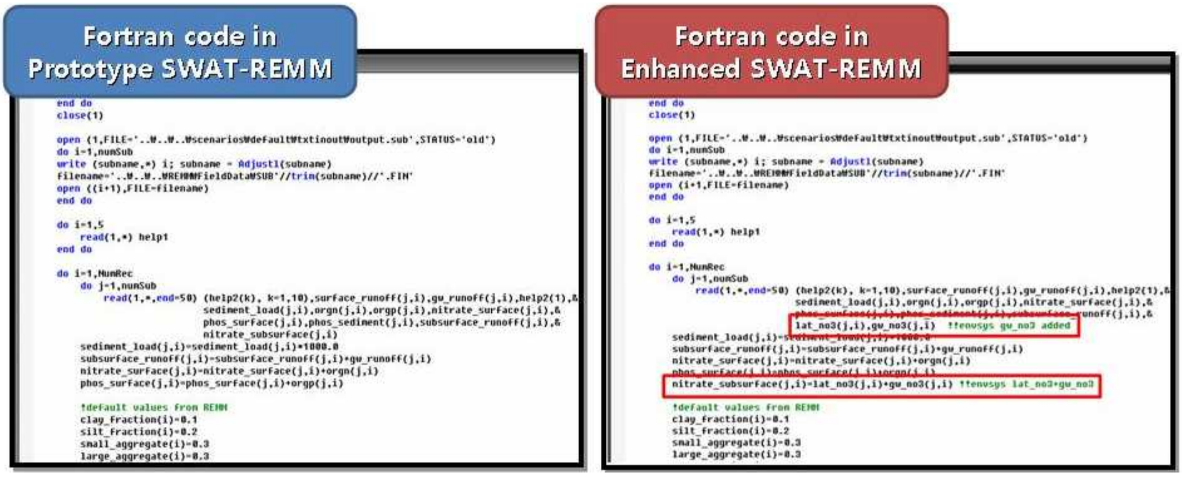
Subbasin	Station
1	dr109
2	dr109
3	dr109
4	dr109
5	dr109
6	dr109
7	dr109
8	dr109
9	dr109
10	dr109
11	dr109
12	dr113
13	dr128
14	dr128
15	dr113
16	dr113
17	dr101
18	dr101
19	dr113
20	dr119
21	dr101
22	dr101
23	dr102
24	dr114
25	dr102
26	dr102
27	dr102
28	dr102
29	dr102

Date	dr109	dr113	dr128	dr101	dr119	dr102	dr114
19980101	0.4	1.8	0.0	0.4	0.0	0.2	0.0
19980102	0.0	0.0	[illegible]	[illegible]	0.0	0.0	0.0
19980103	0.0	0.0	[illegible]	[illegible]	0.0	0.0	0.0
19980104	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980105	2.7	2.6	0.0	2.7	0.0	3.0	2.5
19980106	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980107	0.6	2.4	0.0	1.8	0.0	0.5	2.5
19980108	25.9	7.5	0.0	7.2	0.0	6.5	7.6
19980109	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980110	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980111	11.0	0.0	0.0	0.0	0.0	0.0	0.0
19980112	2.2	0.0	0.0	0.0	0.0	0.0	0.0
19980113	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980114	14.3	0.0	0.0	0.0	0.0	0.0	0.0
19980115	28.7	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0
19980117	0.1	0.0	0.0	0.1	0.0	0.2	0.0
19980118	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980119	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980120	5.7	2.5	0.0	2.4	0.0	2.1	2.5
19980121	0.0	0.0	0.0	0.0	0.0	0.1	0.0
19980122	1.3	0.0	0.0	0.1	0.0	0.4	0.0
19980123	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980124	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980125	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980126	1.3	0.0	0.0	0.2	0.0	0.5	0.0
19980127	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980128	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980129	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980130	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980131	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980201	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980202	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19980203	0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
1    1  01     0     0  -99  -99   3.8   -9.5   1067   1.4  -99     8
2    1  01     0     0  -99  -99   4.2   -3.9    579   3.3  -99     2
3    1  01     0     0  -99  -99  -1.1   -9.6    866   1.9  -99     6
4    1  01     0     0  -99  -99  -1.7  -10.5   1148   2.1  -99     8
5    1  01     0     0  -99  -99   1.1  -11.6   1061   1.2  -99     8
6    1  01     0     0  -99  -99   4.4   -9.5    960   1.7  -99     6
7    1  01     0     0  -99  -99   3.4    0.3    103   2.7  -99     0
8    1  01     0     0  -99  -99   8.7   -0.1   1123   1.6  -99     8
9    1  01     0     0  -99  -99   4.8   -2.4    194   3.6  -99     0
10   1  01     0     0  -99  -99   1.7   -7.3   1282   1.6  -99     8
11   1  01     0     0  -99  -99   0.4     -9   1236   2.4  -99     8
12   1  01     0     0  -99  -99  -4.2    -12   1205   1.9  -99     8
13   1  01     0     0  -99  -99  -2.1   -9.5    846   2.7  -99     4
14   1  01     0     0  -99  -99  -6.2  -13.9   1166   3.7  -99     6
15   1  01     0     0  -99  -99    -7  -17.4   1345   2.6  -99     8
16   1  01     0     0  -99  -99  -4.3  -15.4   1308   2.2  -99     7
17   1  01     0     0  -99  -99   0.2  -13.9   1240   0.9  -99     9
18   1  01     0     0  -99  -99     5   -3.2    652   1.1  -99     2
19   1  01     0     0  -99  -99   4.5     -3    499   0.6  -99     0
20   1  01     0     0  -99  -99   4.4   -0.6    467   1.1  -99     0
21   1  01     0     0  -99  -99   4.8   -4.7    866   1.3  -99     4
22   1  01     0     0  -99  -99   3.4   -3.7    629   0.6  -99     0
23   1  01     0     0  -99  -99   3.4   -7.5   1234   1.2  -99     8
24   1  01     0     0  -99  -99   6.1   -7.1    731   1.5  -99     2
25   1  01     0     0  -99  -99     9   -1.1    909   1.3  -99     5
26   1  01     0     0  -99  -99   6.5    2.5    587   4.3  -99     1
27   1  01     0     0  -99  -99   2.5   -0.1    468   1.4  -99     0
28   1  01     0     0  -99  -99   3.1   -4.4    971   2.7  -99     5
29   1  01     0     0  -99  -99   4.3   -7.3   1106   1.5  -99     6
```

Figure 13. SWAT-REMM weather input file for multiple weather stations

Last, the SWAT-REMM enhanced model was able to consider HRU NO_3-N load in baseflow flowing into through riparian buffer system. Figure 14(a) is SWAT-REMM prototype Fortran code to extract pollutant load in SWAT model and Figure 14(b) is SWAT-REMM enhanced Fortran code added to consider pollutant loads in baseflow



```
end do
close(1)

open (1,FILE='..₩..₩..₩scenarios₩default₩txtinout₩output.sub',STATUS='old')
do i=1,numSub
write (subname,*) i; subname = Adjustl(subname)
Filename='..₩..₩..₩REMM₩FieldData₩SUB'//trim(subname)//'.FIN'
open ((i+1),FILE=filename)
end do

do i=1,5
    read(1,*) help1
end do

do i=1,NumRec
    do j=1,numSub
        read(1,*,end=50) (help2(k), k=1,10),surface_runoff(j,i),gw_runoff(j,i),help2(1),&
                         sediment_load(j,i),orgn(j,i),orgp(j,i),nitrate_surface(j,i),&
                         phos_surface(j,i),phos_sediment(j,i),subsurface_runoff(j,i),&
                         nitrate_subsurface(j,i)
    sediment_load(j,i)=sediment_load(j,i)*1000.0
    subsurface_runoff(j,i)=subsurface_runoff(j,i)+gw_runoff(j,i)
    nitrate_surface(j,i)=nitrate_surface(j,i)+orgn(j,i)
    phos_surface(j,i)=phos_surface(j,i)+orgp(j,i)

    !default values from REMM
    clay_fraction(i)=0.1
    silt_fraction(i)=0.2
    small_aggregate(i)=0.3
    large_aggregate(i)=0.3
```

```
end do
close(1)

open (1,FILE='..₩..₩..₩scenarios₩default₩txtinout₩output.sub',STATUS='old')
do i=1,numSub
write (subname,*) i; subname = Adjustl(subname)
Filename='..₩..₩..₩REMM₩FieldData₩SUB'//trim(subname)//'.FIN'
open (i+1,FILE=filename)
end do

do i=1,5
    read(1,*) help1
end do

do i=1,NumRec
    do j=1,numSub
        read(1,*,end=50) (help2(k), k=1,10),surface_runoff(j,i),gw_runoff(j,i),help2(1),&
                         sediment_load(j,i),orgn(j,i),orgp(j,i),nitrate_surface(j,i),&
                         phos_surface(j,i),phos_sediment(j,i),subsurface_runoff(j,i),&
                         lat_no3(j,i),gw_no3(j,i)  !envsys gw_no3 added
    sediment_load(j,i)=sediment_load(j,i)*1000.0
    subsurface_runoff(j,i)=subsurface_runoff(j,i)+gw_runoff(j,i)
    nitrate_surface(j,i)=nitrate_surface(j,i)+orgn(j,i)
    phos_surface(j,i)=phos_surface(j,i)+orgp(j,i)
    nitrate_subsurface(j,i)=lat_no3(j,i)+gw_no3(j,i) !envsys lat_no3+gw_no3

    !default values from REMM
    clay_fraction(i)=0.1
    silt_fraction(i)=0.2
    small_aggregate(i)=0.3
    large_aggregate(i)=0.3
```

No NO_3-N baseflow load to subsurface flow in prototype SWAT-REMM

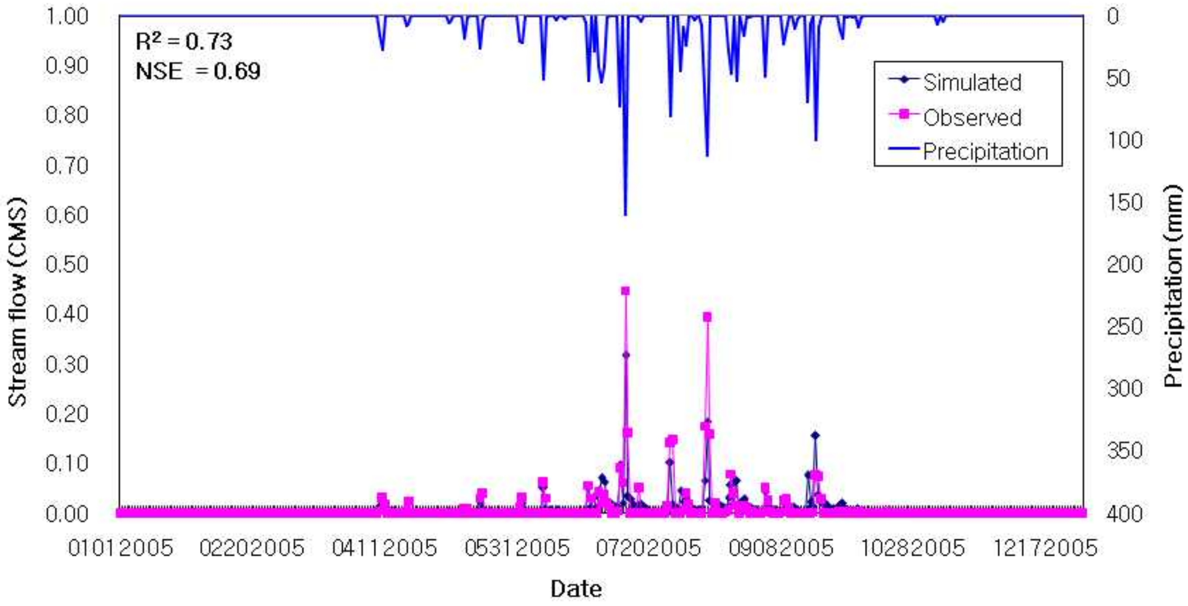
NO_3-N baseflow load added to subsurface flow in enhanced SWAT-REMM

Figure 14. Preprocessor to convert SWAT output into REMM input

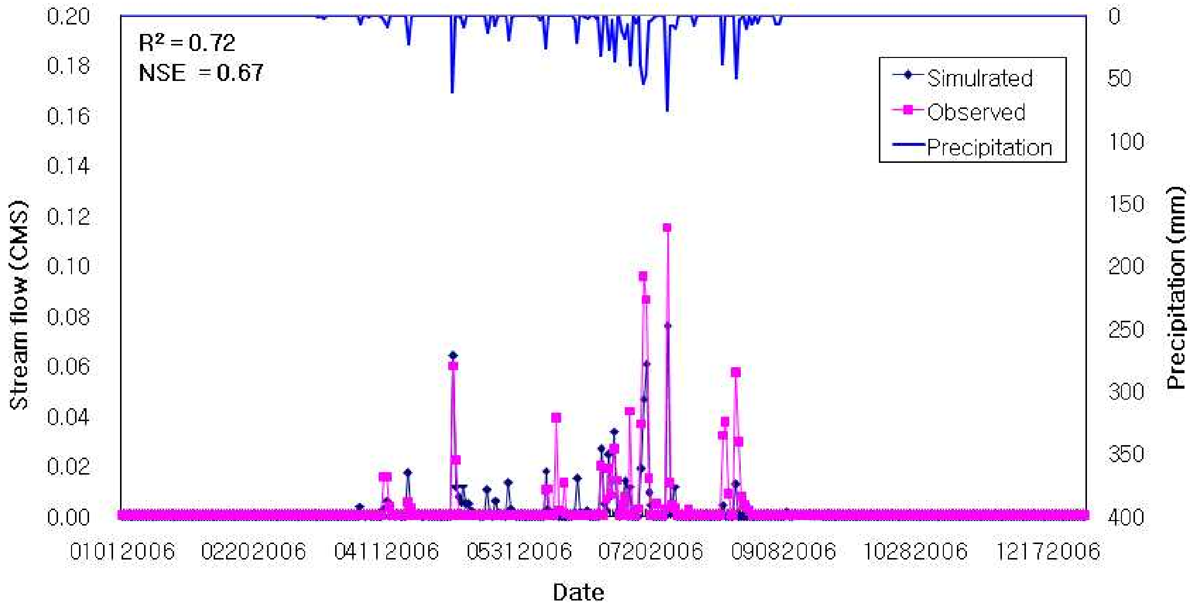
Calibration and Validation of SWAT model

Figure 15(a) shows calibrated daily stream flow at Bonggok watershed with R^2 and NSE value of 0.73 and 0.69, respectively. Figure 15(b) shows validated daily stream flow in Bonggok watershed with R^2 and NSE value of 0.72 and 0.67. According to the Donigan and

Love (2003), the calibration and validation of daily flow simulation could be classified as 'Fair'. Figures 16(a) and (b) show calibrated and validated daily T-N at Bonggok watershed with with R^2 and NSE values of 0.67 and 0.62 for calibration and 0.63 and 0.60 for validation. These statistics indicate that flow and TN calibrated/validated SWAT model now can simulate flow and pollutant generation from the watershed reasonably well with the NSE value of 0.60 or greater.

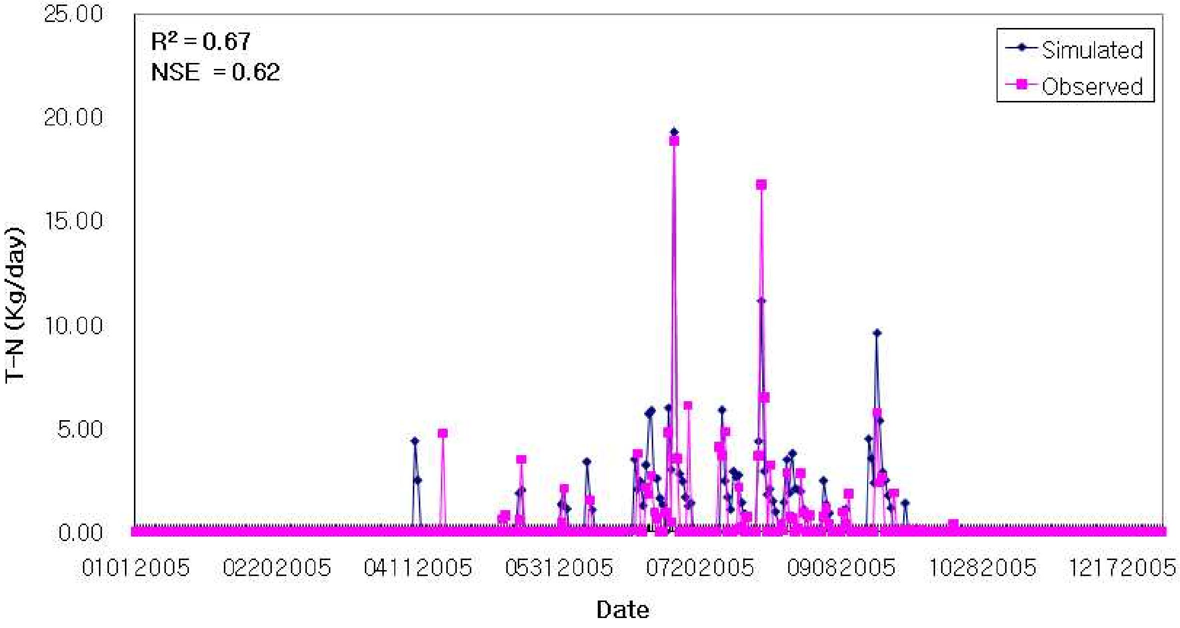


(a) Flow calibration in year 2005

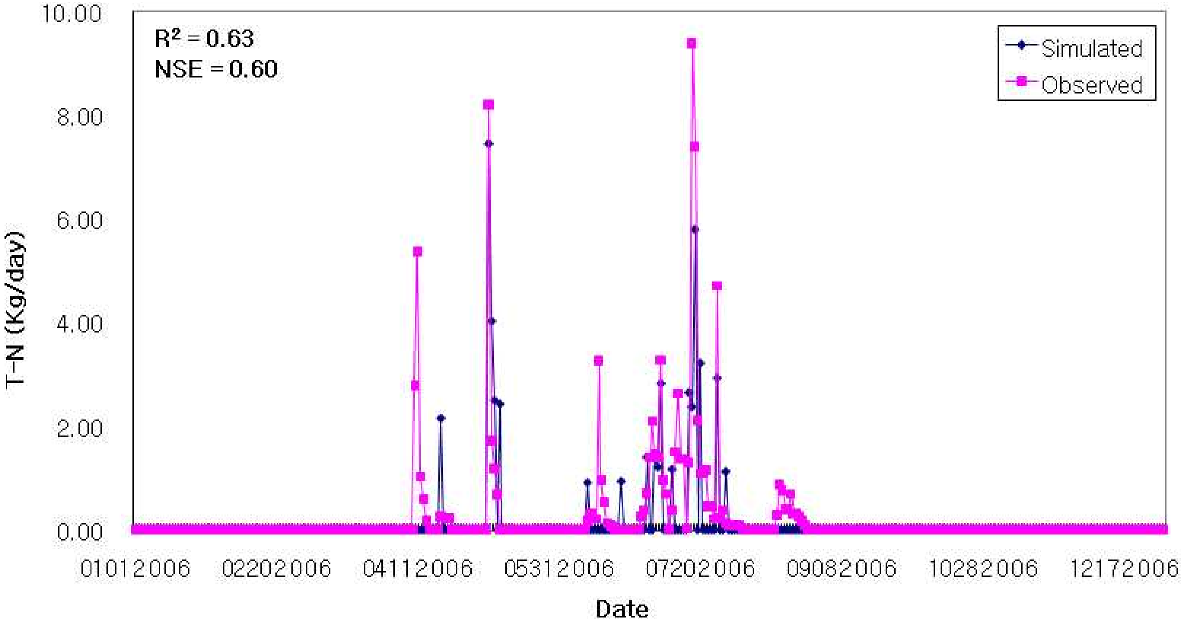


(b) Flow validation in year 2006

Figure 15. Calibration and validation of daily stream flow at Bonggok watershed



(a) T-N calibration in year 2005



(b) T-N calibration in year 2006

Figure 16. Calibrations and Validation of T-N at Bonggok watershed

Application of the SWAT-REMM enhanced model

The calibrated/validated SWAT-REMM was used to evaluate the effects of riparian buffers on water quality improvement. In this study, the riparian buffer zones are established at subwatersheds 10, 11, and 12. Table 1 shows that annual runoff was reduced slightly with riparian buffers. The SWAT-REMM enhanced system simulated (Scenario 1) stream flow reduction for each subwatershed ranged from 4.7 % ~ 23.1 % and Scenario 2 reduction within each subwatershed ranged from 4.3% ~ 18.5 % , depending on the percentage of riparian buffer contributing areas and the physical characteristics of riparian buffers. The riparian buffers in subwatershed 11 and 12 had the highest impact on stream flow abatement. The buffer drainage area at subwatersheds of 11 and 12 were bigger than that of subwatershed 10, As the width of riparian buffer decreased, the runoff reduction ratio decreased as expected. Thus it was found that runoff could be reduced with riparian buffer zone to some degrees.

Table 1. Estimated stream flow reduction with three riparian buffer system scenarios

Stream flow							
Sub-watershed	Before RBS	Buffer 10m (Scenario 1)		Buffer 5m (Scenario 2)		Buffer 1m (Scenario 3)	
		After RBS (m^3/sec)	Reduction (%)	After RBS (m^3/sec)	Reduction (%)	After RBS (m^3/sec)	Reduction (%)
10	8.7	8.3	**4.7**	8.4	**4.3**	8.6	**2.1**
11	3.5	2.8	**18.7**	3.0	**14.5**	3.2	**6.9**
12	7.8	6.0	**23.1**	6.3	**18.5**	7.0	**10.2**

The similar trend was found in T-N analysis as shown in runoff analysis with riparian buffers (Table 2). These trend and reduction were related with the percentage of buffer drainage, physical characteristics of riparian buffer, and nutrient used in upper areas. The SWAT-REMM enhanced system simulated (Scenario 1) T-N reduction within each subwatershed ranged from 14.8 % ~ 54.0 % and Scenario 2 reduction within each subwatershed ranged from 10.5 % ~ 35.7 %. As shown in this study, the SWAT-REMM enhanced system can be used to determine/design optimum width of riparian buffer zone for target nutrient reduction.

Table 2. Estimated T-N reduction with three riparian buffer system scenarios

T-N							
Sub-watershed	Before RBS	Buffer 10m (Scenario 1)		Buffer 5m (Scenario 2)		Buffer 1m (Scenario 3)	
		After RBS (kg/year)	Reduction (%)	After RBS (kg/year)	Reduction (%)	After RBS (kg/year)	Reduction (%)
10	86.6	73.7	**14.8**	77.5	**10.5**	80.6	**6.9**
11	18.3	10.5	**42.4**	12.6	**31.3**	13.8	**24.5**
12	75.8	34.8	**54.0**	48.7	**35.7**	51.9	**31.6**

Conclusion

In this study, the SWAT-REMM prototype model was enhanced with four major improvements, and then T-N reduction efficiency was evaluated with established riparian buffer system at Bonggok study watershed.

The SWAT-REMM enhanced model was able to simulate with established riparian buffer system at user selected subwatersheds with soil properties at riparian buffer zone at buffer drainages. Also, the SWAT-REMM enhanced model was able to simulate multiple weather stations and consider NO_3-N load baseflow flowing into through riparian buffer system. Three riparian buffer scenarios with different widths (10m, 5m, and 1m) of buffer zones with different canopies. It was found that T-N reduction efficiency ranged from 14.8 to 54.0 % in each subwatershed in scenario 1 - 10m width of established riparian buffer system. Also, T-N reduction efficiency was from 6.9 to 31.6 % in each subwatershed in scenario 3 which is 1m width of established riparian buffer system. The reduction efficiency was not proportional to the width of riparian buffer system. As shown in this study, the SWAT-REMM enhanced system could be used to evaluate the effects of various riparian buffer scenarios on water quality improvement at spatiotemporal aspects.

The SWAT-REMM prototype system was developed in ArcView 3.x platform. However the ArcGIS has replaced the ArcView in recent years. So, the SWAT-REMM interface should be developed based on ArcGIS interface. In the SWAT-REMM enhanced system, developed in this study, only one single representative soil symbol for each riparian buffer zone at each subwatershed is simulated. However, detailed soil information at the riparian buffer zone should be used in the SWAT-REMM simulation for exact modeling of runoff-infiltration and nutrient cycles at the buffer zones.

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Development of the Integrated SWAT-VFSMOD model

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Abstract

Because of negative impacts of sediment-laden water by accelerated soil erosion and transport processes, many researchers have been investigating to develop most effective soil erosion management practices. Hydraulic structures such as soil erosion control dams and grit chamber are installed widely. Instead of structural best management practices, non-structural best management practices, such as the Vegetative Filter Strip (VFS) has been thought as one of effective methods with less effort. The VFS is designed for reducing sediment from upland areas such as cultivated area. In addition, it has many positive functions by providing wildlife habitat. For these reasons, various researches regarding the VFS effects have been increasing in many countries. For maximum effects of the VFS on water quality improvement, the sediment trapping efficiency by VFS needs to be investigated and designed before its installation at the fields. For this purpose, the desktop-version of the VFSMOD system can used to estimate sediment trapping efficiency of vegetative filter strip under various field and vegetation conditions. However, the VFS effects at the receiving water body cannot be simulated with independent VFSMOD and SWAT system. In the current SWAT model, the VFS is simulated with simple regression equation, which is a function of VFS width solely. Thus the VFSMOD system was integrated with the SWAT model to simulate the VFS dynamically by considering most factors affecting the VFS performance, such as CN, soil type, rainfall, and other various factors, instead of evaluating its performance with VFS width only. With the integrated SWAT-VFSMOD system, SWAT simulated output data are used as input to the VFSMOD dynamically and its effects are simulated with existing SWAT routing component. It was found that the SWAT-VFSMOD system can be efficiently used to simulate VFS effects on water quality improvement.

KEYWORDS: Filter strip, soil erosion, sediment, SWAT, water quality, VFSMOD

Introduction

There are many methods to manage and prevent sediment-laden water in watersheds. There are not only many structural but non-structural Best Management Practices (BMPs) to prevent sediment-laden water. Among them, the Vegetative Filter Strip (VFS) is deemed as one of effective methods at reducing sediment and pollutants from agricultural fields (Park et al., 1994; Muñoz-Carpena, 1999; Inamdar et al., 2001; SWCS, 2001; Vennix and Northcott, 2002; Guber et al., 2007). The VFS, usually, is installed at the edge of cultivated areas or areas along streams, and it is designed for reduction of sediment and other various pollutants that are nutrients from runoff by filtration, infiltration, plant uptake, and so on (Muñoz-Carpena, 1999). Although it can reduce sediment from cultivated area with various processes, the effect to prevent sediment-laden water can be varied by diverse conditions in watershed, affected by diverse factors such as precipitation, slope, soil type, etc. When VFS is designed before installation in watershed, it needs to be simulated for effective installation with a model that affords to reflect these diverse factors. The semi-distributed, continuous daily time step, and watershed-scale model, Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998; Arnold and Fohrer, 2005) has been applied to watersheds (Arabi et al., 2006; Behera and Panda, 2006; Bracmort et al., 2006; Jha et al., 2007; Mishra et al., 2007) and used as an effective tool for assessing watershed management plans on hydrologic and water quality impacts (Gassman et al., 2007, Luo et al., 2008, Parajuli et al., 2008). The model, although, has many advantages and used widely for diverse purposes, it is deemed as the model has limitations to simulate VFS effect for sediment reduction. Considering only one factor that is filter strip width, the model calculates sediment trapping efficiency, although VFS is affected by various field conditions. In contrast to the SWAT model in VFS simulations, the VFSMOD model, which is developed by developed by Rafael Muñoz-Carpena (1999) and is field-scale model, considers various factors of fields.

The objectives of this study were to: 1) integrate the VFSMOD model to SWAT model for calculation of sediment trapping efficiency affected by continuous-daily-changing factors, and 2) apply to given watershed for sediment reduction by daily-changing sediment trapping efficiency.

Limitation of SWAT and Integration VFSMOD into SWAT

Limitation of current SWAT

The sediment trapping efficiency of the filter strip in the current SWAT is a function of only filter strip width through 'FILTERW' variable. Equation 1 is the sediment trapping efficiency used in the current SWAT model (Neitsch et al., 2000).

$$trap_{ef} = 0.367 \bullet (width_{filter\ strip})^{0.2967} \qquad (1)$$

Where $trap_{ef}$ is trapping efficiency and $width_{filter\ strip}$ is width of the vegetative filter strip (m).

Various studies, however, show that the sediment trapping efficiency by VFS is varied by many factors, such as VFS slope, runoff volume from upland areas, soil type, and vegetation characteristics (Muñoz–Carpena, 1999, Park et al., 2008, Otto et al., 2008). Therefore, these factors have to be considered to evaluate the pollutant reduction efficiency of the VFS (Otto et al., 2008) in the SWAT VFS simulation.

When Equation (1) is used for sediment trapping efficiency simulation with the current SWAT, the sediment trapping efficiency becomes '1' (i.e., 100 % sediment trap with the VFS) with the filter width of 30 m or greater as shown in Figure 1, irrespective of the magnitude of the storm events and runoff generated from it. Thus, the sediment trapping efficiency module of the SWAT needs to be enhanced or modified to estimate sediment trapping efficiency reflecting other sensitive factors, such as runoff volume.

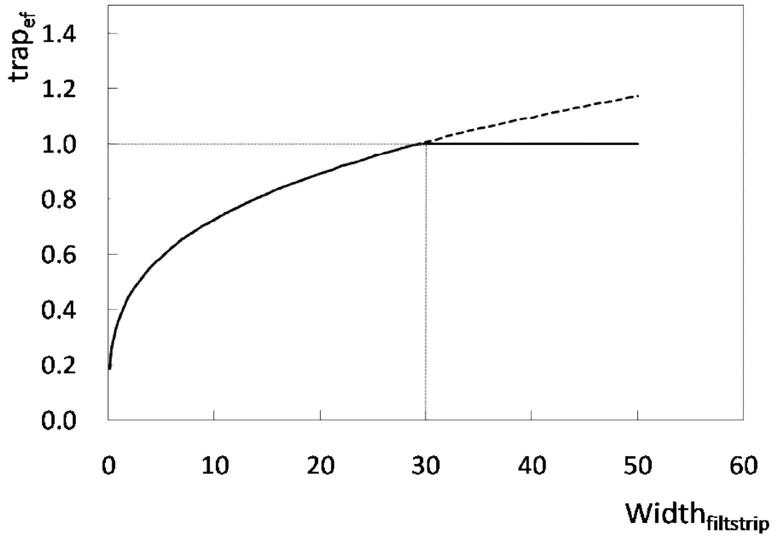


Figure 1. Sediment trapping efficiency in current SWAT

Integration VFSMOD into SWAT ,odel

‘Filter’ subroutine in current SWAT model calculates sediment trapping efficiency of each time step, also reduced sediment of each HRUs, which are applied ‘FILTERW’ variable, is calculated in this subroutine. This subroutine, however, uses solely filter strip width to calculate sediment trapping efficiency, the sediment trapping efficiency calculated with Equation 1 has limitation to reflect various field conditions. Thus, this subroutine has been modified to use another subroutine named ‘VFSMOD’ subroutine, the added subroutine ‘VFSMOD’ prepares several input files for VFSMOD model simulation. The input files for VFSMOD model by ‘VFSMOD’ subroutine are 6 files that contain information of each HRU, such as soil type, daily USLE C factor for crop growth, Curve Number which is daily-continuous values, precipitation of each day, and several physical values of each HRU. Also, the subroutine executives VFSMOD model as external program, modified model to return sediment trapping efficiency value (Figure 2).

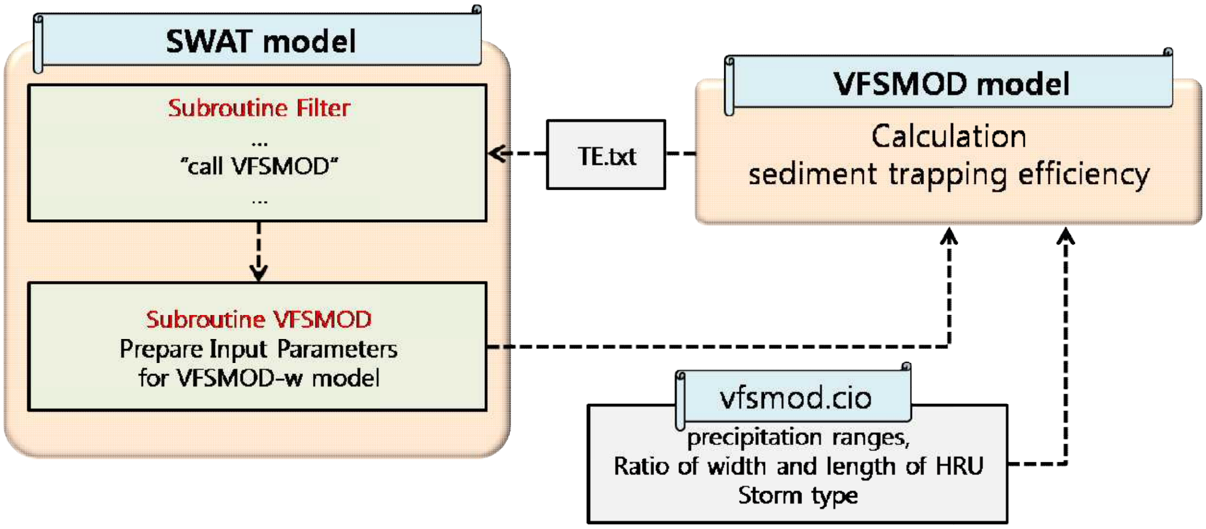


Figure 2. Overview of SWAT-VFSMOD model running.

Application of Integrated Model

In this study, a 'Haean-myeon' watershed, located at Gangwon province, South Korea, was selected to simulate the effects on sediment reduction affected daily-changing sediment trapping efficiency. The study watershed has some land uses; forest (36.39 ha, 59.32 %), agriculture (22.49 ha, 36.55%), urban (1.18 ha, 1.92 %), water (0.88 ha, 1.43 %), bare land (0.38 ha, 0.61 %), and pasture (0.10 ha, 0.17 %). Maximum and minimum annual precipitation was 1,876 mm and 867 mm from 2000 ~ 2006 with annual average precipitation of 1,396 mm. Approximately 60 % of annual precipitation is concentrated during the summer in the watershed, causing significant soil erosion and sediment yield. Average temperature ranged from -24.6 ~ 36.5℃, with mean temperature of 11.2℃. Extensive agricultural farming is performed at the center areas of the study watershed. Thus, the Korea government designated this area as a nonpoint source pollutant hotspot area. It is expected that various soil erosion Best Management Practices (BMPs) will be introduced in the study watershed to reduce soil erosion and sediment yields.

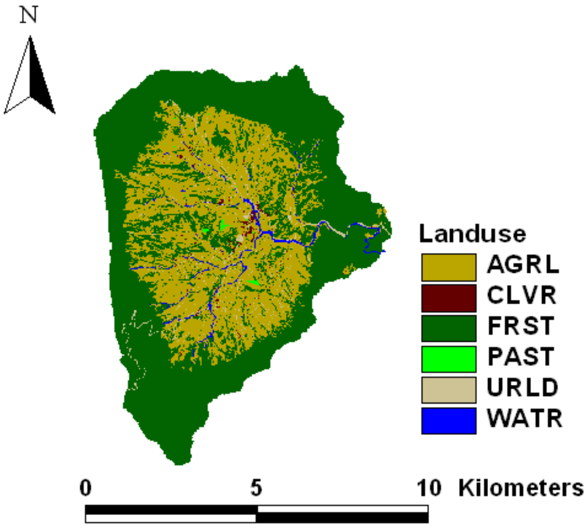
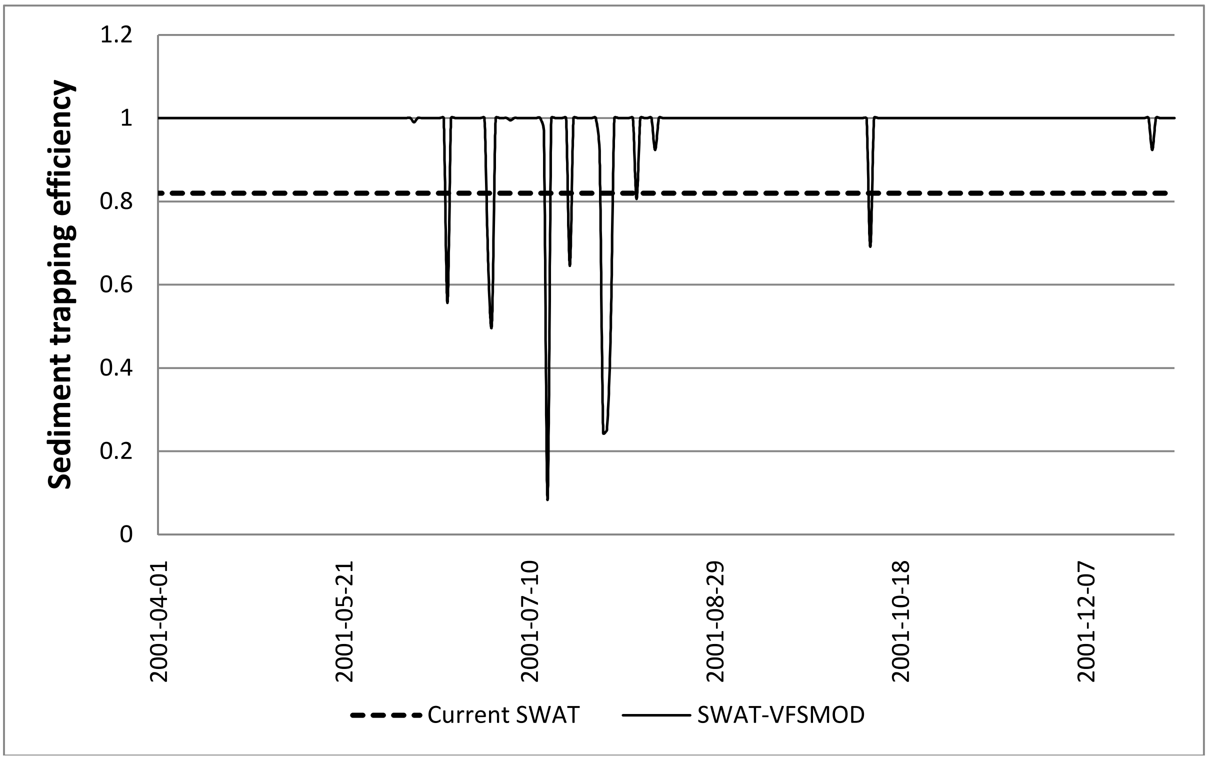


Figure 3. Study watershed applied with integrated SWAT-VFSMOD model.

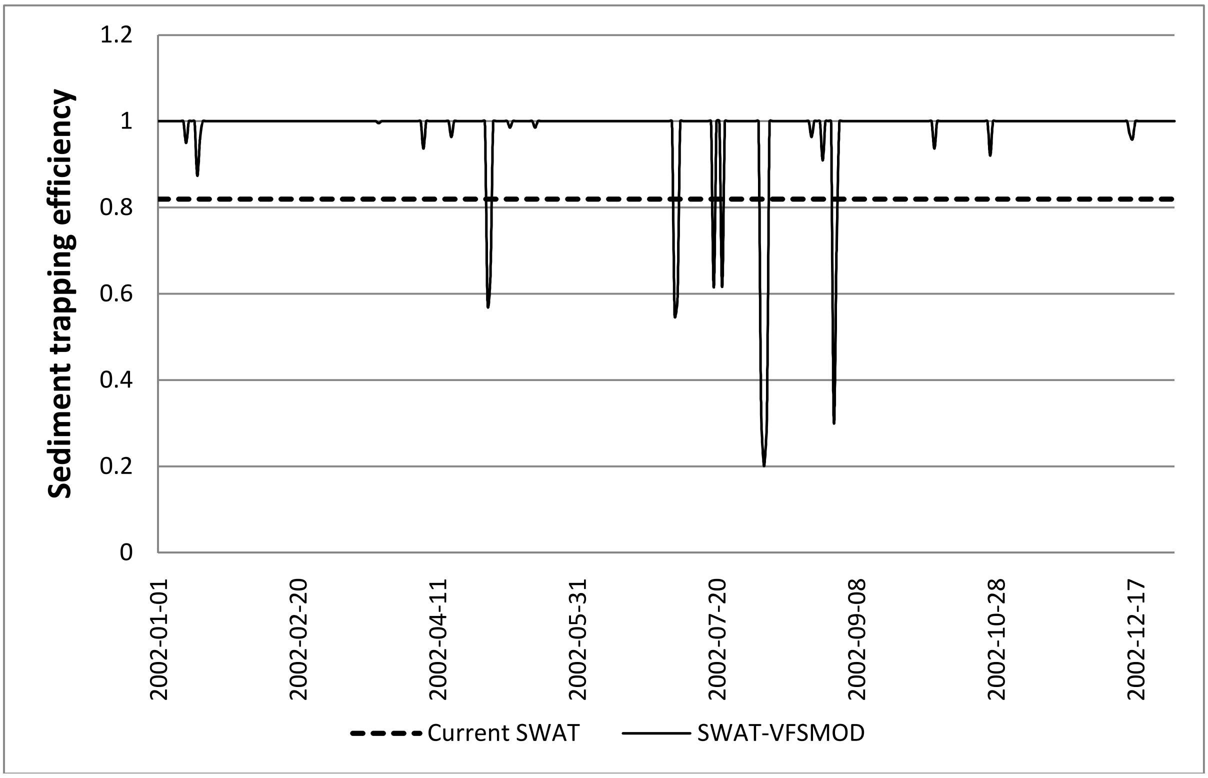
15 m (50 ft) widths of VFSs were applied to 3 subbasins, that have 32.2 %, 33.9 %, and 32.7 % of slope.

Result

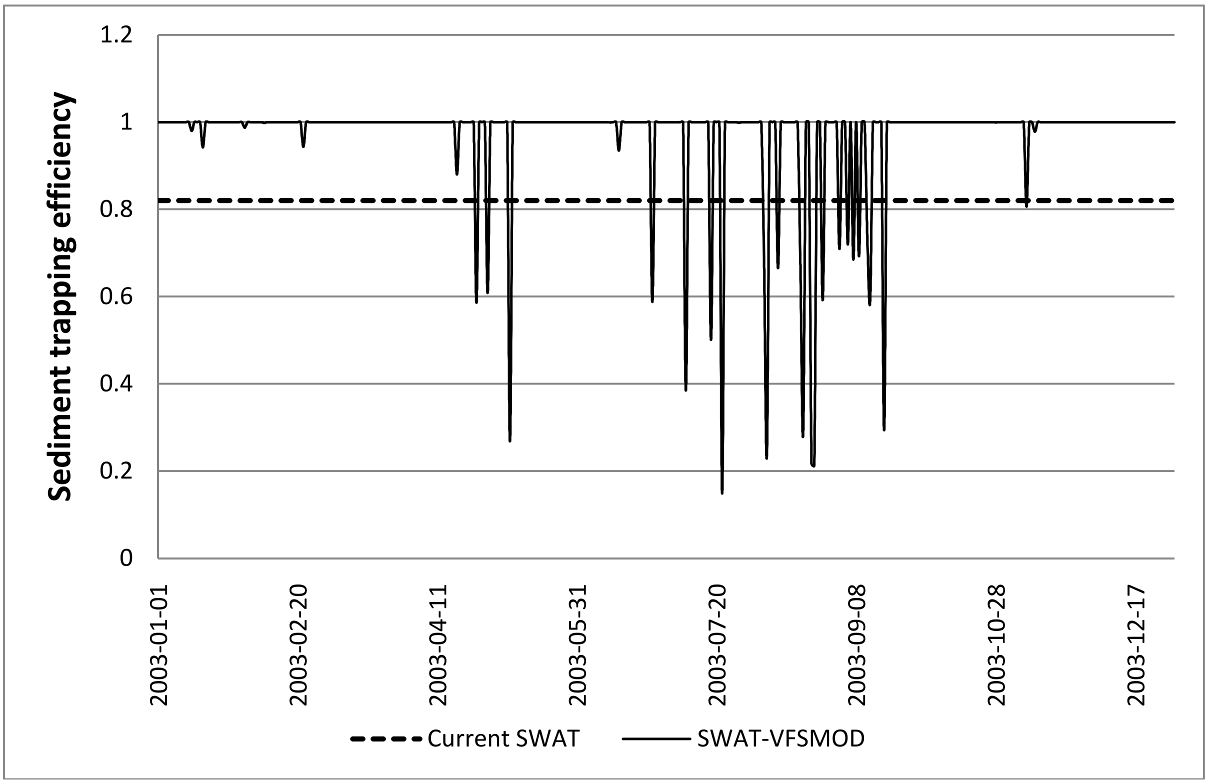
Shown as Figure 4(a), (b), (c), sediment trapping efficiency of current SWAT model showed solely value 0.82, because it was calculated Equation 1 with 15 m of 'FILTERW' value. However, the sediment trapping efficiency of integrated SWAT-VFSMOD model showed various values during simulation period, affected by daily and various factors such as precipitation, CN, USLE C, and so on. The sediment trapping efficiency of integrated SWAT-VFSMOD model showed from 1 (maximum) to 0.08 (minimum value of 2001 in July 15th), 0.20 (minimum value of 2002 in August 6th), and 0.15 (minimum value of 2003 in July 22th).



(a) Sediment Trapping Efficiency of Current and Integrated SWAT in 2001



(b) Sediment Trapping Efficiency of Current and Integrated SWAT in 2002



(c) Sediment Trapping Efficiency of Current and Integrated SWAT in 2003

Figure 4. Comparison of Sediment Trapping Efficiency of Current and Integrated SWAT.

Conclusion

The current SWAT model has limitation to simulate the effects of VFS, because current model consider only filter strip width when it calculates sediment trapping efficiency. Sediment trapping efficiency of VFS in field, however, are affected by various field conditions such as daily precipitation, crop growth in agricultural area, Curve Number, slope of agricultural area and so on. Thus, when VFS is simulated with models, those various field conditions need to be considered in estimation of sediment trapping efficiency. In this study, VFSMOD model, which is filed scale model for VFS simulations using various field conditions, was integrated into SWAT model, because SWAT model has limitation to estimation of sediment trapping efficiency considering solely filter strip width. The integrated SWAT-VFSMOD model was applied to ‘Haean-myeon’ watershed in South-Korea, in contrast to current SWAT model, it showed daily-changing sediment trapping efficiency in simulation period. This daily-changing sediment trapping efficiency means simulation considering not only daily-changing but various physical conditions. Also, to use integrated SWAT-VFSMOD model, there are not many addictive processes to need.

Thus, to simulate VFS effect with model, the integrated SWAT-VFSMOD model is deemed as effective model with daily-changing sediment trapping efficiency, reflecting daily-changing and various physical factors.

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New Shallow Water Table Depth Algorithm in SWAT2005: Recent Modifications

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The proximity of the shallow water table depth (*wtd*) to the soil surface impacts agricultural production, farm machine trafficability, and water quality due to agricultural chemical transport, soil salinity. Therefore, it is essential for hydrologic models to accurately simulate *wtd*. Recently, an alternative shallow *wtd* algorithm that relates drainage volume (*vol*) with *wtd* was incorporated into the Soil and Water Assessment Tool (SWAT Release 2005) model. Water table depth is computed as a function of *vol* and a factor *wtdconv*, which converts vol into *wtd*. The conversion factor *wtdconv* is currently a calibration parameter that is a function of the soil physical properties. However, at the watershed-scale where there are many fields (hydrologic response units, HRUs), it is difficult if not impossible to determine an optimum *wtdconv* value for each HRU through the calibration process. The objectives of this study were to: 1) modify the alternative shallow *wtd* algorithm in SWAT2005 so that *wtdconv* is automatically computed by the model as a function of soil physical properties and the location of the *wtd*, in order to eliminate determination of *wtdconv* through the calibration process; and 2) evaluate the modified *wtd* algorithm within SWAT2005 using measured water table depth data for three soils located in forest fields without tile drainage within the Muscatatuck River basin in southeast Indiana. On average the calibrated *wtdconv* yielded daily calibration and validation Nash-Sutcliffe efficiency (NSE) values of 0.64 and 0.41, respectively, the percent bias (PBIAS) values of -13% and -4%, respectively, and root mean square error (RMSE) values of 0.41 m and 0.59 m, respectively, while the automatic wtdconv yielded NSE values of 0.65 and 0.48, respectively, PBIAS values of -3% and 1%, respectively, and RMSE values of 0.40 m and 0.55 m, respectively, for the three observation wells. Based on these model outputs, there were no significant differences between the *wtd* simulated using the manually calibrated and the automatically computed *wtdconv* coefficient. Automatically computed coefficient *wtdconv* will enable this alternative shallow *wtd* algorithm to be used at the watershed scale.

B1-4

Modelling Onsite Wastewater Systems in SWAT

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It is common practice to use onsite wastewater systems (OWSs) to treat domestic wastewater in the United States and the use of OWSs is growing every year with the development of new residential houses. However, OWSs are considered a cause of significant non-point pollution sources to water bodies especially in rural and suburban areas. OWSs discharge septic tank effluent to the soil wherein percolation through an unsaturated zone provides treatment of many pollutants. Remaining constituents are eventually transported via ground water into surface waters. Watershed scale models can serve as useful tools for tracking the fate of nutrients discharged to the receiving waters of a river basin. The objective of this study is to develop modeling capability within the Soil Water Assessment Tool (SWAT) to simulate various types of OWSs and quantify environmental impacts by assessing nutrient loadings to the watershed. The new biozone module simulates biophysical processes taking place in the biologically active soil layer (biozone) that receives septic tank effluent. The new capability, available in ArcSWAT 2009 version, has significant impacts on predicting water quality of the receiving waters due to the combined effect of all point and nonpoint source loads, including septic tanks. The new algorithm incorporates the impacts of effluents delivered from conventional, advanced and failing septic tank systems on downstream water quality in a large watershed. Model parameters were calibrated to monitoring well data collected at residential sites in Hoods Creek Watershed, NC. Integrated modeling approach will also be presented.

B1-5

SWAT-CUP: A Calibration and Uncertainty Analysis Program for SWAT

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Abstract

As watershed models are being used more and more for making management decisions, it is imperative that they are calibrated and validated with proper attention given to sensitivity and various uncertainties. Technically, calibration of complex watershed models is not an easy task for reasons ranging from lack of observed data to the large number of parameters and the long time that model execution requires. Conceptually, calibration of watershed models is beset with four important issues. These are i) parameterization, ii) objective function definition, iii) uncertainty quantification, and finally, iv) conditionality of the calibrated model. In this paper we discuss these issues and describe a program generally referred to as the CUP (Calibration and Uncertainty Procedures) and its coupling with the hydrologic program Soil and Water Assessment Toll (SWAT). SWAT-CUP consists of five different optimization programs Sequential Uncertainty Fitting ver. 2 (SUFI2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Monte Carlo Markov Chain (MCMC), and Particle Swarm Optimization (PSO), which are linked with similar inputs to SWAT. This easy-to-use program allows the user to compare different optimization algorithms as well as the effect of different objective functions (only with SUFI2) on the final parameter sets. The program allows detailed parameterization of the model based on hydrologic group, soil and landuse type, subbasin, and slope. The program further allows for the calibration of rainfall and temperature data. The SWAT-CUP interface allows visualization of the 95% prediction uncertainty (95PPU) band along with observed and best simulation results in the same graph, and calculates local and global sensitivities. The five procedures are briefly described here. No attempt is made to compare the procedures as this is beyond the scope of this paper.

Keywords: Calibration, uncertainty, SUFI2, GLUE, ParaSol, MCMC, PSO, SWAT-CUP

Introduction

There is an intimate relationship between calibration and uncertainty assessment in watershed models. Hence statements such as "..the process of calibration is often described as having more to do with improving agreement with experimental data than assessing error or model uncertainty" (*AIAA G-077-1998*) are particularly inapt for large-scale distributed watershed models. Hydrologists and engineers are often asked to assess their calibration by addressing model uncertainties such as: is this parameter set unique? Does it correctly describe the watershed processes? Or, can we use it to describe water quality as well as water quantity?

Technically, calibration of complex watershed models is not an easy task for reasons such as lack of observed data, large number of parameters to be estimated, and the long model execution time. Conceptually, calibration of watershed models is beset with four important issues. These are i) parameterization, ii) objective function definition, iii) uncertainty issue, and finally, iv) conditionality of the calibrated model. In this paper we discuss these issues, and although we may not have a solution for every problem, we offer a tool that can help to investigate them in more detail. The software developed is generally referred to as the CUP (Calibration and Uncertainty Procedures) and currently it is coupled with the hydrologic program Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and the nitrogen leaching model, LEACHN (Hutson and Wagenet, 1992).

SWAT-CUP consists of five different optimization programs, which include: Sequential Uncertainty Fitting ver. 2 (SUFI2) (Abbaspour 2007, 2004), Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992), Parameter Solution (ParaSol) (van Griensven and Meixner, 2006), Monte Carlo Markov Chain (MCMC) (Vrugt et al., 2003), and Particle Swarm Optimization (PSO) (Kennedy and Eberhart, 1995), which are linked with similar inputs to SWAT. This easy-to-use program allows the user to compare different optimization algorithms as well as the effect of different objective functions (only with SUFI2) on the final parameter sets. The program allows detailed parameterization of the model based on hydrologic group, soil and landuse type, subbasin, and slope. The program further allows for the calibration of rainfall and temperature data, as well as global and local sensitivity analysis. The five procedures are briefly described here with an example. We do not make an attempt to compare these methods, but simply to show the results of their applications to the same problem from a previous work (Yang et al., 2008). Further functionalities being added to SWAT-CUP include gridification of the runs where parallel jobs are submitted to different computer CUPs and the output collected after the runs are completed, and visualization of the SWAT calibrated outputs on Google Earth and similar platforms.

Model Parameterization

As SWAT is a spatially continuous model, its parameterization is a difficult task. On the one hand the watershed's spatial heterogeneity should be reflected in the model for a better model performance throughout the watershed. On the other hand this may result in the definition of too many parameters. Too many parameters may render a calibration process arbitrary due to interaction between parameters causing identifiably problems. There are no general rules for parameterization and in each case the analyst must decide the degree of parameterization based on the objectives and data availability. Having said this, it should be emphasized that detailed information on spatial parameters and knowledge of dominant hydrologic processes in a watershed is essential for building a correct watershed model. A combination of measured data and spatial analysis techniques using pedotransfer functions, geostatistical analysis, and remote sensing data would be the way forward.

In the SWAT, the hydrologic response unit, HRU, is the smallest unit of spatial disaggregation. As a watershed is divided into HRUs by overlaying elevation, slope, soil, and landuse, a distributed parameter such as hydraulic conductivity can potentially be defined for each HRU. An analyst is, hence, confronted with the difficult task of collecting or estimating a large number of input parameters, which are usually not available. An alternative approach for the estimation of distributed parameters is by calibrating a single global modification term that can scale the initial estimates by a multiplicative, or an additive term. This leads to the following proposed parameterization scheme, which we have implemented in SWAT-CUP:

x__<parname>.<ext>__<hydrogrp>__<soltext>__<landuse>__<subbsn>__<slope>

Where

x__ = a code to indicate the type of change to be applied to a parameter:

v__ means the existing parameter value is to be replaced by a given value,

a__ means a given value is added to the existing parameter value, and

r__ means the existing parameter value is multiplied by (1+ a given value).

<parname> = SWAT parameter name

.<ext> = SWAT file extension code for the file containing the parameter

<hydrogrp> = (optional) soil hydrological group (‘A’,’B’,’C’ or ‘D’)

<soltext> = (optional) soil texture

<landuse> = (optional) name of the landuse category

<subbsn> = (optional) subbasin number(s)

<slope> = (optional) slope

Any combination of the above factors can be used to describe a parameter identifier. If a parameter is to be calibrated globally (i.e., changes applied to all HRUs), the identifiers <hydrogrp>, <soltext>, <landuse>, <subbsn>, and <slope> are then omitted. Examples of specifications for different parameters are provided in Tables 1-5. SWAT-CUP basically accounts for every single SWAT parameter, all layers - as in the soil data files, all rotations and operations - as in the management files, and all crop parameters in the crop file.

Table 1. Specification of management parameters.

Parameter identifiers	Description
v__HEAT_UNITS{rotation no,operation no}	Management parameters that are subject to operation/rotation must have both specified

Table 2. Specification of crop parameters.

Parameter identifiers	Description
v__T_OPT{30}.CROP.DAT*	Parameter T_OPT for crop number 30 in the crop.dat file
v__PLTNFR(1){3}.CROP.DAT	Nitrogen uptake parameter #1 for crop number 3 in crop.dat file

Table 3. Specification of soil parameters.

Parameter identifiers	Description
r__SOL_K(1).sol	K of Layer 1 of all HRUs
r__SOL_K(1,2,4-6).sol	K of Layer 1,2,4,5, and 6 of all HRUs
r__SOL_K().sol	K of All layers and all HRUs
r__SOL_K(1).sol__D	K of layer 1 of HRUs with hydrologic group D
r__SOL_K(1).sol____FSL	K of layer 1 of HRUs with soil texture FSL
r__SOL_K(1).sol____FSL__PAST	K of layer 1 of HRUs with soil texture FSL and landuse

	PAST
r__SOL_K(1).sol____FSL__PAST__1-3	K of layer 1 of subbasins 1,2, and 3 with HRUs containing soil texture FSL and landuse PAST
r__SOL_K(1,2).sol________1-3	K of layers 1 and 2 of subbasins 1,2, and 3

Table 4. Specification of Pesticide Parameters.

Parameter identifiers	Description
v__WSOL{1}.pest.dat	This changes parameter WSOL for pesticide number 1 in pest.dat file

Table 5. Specification of slope Parameters

Parameter identifiers	Description
v__SOL_K(1).sol____________0-10	K of layer 1 for HRUs with slope 0-10

* Note that each identifier is separated by two underscores, which must be kept even if the identifier is not used

Objective Function Definition

There are a large number of objective functions defined in the literature. Examination and comparison of these functions is beyond the scope of this paper. What we would like to emphasize, however, is the fact that different objective functions lead to different "calibrated" parameters at the end. Therefore, the analyst needs to be aware of this fact. In SUFI2 program we have given the option of choosing from 7 different objective functions. These include:

1) Multiplicative form of the sum of square errors (*MSSQE*):

$$g = \frac{\sum_{i}^{n_Q} (Q_m - Q_s)_i^2}{n_Q} * \frac{\sum_{i}^{n_S} (S_m - S_s)_i^2}{n_S} * \frac{\sum_{i}^{n_N} (N_m - N_s)_i^2}{n_N} * \ldots. \qquad (1)$$

where g is the objective function, Q stands for discharge, S for sediment, N for nitrate, m for measured and s for simulated. n_Q, n_S, amd n_N are, respectively, number of measured data for Q, S, and N. This formulation does not require weights for different variables.

2) Summation form of the sum of square errors (*SSSQE*):

$$g = w_1 \sum_{i=1}^{n_Q} (Q_m - Q_s)_i^2 + w_2 \sum_{i=1}^{n_S} (S_m - S_s)_i^2 + w_3 \sum_{i=1}^{n_N} (N_m - N_s)_i^2 + \ldots.. \qquad (2)$$

where weights w's could be calculated as:

i) $w_i = {}^{1}\!/_{n_i \sigma_i^2}$ (3)

where σ_i^2 is variance of the ith measured variable, or:

ii) $w_1 = 1, \quad w_2 = {}^{\overline{Q}_m}\!/_{\overline{S}_m}, \quad w_3 = {}^{\overline{Q}_m}\!/_{\overline{N}_m}$ (4)

where bars indicate averages (see Abbaspour et al., 1999). Note that choice of weighs can also affect the outcome of an optimization exercise (see Abbaspour, et al., 1997).

3) Coefficient of determination R^2 calculated as:

$$R^2 = \frac{\left[\sum_i (Q_{m,i} - \overline{Q}_m)(Q_{s,i} - \overline{Q}_s)\right]^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2 \sum_i (Q_{s,i} - \overline{Q}_s)^2} \tag{5}$$

If there is more than one variable, then the objective function is defined as:

$$g = \sum_j w_j R_j^2 \tag{6}$$

where j is the counter for variables, and weights could be calculated as above or calculated in a way as to make the contribution of all variables to the objective function equal.

4) Chi-squared χ^2 calculated as:

$$\chi^2 = \frac{\sum_i (Q_m - Q_s)_i^2}{\sigma_Q^2} \tag{7}$$

If there is more than one variable, then the objective function is calculate as:

$$g = \sum_j w_j \chi_j^2 \tag{8}$$

where weights could be calculated as above or calculated in a way as to make the contribution of all variables to the objective function equal.

5) Nash-Sutcliffe, NS, coefficient calculated as:

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2} \tag{9}$$

If there is more than one variable, then the objective function is defined as:

$$g = \sum_j w_j NS_j \tag{10}$$

where weights could be calculated as above or calculated in a way as to make the contribution of all variables to the objective function equal.

6) Coefficient of determination R^2 has the problem of not accounting for the quantity, just the linearity. For this reason the two signals in Figure 1 have $R^2=1$. An objective function could be defined where R^2 is multiplied by the slope of the regression line, *b*. This function allows accounting for the discrepancy in the magnitude of the two signals (depicted by *b*) as well as their linearity (depicted by R^2). The objective function is expressed as:

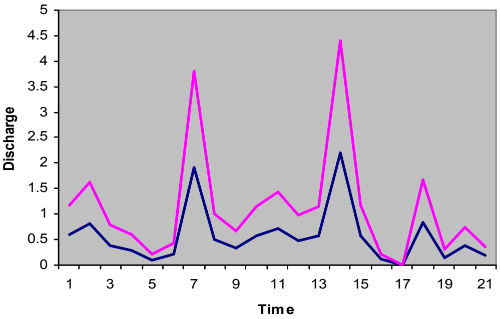

Figure 1. Two signals having R^2=1 but different in quantity.

$$\phi = \begin{cases} |b|R^2 & \text{if} \quad |b| \le 1 \\ |b|^{-1}R^2 & \text{if} \quad |b| > 1 \end{cases} \tag{11}$$

in case of multiple variables, *g* is defined as:

$$g = \sum_j w_j \phi_j \tag{12}$$

where weights could be calculated as above or calculated in a way as to make the contribution of all variables to the objective function equal.

7) The ranked sum of squared errors (*RSSQE*) aims at the fitting of the frequency distributions of the observed and the simulated series. After independent ranking of the measured and the simulated values, new pairs are formed and the *RSSQE* is calculated as:

$$RSSQE = \sum_{j=1}^{n} (Q_m - Q_s)_j^2 \tag{13}$$

where *j* represents the rank. As opposed to the *SSSQE* or *MSSQE* methods, the time of occurrence of a given value of the variable is not accounted for in the *RSSQE* method.

Uncertainty Issues

Another issue with calibration of watershed models is that of uncertainty in the predictions. Watershed models suffer from large modeling uncertainties. These can be divided into: conceptual model uncertainty, input uncertainty, and parameter uncertainty. The conceptual model uncertainty (or structural uncertainty) could be of the following situations:

a) Model uncertainties due to simplifications in the conceptual model. For example, the assumptions in the universal soil loss equation for estimating sediment loss, or the assumptions in calculating flow velocity in a river.

b) Model uncertainties due to processes occurring in the watershed but not included in the model. For example wetland processes, wind erosion, erosions caused by landslides, and the “second-storm effect” (Abbaspour et al., 2007) affecting the mobilization of particulates from soil surface. Figure 2 shows the effect of wetland on discharge upstream, in the middle, and downstream of Niger Inland Delta (NID).

c) Model uncertainties due to processes that are included in the model, but their occurrences in the watershed are unknown to the modeler or unaccountable; for example various forms of reservoirs, water transfer irrigation, or farm management affecting water quality.

d) Model uncertainties due to processes unknown to the modeler and not included in the model either. These include dumping of waste material and chemicals in the rivers, or processes that may last for a number of years and drastically change the hydrology or water quality such as large-scale constructions of roads, dams, bridges, tunnels, etc.

e) Model uncertainties due to highly managed watersheds. In highly managed watersheds, natural processes play a secondary role. If detailed management data is not available, then modeling these watersheds will not be possible. Examples of managements are dams and reservoirs, water transfers, and irrigation

from deep wells. In Figure 3 the effect of Aswan dam on downstream discharge before and after its operation is shown. It is clear that without the knowledge of dam's operation, it would not be possible to model downstream processes.

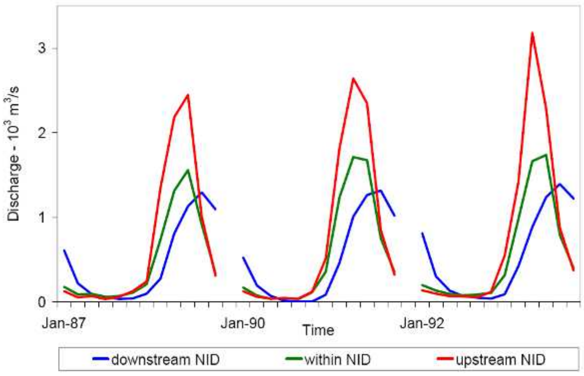

Figure 2. The influence of Niger Inland Delta on the through flow at upstream, within, and downstream of the wetland. (After Schuol et al., 2008a,b).

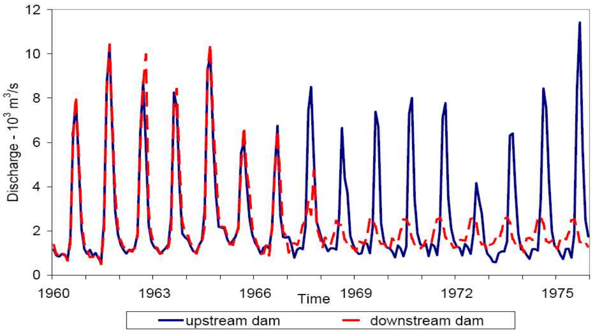

Figure 3. Effect of Aswan dam on down stream discharge before and after its operation in 1967.

In Figure 4 the effect of irrigation on actual ET and soil moisture is illustrated in Esfahan, Iran. Esfahan is a region of high irrigation with a negative water balance for almost half of the year.

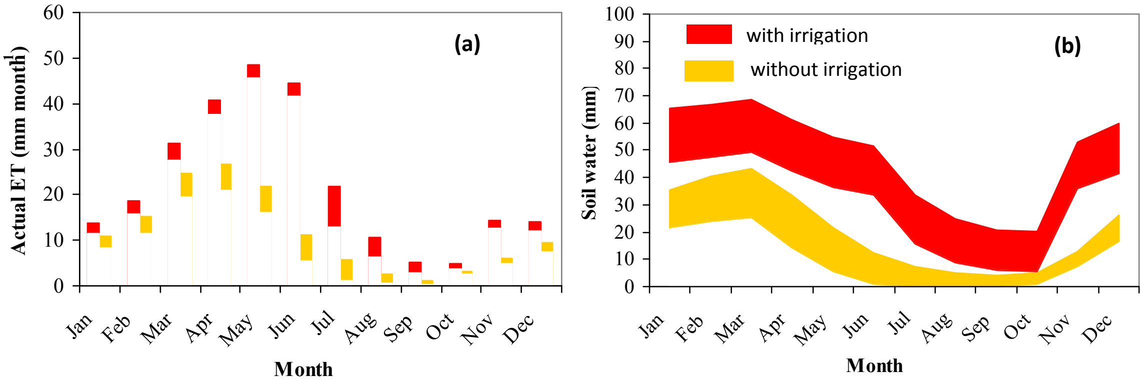

Figure 4. Illustration of the differences in predicted actual ET and soil moisture with and without considering irrigation in Esfahan province. The variables are monthly averages for the period of 1990-2002. (After Faramarzi et al., (2008).

In the study of water resources in Iran, Faramarzi et al., (2009) produced a “water management map” (Figure 5) in order to explain the poor calibration results in some outlets in the country. There was a good correlation between badly simulated outlets and the level of management.

In addition to *conceptual model uncertainty*, there are *input uncertainties* due to errors in input variables such as rainfall and temperature and other inputs such as soil map, landuse map, etc. In distributed hydrologic models an important error is due to the assignment of point measurements to large areas (subbasin in SWAT). In general, it is quite difficult to account for input uncertainty. Some researchers propose treating inputs as random variable, which allows fitting them to get better simulations. In the SWAT-CUP we have provided options for fitting climate data. As model outputs are very sensitive to input data, especially rainfall, care must be taken in such approaches. In mountainous regions, input uncertainty could be very large.

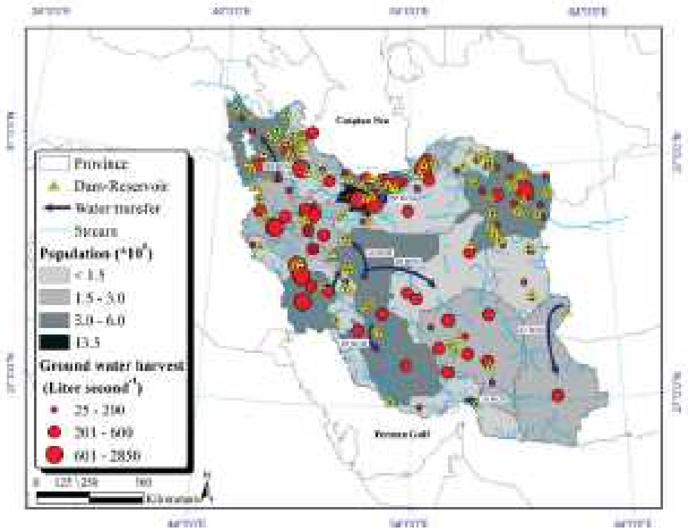

Figure 5. Water management map of Iran showing some of man’s activities during 1990-2002. The map shows locations of dams, reservoir, water transfers and groundwater harvest (background shows provincial-based population). After Faramarzi et al., (2008).

Finally, *parameter uncertainty* is usually caused as a result of inherent non-uniqueness of parameters in inverse modeling. Parameters represent processes. The fact that processes can compensate for each other gives rise to many sets of parameters that produce the same output signal.

A single valued parameter set results in a single model signal in direct modeling. In an inverse application, an observed signal, however, could be more-less reproduced with thousands of different parameter sets. This non-uniqueness is an inherent property of inverse modeling (IM). IM, has in recent years become a very popular method for calibration (e.g., Beven and Binley, 1992, 2001; Abbaspour et al., 1997, 2007; Duan et al., 2003; Gupta et al., 1998). IM is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g., river discharge, sediment concentration). This is attractive because direct measurement of parameters describing the physical system is time consuming, costly, tedious, and often has limited applicability. Because nearly all measurements are subject to some uncertainty, the inferences are usually statistical in nature.

Furthermore, because one can only measure a limited number of (noisy) data and because physical systems are usually modelled by continuum equations, no hydrological inverse problem is really uniquely solvable. In other words, if there is a single model that fits the measurements there will be many of them. An example is shown in Figure 6 where two very different parameter sets produce signals similar to the observed discharge. Our goal in inverse modelling is then to characterize the set of models, mainly through assigning distributions (uncertainties) to the parameters, which fit the data and satisfy our presumptions as well as other prior information.

To limit the contribution of parameter non-uniqueness to total uncertainty, the objective function should include different fluxes and loads (see Abbaspour et al., 2007). The downside of this is that a lot of data must be measured for calibration. The use of remote sensing data, when it becomes available, could be extremely useful.

Furthermore, errors could also exist in the very measurements we use to calibrate the model. These errors could be very large, for example, in sediment data and grab samples. Another uncertainty worth mentioning is that of “modeler uncertainty”! It has been shown before that the experience of modelers could make a big difference in model calibration. We hope that packages like SWAT-CUP can help decrease modeler uncertainty by removing some probable sources of modeling and calibration errors.

On a final note, it is highly desirable to separate quantitatively the effect of different uncertainties on model outputs, but this is very difficult to do. The combined effect, however, should always be quantified on model outputs.

Non-uniqueness: The Swiss cheese effect

The non-uniqueness problem can also be looked at from the point of view of the objective function. Plotting the objective-function response surface for two by two combinations of parameters could be quite revealing. As an example, see Figure 7 where the inverse of an objective function is plotted against two parameters, hence, local minima are shown as peaks. Size and distribution of these peaks resembles the mysterious holes in a block of Swiss Emmentaler cheese where the size of each hole represents the local uncertainty. Our experience shows that each calibration method converges to one such peak (see the papers by Yang et al., 2008, Schuol et al., 2008a,b, and Faramarzi et al., 2009). Yang et al., (2008) compared GLUE, ParaSol, SUFI2, and MCMC methods in an application to a watershed in China. They found that these different optimization programs each identified a different solution at different locations in the parameter spaces with more less the same discharge results, hence, the Swiss cheese effect as discussed above.

Table 6 has a summary of the comparison. This Table shows the results of fitting 10 SWAT parameters with the 5 different optimization routines. For each routine, the best fit parameter value and the uncertainty range is shown in brackets. Also shown are the values of Nash-Sutcliffe (*NS*), R^2, *P-factor* and *R-factor* (for a definition of these terms see section 7.3), the level of difficulty of implementation, and also the number of SWAT runs that it took to produce the results. The Table shows that *NS* and R^2 values are almost the same for most of the routines. With the exception of ParaSol, other routines also have the same *P-factor*, and *R-factor* values. This is because ParaSol only accounts for parameter uncertainty, while SUFI2 and GLUE give aggregated total uncertainties. MCMC and IS also produce parameter uncertainties only, but the uncertainties are rather large due to the 4 extra parameters added to these models to force production of iid (independent identically distributed) results (see Yang et al., 2008). An interesting result is the number of runs in each routine. As SWAT runs are time consuming, this parameter is quite important. It is seen that the Bayesian-based procedure needed the largest number of runs, while SUFI2 needed, the smallest number of SWAT runs.

GW_DELAY	CH_N2	CN2	REVAPMN	Sol_AWC	*g*
3.46	0.0098	50	0.8	0.11	0.010
0.34	0.131	20	2.4	0.2 3	0.011

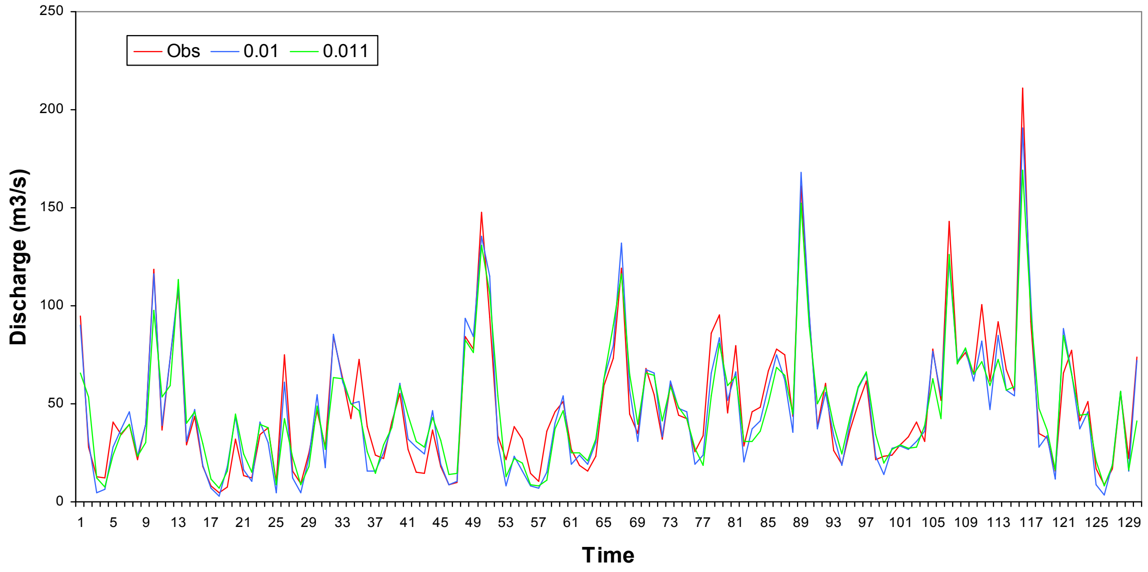

Figure 6. Example of parameter non-uniqueness showing two similar discharge signals based on quite different parameter values

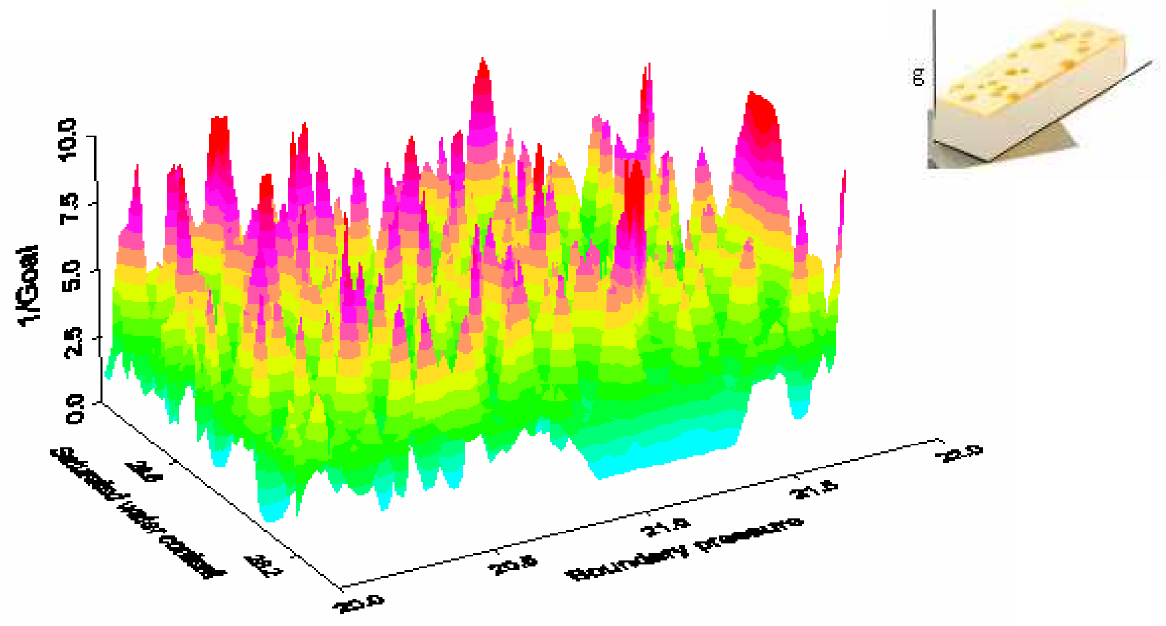

Figure 7. A multidimensional objective function is "multimodal" meaning that there are many areas of good solutions with different uncertainties much like the mysterious holes in a slice of Swiss cheese.

Conditionality of the Calibrated Watershed Models

When is a watershed model calibrated?

If a watershed model is calibrated using discharge data at the watershed outlet, can the model be called "calibrated" for that watershed? If we add water quality to the data and recalibrate, the hydrologic parameters obtained based on discharge alone will change. Is the new model now calibrated for that watershed? What if we add discharge data from stations inside the watershed? Will the new model give correct loads from various landuses in the watershed? Perhaps not, unless we include the loads in the calibration process (see Abbaspour et al., 2007). Hence, an important question arises as to: "for what purpose can we use a calibrated watershed model?" For example: What are the requirements of a calibrated watershed model if we want to do landuse change analysis? Or, climate change analysis? Or, analysis of upstream/downstream relations in water allocation and distribution? Can any single calibrated watershed model address all these issues? Can we have several calibrated models for the same watershed where each model is applicable to a certain objective? Note that these models will most likely have different parameters representing different processes (see Abbaspour et al. 1999).

Conditionality is an important issue with calibrated models. This is related to the previous question on the limitation of the use of a calibrated model. Calibrated parameters are conditioned on the choice of objective function, the type and number of data points, and the procedure used for calibration, among other factors. Hence, model conditionality must be kept in mind when using a "calibrated" model for watershed management purposes and the model outputs in a chain of decision making process.

The Soil and Water Assessment Tool (SWAT) Program

SWAT (Arnold et al., 1998) is a watershed simulation program that was originally developed by a research team in the US Department of Agriculture. SWAT solves water balances in hydrologic response units (HRUs) which are defined by unique landuse–soil-slope type combinations within sub-basins of the watershed. For each HRU the water balance is calculated considering precipitation, evapotranspiration, runoff, infiltration, interflow, and percolation into a shallow aquifer. River flow is routed downstream to the outlet of the watershed. The current version of SWAT (SWAT2009) is linked to ArcGIS 9.3 (ESRI, http://www.esri.com) in order to facilitate handling of input and output. SWAT implements also a water quality sub-model describing transport of sediment, and transport and transformation of nutrients and pesticides. Running SWAT is based on a four-step procedure:

1. In the first step, the ArcGIS interface of SWAT (ArcSWAT) is used to delineate sub-basins from digital elevation data, and then generate HRUs within each sub-basin by overlaying the layers soil, landuse, and slope.

2. In the second step, climate and various water and management options are inputted by the user also using the ArcGIS interface.

3. In the third step, ArcSWAT produces a large number of input text files.

4. Finally, the FORTRAN program "SWAT2009" reads these text input files, performs the simulation, and writes text output files.

As SWAT-CUP is a stand alone program independent of ArcGIS interface, after the initial setup of a SWAT project, the text file-based project (TxtInOut directory) is used to run SWAT-CUP.

Table 6. Summary statistics comparing different calibration uncertainty procedures.

Criterion	GLUE	ParaSol	SUFI-2	Bayesian inference with cont. autoregr. error model	
				MCMC	IS
Goal function	Nash-Sutcliffe	Nash-Sutcliffe	Nash-Sutcliffe	post. prob. density	post. prob. density
a__CN2.mgt	-16.8 (-29.6, -9.8)[1]	-21.0 (-21.9, -20.1)	-26.9 (-30.0, -7.2)	-14.2 (-16.8, -11.6)	-19.60
v__ESCO.hru	0.76 (0.02, 0.97)	0.67 (0.65, 0.69)	0.82 (0.43, 1.0)	0.74 (0.63, 0.75)	0.62
v__EPCO.hru	0.22 (0.04, 0.90)	0.16 (0.13, 0.20)	1 (0.34, 1.0)	0.94 (0.39, 0.98)	0.27
r__SOL_K.sol	-0.16 (-0.36, 0.78)	-0.37 (-0.41, -0.34)	-0.1 (-0.58, 0.34)	-0.29 (-0.31, 0.78)	0.01
a__SOL_AWC.sol	0.11 (0.01, 0.15)	0.07 (0.08, 0.08)	0.07 (0.05, 0.15)	0.12 (0.1, 0.13)	0.05
v__ALPHA_BF.gw	0.12 (0.06, 0.97)	0.12 (0.08, 0.13)	0.51 (0.23, 0.74)	0.14 (0.11, 0.15)	0.91
v__GW_DELAY.gw	159.58 (9.7, 289.3)	107.7 (91.2,115.2)	190.07 (100.2, 300)	25.5 (17.8, 33.3)	33.15
r__SLSUBBSN.hru	-0.45 (-0.56, 0.46)	-0.59 (-0.60, -0.58)	-0.52 (-0.60, 0.03)	-0.55 (-0.56, 0.15)	0.58
a__CH_K2.rte	78.19 (6.0, 144.8)	35.70 (27.72,37.67)	83.95 (69.4, 150.0)	78.3 (68.0, 86.2)	147.23
a__OV_N.hru	0.05 (0.00, 0.20)	0.11 (0.07, 0.10)	0.06 (0.00, 0.11)	0.12 (0.00, 0.19)	0.08
[2]σ_{dry}	-	-	-	0.93 (0.81, 1.10)	0.87
[2]σ_{wet}	-	-	-	2.81 (2.4, 3.9)	2.30
[2]τ_{dry}	-	-	-	38.13 (29.5, 53.8)	28.47
[2]τ_{wet}	-	-	-	3.42 (2.4, 8.0)	0.92
NS for cal (val)	0.80 (0.78)	0.82 (0.81)	0.80 (0.75)	0.77 (0.77)	0.64 (0.71)
R^2 for cal (val)	0.80 (0.84)	0.82 (0.85)	0.81 (0.81)	0.78 (0.81)	0.70 (0.72)
LogPDF for cal (val)	-1989 (-926)	-2049 (-1043)	-2426 (-1095)	-1521 (-866)	-1650 (-801)
[3]*P-factor* for cal (val)	79% (69%)	18% (20%)	84% (82%)	85% (84%)	-
[4]*R-factor* for cal (val)	0.65 (0.51)	0.08 (0.07)	1.03 (0.82)	1.47 (1.19)	-
Uncertainty described by parameter uncertainty	All sources of uncertainty	Parameter uncertainty only	All sources of uncertainty	Parameter uncertainty only	Parameter uncertainty only
Difficulty of implement.	very easy	easy	easy	more complicated	more complicated
Number of runs	10000	7500	1500 + 1500	5000 + 20’000 + 20’000	100’000

[1] c(a, b) for each parameter means: c is the best parameter estimate, (a,b) is the 95% parameter uncertainty range except SUFI-2 (in SUFI-2, this interval denotes the final parameter distribution).

[2] the σ_{dry}, σ_{wet}, τ_{dry}, and τ_{wet} used to calculate the Calculate the logarithm of the posterior probability density function (PDF) are from the best of MCMC.

[3] *p-factor* means the percentage of observations covered by the 95PPU

[4] *d-factor* means relative width of 95% probability band. (After Yang et al., 2008).

Interface Description

The text input/output format of SWAT provides the simplest coupling platform with system analysis tools. The coupling algorithm is illustrated in Figure 8 and is as follows:

i) The optimization programs write parameter names and corresponding values into a file called model.in,

ii) A program called SWAT_Edit.exe edits the input files of SWAT replacing the required parameters with those in the model.in,

iii) The SWAT program executes producing SWAT output files,

iv) An extract program extracts the required variables from the SWAT output files and writes them to a file called model.out,

v) The optimization program generates a new set of parameters and the procedure continues from i) until the requirements of the optimization program is met.

A description of different optimization routines is provided below.

GLUE

In the GLUE (Beven and Binley 1992), randomly selected parameter sets are divided into sets of acceptable and non-acceptable solutions. The degree of membership is determined by assessing the extent to which solutions fit the model, which in turn is determined by a subjective likelihood function. In GLUE, parameter uncertainty accounts for all sources of uncertainty, i.e., input uncertainty, structural uncertainty, parameter uncertainty and response uncertainty, because ''the likelihood measure value is associated with a parameter set and reflects all these sources of error and any effects of the covariation of parameter values on model performance implicitly'' (Beven and Freer, 2001). Also, from a practical point of view, disaggregation of the error into its source components is difficult, particularly in cases common to hydrology where the model is non-linear and different sources of error may interact to produce the measured deviation (Gupta et al., 2005). In GLUE, parameter uncertainty is described as a set of discrete ''behavioral'' parameter sets with corresponding ''likelihood weights''. A GLUE analysis consists of the following three steps:

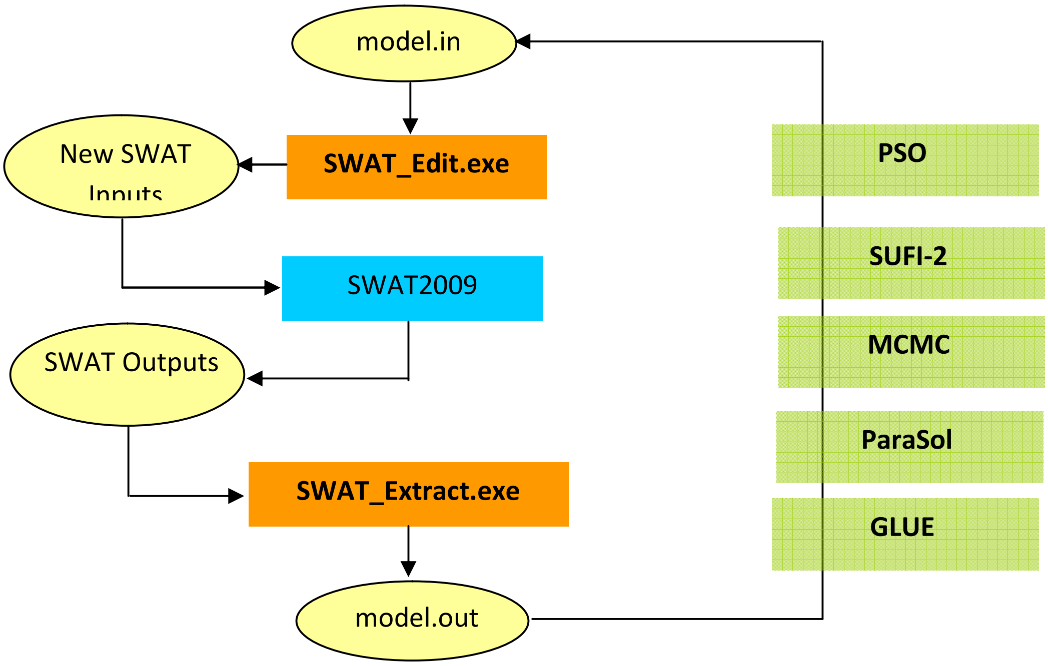

Figure 8. The schematic structure of coupling SWAT to system analysis programs

(1) After the definition of the ‘‘generalized likelihood measure’’, $L(\theta)$, a large number of parameter sets are randomly sampled from the prior distribution and each parameter set is assessed as either ‘‘behavioral’’ or ‘‘non-behavioral’’ through a comparison of the ‘‘likelihood measure’’ with a selected threshold value.
(2) Each behavioral parameter set is given a ‘‘likelihood weight’’ according to:

$$w_i = \frac{L(\theta_i)}{\sum_{k=1}^{N} L(\theta_k)} \qquad (14)$$

where N is the number of behavioral parameter sets. (3) Finally, prediction uncertainty is described by quantiles of the cumulative distribution realized from the weighted behavioral parameter sets. In the literature, the most frequently used likelihood measure for GLUE is the Nash–Sutcliffe coefficient (*NS*) (e.g., Beven and Freer, 2001; Freer et al., 1996), which is also used in SWAT-CUP:

$$NS = 1 - \frac{\sum_{t_i=1}^{n} (y_{t_i}^{M}(\boldsymbol{\theta}) - y_{t_i})^2}{\sum_{t_i=1}^{n} (y_{t_i} - \bar{y})^2} \qquad (15)$$

where n is the number of the observed data points, and y_{t_i} and $y_{t_i}^{M}(\boldsymbol{\theta})$ represent the observation and model simulation with parameters $\boldsymbol{\theta}$ at time t_i, respectively, and $\bar{y}$ is the average value of the observations.

ParaSol

ParaSol (van Griensven and Meixner, 2006) is based on a modification to the global optimization algorithm SCE-UA (Duan et al., 1992). The idea is to use the simulations performed during optimization to derive prediction uncertainty. The prediction uncertainty in ParaSol only reflects the uncertainty in the parameters. The procedure of ParaSol is as follows:

(1) After optimization applying the modified SCE-UA (the randomness of the algorithm SCE-UA is increased to improve the coverage of the parameter space), the simulations performed are divided into ‘‘good’’ simulations and ‘‘not good’’ simulations by a threshold value of the objective function as in GLUE. This leads to ‘‘good’’ parameter sets and ‘‘not good’’ parameter sets.
(2) Prediction uncertainty is constructed by equally weighting all ‘‘good’’ simulations. The objective function used in ParaSol is the sum of the squares of the residuals (*SSSQ*):

$$SSSQ = \sum_{t_i=1}^{n} (y_{t_i}^{M}(\boldsymbol{\theta}) - y_{t_i})^2 \qquad (16)$$

The relationship between *NS* and *SSSQ* is

$$NS = 1 - \frac{SSSQ}{\sum_{t_i=1}^{n} (y_{t_i} - \bar{y})^2} \tag{17}$$

where $\sum_{t_i=1}^{n} (y_{t_i} - \bar{y})^2$ is a fixed value for given observations. To improve the comparability with GLUE, all objective function values of ParaSol were converted to *NS*. As the choice of the threshold of the objective function in ParaSol is based on the χ^2-statistics it mainly accounts for parameter uncertainty under the assumption of independent measurement errors.

SUFI-2

In SUFI-2, parameter uncertainty is described by a multivariate uniform distribution in a parameter hypercube, while the output uncertainty is quantified by the 95% prediction uncertainty band (95PPU) calculated at the 2.5% and 97.5% levels of the cumulative distribution function of the output variables (Abbaspour et al., 2007). Latin hypercube sampling is used to draw independent parameter sets (Abbaspour et al., 2007). Similar to GLUE, SUFI-2 represents uncertainties of all sources through parameter uncertainty in the hydrological model. The procedure of SUFI-2 is as follows:

(1) In the first step, the objective function $g(\theta)$ and physically meaningful parameter ranges $[\theta_{abs\_min}, \theta_{abs\_max}]$ are defined. These exist in a file called Absolute_SWAT_Values.txt.
(2) Then Latin Hypercube sampling is carried out in the hypercube $[\theta_{min}, \theta_{max}]$ (initially could be set to as large as $[\theta_{abs\_min}, \theta_{abs\_max}]$ if no information is available), the corresponding objective functions are evaluated, and the sensitivity matrix J and the parameter covariance matrix C are calculated according to:

$$\mathrm{J}_{ij} = \frac{\Delta \mathrm{g_i}}{\Delta \theta_\mathrm{j}} \qquad i = 1,\ldots, C_2^m, \quad j = 1,\ldots, n, \tag{18}$$
$$\mathrm{C} = s_g^2 \left(\mathrm{J}^T \mathrm{J}\right)^{-1}$$

where s_g^2 is the variance of the objective function values resulting from the *m* model runs.
(3) A 95% predictive interval of a parameter θ_j is computed as follows:

$$\theta_{j,lower} = \theta_j^* - \mathbf{t}_{\nu,0.025}\sqrt{C_{jj}} \quad , \quad \theta_{j,upper} = \theta_j^* + \mathbf{t}_{\nu,0.025}\sqrt{C_{jj}} \tag{19}$$

where θ_j^* is the parameter θ_j for the best estimates (i.e., parameters which produce the optimal objective function), and ν is the degrees of freedom (m-n).
(4) The 95PPU is then calculated. The 95PPU is actually our model output, which needs to be compared with the measurement. As we are not comparing two signals, statistics such as R^2 or *NS* cannot be used for the comparison of the result. For this reason we define two other statistics referred to as *P-factor* (the percent of observations bracketed by the 95PPU) and the *R-factor* calculated according to:

$$R\text{-}factor = \frac{\frac{1}{n}\sum_{t_i=1}^{n}(y_{t_i,97.5\%}^{M} - y_{t_i,2.5\%}^{M})}{\sigma_{obs}} \quad (20)$$

where $y_{t_i,97.5\%}^{M}$ and $y_{t_i,2.5\%}^{M}$ represent the upper and lower boundary of the 95PPU, and σ_{obs} stands for the standard deviation of the measured data. The goodness of calibration and prediction uncertainty is judged on the basis of the closeness of the *P-factor* to 100% (i.e., most observations bracketed by the prediction uncertainty) and the *R-factor* to 0 (i.e., achievement of rather small uncertainty band). As all uncertainties in the conceptual model and inputs are reflected in the measurements (e.g., discharge), bracketing most of the measured data in the prediction 95PPU ensures that all uncertainties are depicted by (and mapped on) the parameter uncertainties. If the two factors have satisfactory values, then the uniform distribution in the parameter hypercube [$\theta_{\min}$, $\theta_{\max}$] is interpreted as the posterior parameter distribution. Otherwise, [$\theta_{\min}$, $\theta_{\max}$] is updated according to:

$$\begin{aligned} \theta_{j,\min,\text{new}} &= \theta_{j,lower} - \max\left(\frac{\theta_{j,\text{lower}} - \theta_{j,\min}}{2}, \frac{\theta_{j,\max} - \theta_{j,\text{upper}}}{2}\right) \\ \theta_{j,\max,\text{new}} &= \theta_{j,\text{upper}} + \max\left(\frac{\theta_{j,\text{lower}} - \theta_{j,\min}}{2}, \frac{\theta_{j,\max} - \theta_{j,\text{upper}}}{2}\right) \end{aligned} \quad (21)$$

and another iteration needs to be performed.

SUFI-2 allows its users several choices of the objective function such as described in section 3.

Bayesian inference

According to Bayes' theorem, the probability density of the posterior parameter distribution $f_{\mathbf{\Theta}_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}|\mathbf{y}_{\text{meas}})$ is derived from the prior density $f_{\mathbf{\Theta}_{\text{pri}}}(\boldsymbol{\theta})$ and observed data $\mathbf{y}_{\text{meas}}$ as:

$$f_{\mathbf{\Theta}_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}|\mathbf{y}_{\text{meas}}) = \frac{f_{\mathbf{Y}^M|\mathbf{\Theta}}(\mathbf{y}_{\text{meas}}|\boldsymbol{\theta}) \cdot f_{\mathbf{\Theta}_{\text{pri}}}(\boldsymbol{\theta})}{\int f_{\mathbf{Y}^M|\mathbf{\Theta}}(\mathbf{y}_{\text{meas}}|\boldsymbol{\theta}')f_{\mathbf{\Theta}_{\text{pri}}}(\boldsymbol{\theta}')\,d\boldsymbol{\theta}'} \quad (22)$$

where $f_{\mathbf{Y}^M|\mathbf{\Theta}}(\mathbf{y}_{\text{meas}}|\boldsymbol{\theta})$ is the likelihood function of the model, i.e., the probability density for model results for given parameters with the measurements substituted for the model results, and $\mathbf{Y}^{\text{M}}$ is the vector of random variables that characterizes the hydrologic model including all uncertainties. Posterior prediction uncertainty is usually represented by quantiles of the posterior distribution. The crucial point of applying this technique is the formulation of the likelihood function. If the statistical assumptions for formulating the likelihood function are violated, the results of Bayesian inference are unreliable. Unfortunately, when formulating likelihood functions in hydrological applications, it is often assumed that the residuals between measurements and simulations are independently and identically (usually normally) distributed (iid). However, this assumption is often violated. To avoid this problem, we constructed in SWAT-CUP the likelihood function by combining a Box–Cox transformation (Box and Cox, 1964) with a continuous-time autoregressive error model (Brockwell and Davis, 1996; Brockwell, 2001) as follows:

$$f_{\mathbf{Y}^M|\mathbf{\Theta}}(\mathbf{y}|\mathbf{\theta}) = \frac{1}{\sqrt{2\pi}}\frac{1}{\sigma}\exp\left(-\frac{1}{2}\frac{\left[g(y_{t_0}) - g\left(y_{t_0}^M(\mathbf{\theta})\right)\right]^2}{\sigma^2}\right)\cdot\left|\frac{dg}{dy}\bigg|_{y=y_{t_0}}\right|$$

$$\cdot\prod_{i=1}^{n}\left[\frac{1}{\sqrt{2\pi}}\frac{1}{\sigma\sqrt{1-\exp\left(-2\frac{t_i-t_{i-1}}{\tau}\right)}}\exp\left(-\frac{1}{2}\frac{\begin{bmatrix} g(y_{t_i}) - g\left(y_{t_i}^M(\mathbf{\theta})\right) \\ -\left[g(y_{t_{i-1}}) - g\left(y_{t_{i-1}}^M(\mathbf{\theta})\right)\right]\exp\left(-\frac{t_i-t_{i-1}}{\tau}\right)\end{bmatrix}^2}{\sigma^2\left(1-\exp\left(-2\frac{t_i-t_{i-1}}{\tau}\right)\right)}\right)\cdot\left|\frac{dg}{dy}\bigg|_{y=y_{t_i}}\right|\right] \tag{23}$$

where σ is the asymptotic standard deviation of the errors, τ is the characteristic correlation time, $\mathbf{\theta}$ is the vector of model parameters, y_{t_i} and $y_{t_i}^M(\mathbf{\theta})$ are the observation and model simulation, respectively, at time t_i, and g(.) represents the Box–Cox transformation (Box and Cox, 1964):

$$g(y) = \begin{cases} \dfrac{(y+\lambda_2)^{\lambda_1} - 1}{\lambda_1} & \lambda_1 \neq 0 \\ \ln(y+\lambda_2) & \lambda_1 = 0 \end{cases} \quad , \quad g^{-1}(z) = \begin{cases} (\lambda_1 z + 1)^{1/\lambda_1} - \lambda_2 & \lambda_1 \neq 0 \\ \exp(z) - \lambda_2 & \lambda_1 = 0 \end{cases} \quad , \quad \frac{dg}{dy} = (y+\lambda_2)^{\lambda_1 - 1} \tag{24}$$

This model extends earlier works with discrete-time autoregressive error models in hydrological applications (e.g., Kuczera, 1983; Duan et al., 1988; Bates and Campbell, 2001). More details are given by Yang et al. (2007a).

Two generic Monte Carlo approaches to sample from the posterior distribution are Markov chain Monte Carlo and Importance Sampling (Gelman et al., 1995; Kuczera and Parent, 1998). Both techniques are used as implemented in the systems analysis tool UNCSIM (Reichert, 2005; http:// www.uncsim.eawag.ch).

Markov chain Monte Carlo (MCMC)

MCMC methods are a class of algorithms for sampling from probability distributions based on constructing a Markov chain that has the desired distribution as its equilibrium distribution. The simplest technique from this class is the Metropolis algorithm (Metropolis et al., 1953; Gelman et al., 1995), which is applied in this study. A sequence (Markov chain) of parameter sets representing the posterior distribution is constructed as follows:

(1) An initial starting point in the parameter space is chosen.
(2) A candidate for the next point is proposed by adding a random realization from a symmetrical jump distribution, f_{jump}, to the coordinates of the previous point of the sequence:

$$\mathbf{\theta}_{k+1}^{*} = \mathbf{\theta}_k + rand(f_{jump}) \tag{25}$$

(3) The acceptance of the candidate points depends on the ratio r:

$$r = \frac{f_{\Theta_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}^{*}_{k+1}|\mathbf{y}_{\text{meas}})}{f_{\Theta_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}_{k}|\mathbf{y}_{\text{meas}})} \tag{26}$$

If $r >= 1$, then the candidate point is accepted as a new point, else it is accepted with probability r. If the candidate point is rejected, the previous point is used as the next point of the sequence. In order to avoid long burn-in periods (or even lack of convergence to the posterior distribution) the chain is started at a numerical approximation to the maximum of the posterior distribution calculated with the aid of the shuffled complex global optimization algorithm (Duan et al., 1992).

Importance sampling (IS)

Importance sampling is a well established technique for randomly sampling from a probability distribution (Gelman et al., 1995; Kuczera and Parent, 1998). The idea is to draw randomly from a sampling distribution f_{sample} and calculate weights for the sampling points to make the weighted sample a sample from the posterior distribution. The procedure consists of the following steps:

(1) Choose a sampling distribution and draw a random sample from this sampling distribution.
(2) For each parameter set, $\boldsymbol{\theta}_i$, of the sample, calculate a weight according to

$$w_i = \frac{f_{\Theta_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}_{i}|\mathbf{y}_{\text{meas}}) / f_{sample}(\boldsymbol{\theta}_i)}{\sum_{k=1}^{N} f_{\Theta_{\text{post}}|\mathbf{Y}}(\boldsymbol{\theta}_{k}|\mathbf{y}_{\text{meas}}) / f_{sample}(\boldsymbol{\theta}_k)} \tag{27}$$

(3) Use the weighted sample to derive properties of the posterior distribution, for example, by calculating the expected value of a function h according to:

$$E_{f_{post}}(h) \approx \sum_{k=1}^{N} w_i h(\theta_i) \tag{28}$$

The computational efficiency of this procedure depends strongly on how close the sampling distribution is to the posterior distribution, and hence, the choice of the sampling distribution is crucial (Gelman et al., 1995). Three practical choices for the sampling distribution are sampling from the prior distribution (often uniform sampling over a hypercube referred to in the following as primitive IS or naive IS), use of an over-dispersed multi-normal distribution as a sampling distribution (e.g., Kuczera and Parent, 1998), and the method of iteratively adapting the sampling distribution and using efficient sampling techniques (Reichert et al., 2002). Each of the above methods has some disadvantages. Primitive IS is very inefficient if the posterior is significantly different from the prior, particularly for high dimensional parameter spaces. It is also worth nothing that primitive IS is a special case of GLUE, in which no generalizations are made to the likelihood function and all parameter sets are accepted as behavioral (although some will get a very small weight). For the method with over-dispersed multi-normal distribution, it is difficult to determine a priori for the dispersion coefficients (Kuczera and Parent, 1998). The method of iteratively adapting the sampling distribution becomes more and more difficult to implement as the dimensionality of the parameter space increases (Reichert et al., 2002). This is because larger samples are required to get sufficient information on the shape of the posterior and it becomes more and more difficult to find a reasonable parameterized sampling distribution to approximate the posterior. In this study, only the primitive IS is implemented, as this also allows us to study the behavior of GLUE with different likelihood measures.

PSO

PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching for food in an area. There is only one piece of food in the area being searched. While the birds do not know where the food is, they know how far the food is in each iteration. So what's the best strategy to find the food? The effective one is to follow the bird which is nearest to the food.

In PSO, each single solution is a "bird" in the search space, called "particle". All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities that direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by the following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the population. This best value is a global best and called *gbest*. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called *lbest*.

After finding the two best values, the particle updates its velocity and positions with the following equations:

$$v[\ ] = v[\ ]+c_1*rand()*(pbest[\ ]-present[\ ])+c_2*rand()*(gbest[\ ]-present[\ ]) \tag{29}$$

$$present[] = persent[]+v[\ ] \tag{30}$$

where $v[\ ]$ is the particle velocity, $persent[\ ]$ is the current particle (solution). $pbest[\ ]$ and $gbest[\ ]$ are defined as stated before. $rand()$ is a random number between (0,1). c_1, c_2 are learning factors. usually $c_1 = c_2 = 2$.

The pseudo code of the procedure is as follows

```
For each particle
    Initialize particle
END
Do While maximum iterations or minimum error criteria is not attained
    For each particle
        Calculate fitness value
        If the fitness value is better than the best fitness value (pbest) in history
            set current value as the new pbest
    End
```

```
        Choose the particle with the best fitness value of all the particles as the gbest
        For each particle
                Calculate particle velocity according to equation (29)
                Update particle position according to equation (30)
End
```

Particles' velocities on each dimension are clamped to a maximum velocity $V_{\max}$. If the sum of accelerations would cause the velocity on that dimension to exceed $V_{\max}$, which is a parameter specified by the user, Then the velocity on that dimension is limited to $V_{\max}$.

Functionalities of the SWAT-CUP Program

Calibration

In SWAT-CUP, any of the above 5 programs can be used to calibrate a SWAT project. We tried to make the input files similar for ease of calibrating a project with different algorithms.

Validation

Validation can also be performed after calibration is completed by changing the observation file as well as a few other minor changes.

Uncertainty Analysis

All programs provide a measure of uncertainty as described above, which are plotted as 95% prediction uncertainty (95PPU) as well as measured and the best simulation. An example of this graph is shown in Figure 9.

Sensitivity Analysis

Parameter sensitivities are determined in two ways in SWAT-CUP. First, by calculating the following multiple regression system, which regresses the Latin hypercube generated parameters against the objective function values:

$$g = \alpha + \sum_{i=1}^{m} \beta_i b_i$$

The *t*-test is then used to identify the relative significance of each parameter b_i., while the *p* value estimates the strength of the *t*-test. The sensitivities given above are estimates of the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing. This gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters. Table 7 gives an example the output file where ALPHA_BNK and CH_K2 are, respectively, the most sensitive parameters.

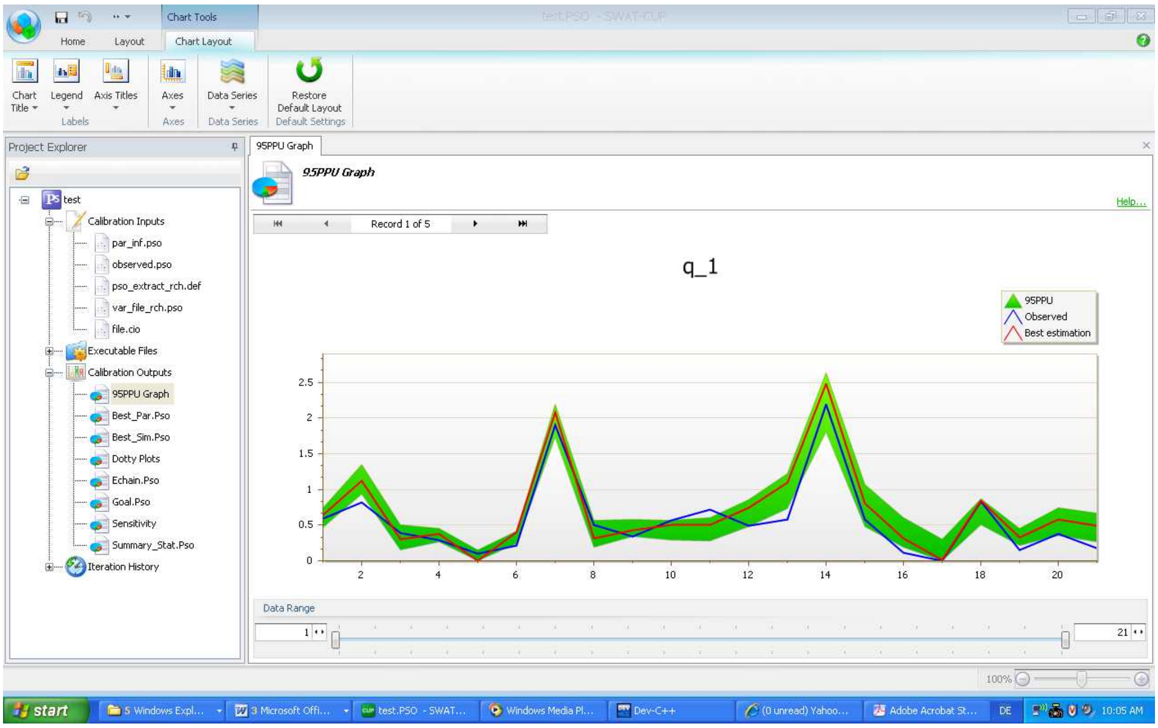

Figure 9. Example of a 95PPU graph in SWAT-CUP.

Table 7. An example of the output of sensitivity analysis in SWAT-CUP.

Parameter Name	t-Stat	P-Value
v__ALPHA_BNK.rte	-1.69	0.15
v__CH_N2.rte	-1.18	0.29
v__GW_DELAY.gw	-1.02	0.35
r__SOL_AWC(1).sol	0.00	1.00
r__SOL_BD(1).sol	0.01	1.00
v__ALPHA_BF.gw	0.30	0.78
v__SFTMP.bsn	0.35	0.74
r__SOL_K(1).sol	0.70	0.52
r__CN2.mgt	0.85	0.43
v__CH_K2.rte	1.19	0.29

A second method of calculating parameter sensitivity is the traditional one at the time sensitivity. This later method is useful in identifying the direction of parameter changes in order to achieve a better fit. An example of SWAT-CUP output is illustrated in Figure 10.

Often SWAT simulations take many minutes to run. A simulation of 1000, therefore, may take many days. To make the process of calibration go faster, we can break up an iteration into several runs (with SUFI2 only). Therefore, a 1000 simulation run could be divided into 5 runs of 200 each, hence taking only 1/5 of the time needed to run 1000 simulations. The procedure is explained in the SWAT-CUP manual.

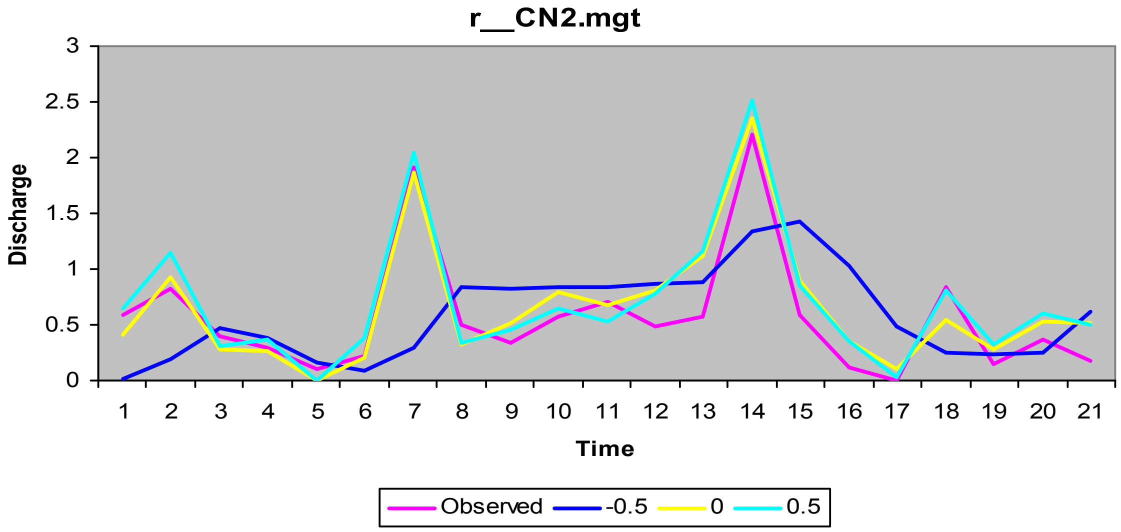

Figure 10. Example of one at a time sensitivity analysis showing the effect of changing relative CN2 values from -0.5 to 0 to +0.5. Clearly, smaller values of CN2 are not desirable.

Dividing a discharge signal into peak and base

A threshold value is introduced as shown in Figure 11 where a signal is divided into two parts. We refer to this as a "multi-component" assignment. Values smaller than the threshold and values larger than the threshold are treated as two variables. This is to ensure that, for example, base flow has the same influence on the objective function as the peak flow. If you choose option 2 for objective function, i.e., mean square error, then base flow my not have much effect on the optimization, hence, peak flow will dominate the processes. With this option they can be given the same weight. This option is most effective for SSSQ objective function and is not defined for R^2 and bR^2.

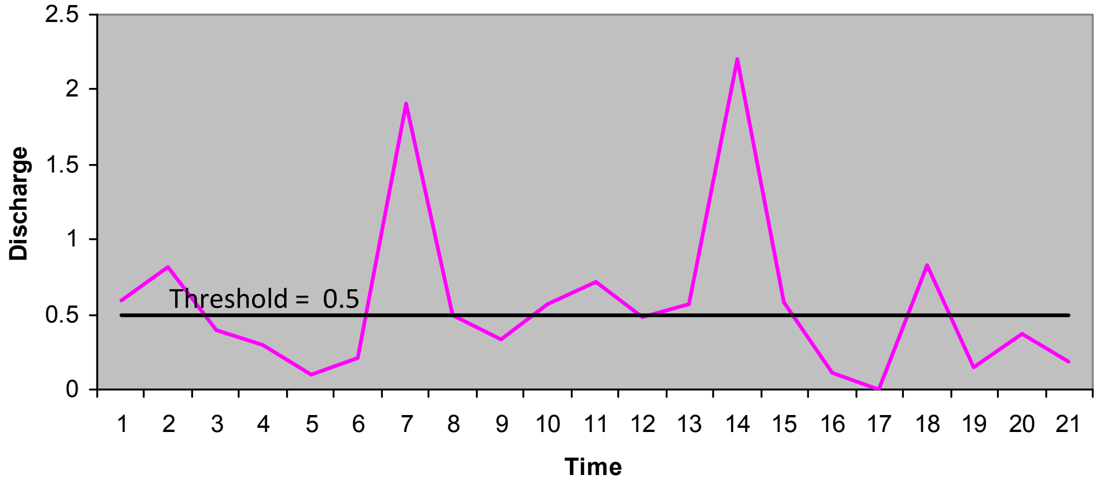

Figure 11. Breaking a signal into two in a multicomponent run. This would help to account for both the peaks and the base flow, especially for objective functions MSSQE and SSSQE

Further functionalities being added to SWAT-CUP involves features that enable automatic parallelization and gridification of SUFI2 runs, and visualization of calibrated SWAT variables on Google Earth, and more advanced graphical options.

Summary and Conclusions

SWAT-CUP, a user-friendly program was created to aid calibration of SWAT models. The program has the following features:

- It includes 5 popular programs for calibration

- It can be used to assess uncertainty in model prediction

- It performs global and local sensitivity analysis

- It can be used for a detailed parameterization of the watershed based on hydrologic group, soil, landuse, subbasin, and slope

- It includes all parameters in SWAT, including those of layered parameters, and those of management with rotation and operation

- It can be used to calibrate rainfall and assess input parameter uncertainty

- It calculates 95PPU of all outputs used in model calibration

- It provides a graphical interface for visualization of outputs including observed data, best-fit model result, and 95PPU for all variables used in the calibration.

- The SUFI-2 program allows the use of 7 different objective functions and enables users to study the effect of objective function of calibration.

The program is available as free download from:
`http://www.eawag.ch/organisation/abteilungen/siam/software/swat/index_EN`

The SUFI2 program of SWAT-CUP also exits for the LINUX platform.
The SWAT-CUP manual has detailed explanation of all components discussed above.

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B1-6

Development of Subdaily Erosion and Sediment Transport Models in SWAT

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In collaboration with City of Austin, Texas, Texas AgriLife Research Scientists are developing algorithms within SWAT for simulation of stormwater best management practices (BMPs) such as detention basin, wet pond, sedimentation filtration pond, retention irrigation. Modeling small watersheds often requires time steps as small as minutes to realistically capture the instantaneous flow and pollutant transport coming from upland areas. SWAT 2005 uses the Modified Universal Soil Loss Equation (MUSLE) for processing upland erosion and the transport of sediments to the stream. While MUSLE model works well at daily simulation scale, the model is inadequate for subdaily simulations mostly because the model is not physically-based, but is conceptualized based on field data collected in the United States. To make the SWAT erosion processes calculated at the same time scale as subdaily flow, MUSLE equation was replaced by a set of physically-based erosion models. In the new algorithm, splash erosion is calculated based on the kinetic energy delivered by rain drops adapted from European Soil Erosion Model (EUROSEM) model, and overland flow erosion is estimated using a physically based equation adapted from ANSWERS model. Two instream sediment routing models including Yang's model and Brownlie model were also added. Sensitivity of new parameters was evaluated and the erosion and sediment transport modules were tested on Riesel Experimental Watershed in Texas USA.

B1-7

Simulation Trends and Other Aspects Regarding the Worldwide Use of the SWAT Model

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Abstract

The Soil and Water Assessment Tool (SWAT) is one of the most widely used watershed-scale water quality models in the world. Over 600 peer-reviewed SWAT-related journal articles have been published and hundreds more have been published in conference proceedings and other formats. The SWAT model has proven to be a very flexible tool for investigating a range of hydrologic and water quality problems at different watershed scales, as well as very adaptable for applications requiring improved hydrologic and other enhanced simulation needs. We briefly investigate here the various technological, networking, and other factors that have supported expanded use of SWAT, and then highlight current worldwide simulation trends in terms of both different regions of the world as well as innovative application trends.

KEYWORDS: SWAT, water quality modeling, hydrologic modeling, model adoption, technology advances

Introduction

Scores of water quality models have been developed in the past few decades to evaluate different hydrologic and environmental problems for varying scales and conditions, as described in extensive peer-reviewed literature including numerous reviews (e.g., Borah et al., 2006; Breuer et al., 2008). One of the most widely used of these models is the Soil and Water Assessment Tool (SWAT) watershed-scale water quality model (Arnold et al., 1998, Arnold and Forher, 2005; Gassman et al., 2007; Williams et al., 2008; Arnold et al., 2010), which incorporates several decades of model development and was developed to evaluate the effects of alternative land use and other scenarios on watershed hydrologic and pollutant load responses. Gassman et al. (2007) reviewed nearly 250 peer-reviewed SWAT-related studies and documented that the model has been successfully used worldwide for a broad suite of conservation practice, land use, climate change and other scenarios, and to replicate observed hydrologic and/or pollutant losses across a wide range of watershed scales and environmental conditions. At present, over 600 peer-reviewed SWAT-related articles have been published (see https://www.card.iastate.edu/swat_articles/index.aspx), which underscores the increasing use of the model (and modified SWAT versions) for investigating hydrologic and environmental problems in different regions across the globe. We briefly investigate here the different technological and networking factors that have influenced this rapid adoption of SWAT worldwide and then describe some specific current development trends, building on previously reported reviews (Gassman et al., 2007; 2010a).

Technological and Networking Factors

SWAT website

The SWAT website (http://swatmodel.tamu.edu/) provides quick access to model documentation and contact information for the main SWAT development team members, model executables and source code, Geographic Information System (GIS) interface tools, SWAT conference proceedings and selected peer-review literature, the SWAT literature database, information on upcoming conferences and workshops, and other useful information. The website also provides an easy way for current and prospective model users to obtain information about software updates, upcoming training workshops and conferences, and to also connect with other SWAT users via support groups and more informal channels.

Open software and comprehensive documentation

The first versions of SWAT were released in the early 1990s. Major releases of the model through SWAT2005 are chronicled in Williams et al. (2008). Arnold et al. (2010) describe major enhancements that have been included in SWAT2009, the latest release of the model, or are currently being developed and will eventually be incorporated into future releases of the model. The ongoing improvements, documentation, and support of the SWAT code have resulted in increasing adoption and application of the model worldwide. The open source code, written in FORTRAN, has resulted in increasing development efforts occurring outside of the main model team and has in some cases resulted in significant contributions to improved algorithms in the standard model. These efforts have also resulted in several modified SWAT models such as SWAT-G (Eckhardt et al., 2002), SWIM (Krysanova et al., 2005), SWAT-VSA (Easton et al., 2008), and SWAT-K (Kim et al., 2009). See Gassman et al. (2007; 2010a) for more detailed reviews of modified SWAT models.

GIS interfaces and other interfaces and software

GIS interfaces (Table 2), have also been key tools in driving the widespread adoption of SWAT. Two key interfaces that have been widely applied by SWAT model users are the ArcView SWAT (AVSWAT) (Di Luzio et al., 2004) and ArcSWAT (Olivera et al., 2006) interfaces. Other examples of useful interfaces include ArcAPEX (Tuppad et al., 2009), which allows integrated applications between SWAT and the Agricultural Policy/ Environmental Extender (APEX) model (Gassman et al., 2010b), and MWSWAT (George and Leon, 2008) which operates within the open source MapWindow GIS environment and has particular appeal for users in developing regions. Additional information on other SWAT GIS interfaces, and other pre- and post- processing software, is provided in Gassman et al. (2007; 2010a).

Networking

Dozens of SWAT training workshops have been held across the U.S. and other regions of the world during the past decade, many of which have been led by the SWAT model development team. However, other user groups have conducted training workshops as well such as the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) who have led several training workshops in Iran. Several major SWAT conferences have also been held in the U.S., Europe and Asia and developers workshops, regional conferences, and other meetings have also been held. These collective interactions have resulted in greatly expanded use and support of the model in many different regions worldwide and are described in more detail in Gassman et al. (2010a).

Application Trends

Specific regions

North America: SWAT has been used extensively throughout the U.S. for a wide range of hydrologic and water quality investigations as chronicled by Gassman et al. (2007). The model has been used for many Total Maximum Daily Load (TMDL) assessments (e.g., Jha et al., 2010) by state agencies and other users, and is also being applied for assessment of conservation practices for specific watersheds and at the national level within the USDA Conservation Effects Assessment Project (CEAP; Duriancik et al., 2008). SWAT is also being modified for applications within the Canadian Forest Watershed and Riparian Disturbance (FORWARD) project (Watson et al., 2008) and being used for other Canadian water quality assessments (e.g., Deslandes et al., 2007).

Europe: Widespread adoption of SWAT has occurred across Europe in response to a variety of hydrological and environmental assessment needs including European Union (EU) Water Framework Directive requirements (van Griensven et al., 2006; Volk et al., 2011) and intra-EU projects such EUROHARP (Kronvang et al., 2009). The use of the model has been especially extensive in some EU countries (e.g., Germany; Volk et al., 2009;2011) and several special journal issues and conference proceedings (accessible on SWAT website) have been generated from conferences, etc. held in Europe; see *Hydrol. Process.* 2005 19(3), *Hydrol. Sci. J.* 2008 53(5), and *J. Environ. Mont.* 2009 11(3).

Africa: A number of studies have also been published in the peer-reviewed literature describing SWAT applications in Africa. Ndomba and Birhanu (2008) reviewed nearly a dozen mostly non-peer-reviewed studies performed for watersheds within the Nile River basin that describe SWAT calibration/validation assessments and/or other applications. Several other studies have recently been published that describe applications of SWAT for watersheds in the same region (e.g., Setgen et al., 2009; Swallow et al., 2009). Other large-scale studies have been published such as Schuol et al. (2008) described below.

Specific countries

China: Nearly 50 peer-reviewed SWAT studies in China are accessible in the SWAT literature database, which cover hydrologic, nonpoint source, climate change, and other applications. These include studies by Zhang et al. (2009), Luo et al. (2008), and Feng and Baoguo (2010) described below as well as studies focused on assessments of nonpoint source pollution impacts for the Taihu Lake basin in eastern China (Yu et al., 2007) and the Dongjiang River basin in South China (Wu and Chen, 2009), climate change impacts in two watersheds in the Qinling Mountain region (He et al., 2009), and an assessment of three different snowmelt routines in a modified SWAT model for mountainous conditions in headwaters of the Yellow River (Zhang et al., 2008).

India: Extensive use of SWAT in India has also been reported in the peer-reviewed literature. These studies include innovative applications such as: (1) assessment of hydropower potential for the Kopili River basin in the state of Assam (Kusre et al., 2010), (2) investigation of vulnerability to climate variability and water stress in the the state of Uttarakhand, including discussions of adaptive strategies with citizens in two local villages (Kelkar et al., 2008), and (3) calibration of SWAT in southern India using remotely sensed ET data (Immerzeel and Droogers, 2007).

South Korea: A large SWAT user community has developed in recent years in South Korea as evidenced by multiple conferences (Gassman et al., 2010a) and a number of papers published in the peer-reviewed literature. These include applications of the standard SWAT model (e.g., Lee et al., 2010) as well as studies performed with SWAT-K, which has been modified to better assess surface water runoff, groundwater, impoundment, and other South Korean water resource conditions (Kim et al., 2009; see other studies described in the following section).

Iran: Recent Iranian SWAT studies include an assessment of land use change (Ghaffari et al., 2009), an uncertainity analysis comparison between SWAT and an Artificial Neural Network (ANN) model (Talebizadeh et al., 2009), a calibration and validation assessment of SWAT runoff and sediment predictions for two relatively large watersheds in central Iran (Rostamian et al., 2008), and a national-scale study (Faramarzi et al., 2008) further discussed below.

Simulation methodology

Large-scale blue and green water assessments: One emerging use of SWAT is for addressing water resource needs based on the paradigm of blue and green water as described by Falkenmark and Rockström (2006). Large-scale blue and green water analyses that have been performed with SWAT include assessments for the entire African continent (Schuol et al., 2008), the entire nation of Iran (Faramarzi et al., 2008), and seven major river basins in China (Feng and Baoguo, 2010). Schuol et al. and Faramarzi et al. present outcomes in terms of precipitation stored in soil water (green water storage), lost via evapotranspiration (green water flow), and discharged in surface water yield or to deep aquifers (blue water flow). Feng and Baoguo describe blue and green water usage for specific crops in the seven basins and also blue and green water depletion rates for each basin.

Runoff Curve Number (RCN) methodology enhancements: Kannan et al. (2008) describe a RCN method that is estimated as a function of evapotranspiration (ET) that is now an alternative option in the standard SWAT model. Other recent SWAT RCN modifications include: (1) the use of the SWAT-VSA (Easton et al., 2009) to more realistically simulate hydrologic conditions characterized by variable source areas, (2) modification of the RCN initial abstraction values to more realistically account for various watershed conditions (Wang et al., 2008; White et al., 2008), (3) better estimation of daily runoff peaks using a temporally weighted average RCN approach in SWAT-K (Kim et al., 2008), and (4) improved estimation of RCN values for South Korean conditions (Kim et al., 2010) based on applications of SWAT that incorporate the temporally weighted average RCN method reported by Kim et al. (2008).

Impoundment and wetland applications: Jones et al. (2008) used SWAT to assess the effect of reservoir construction on annual flow volumes of the Tigris-Euphrates river system and the resultant areal extent of marshlands in southern Iraq. The SWAT reservoir routine was modified by Zhang et al. (2009) to account for Biochemical Oxygen Demand (BOD) and more accurate reservoir inflows/outflows for an analysis in eastern China. The SWAT reservoir module was also modified within SWAT-K (Kim et al., 2009) to better simulate Korean reservoir dynamics. Ouessar et al. (2009) describe the use of a modified SWAT reservoir routine (SWAT-WH) to simulate traditional types of impoundments used in southern Tunisia. Watson et al. (2008) modified the SWAT wetland module to capture the effects of upland wetlands in forested watersheds in the Canadian Boreal Plain.

Best Management Practices (BMPs): Increasing demand is being placed on SWAT for BMP analyses within watershed-level assessments (e.g., Gassman et al., 2007; Arabi et al., 2007; Volk et al., 2011). Gassman et al. (2007) described the utility of SWAT for performing BMP assessments but also noted the need for improved BMP representation. Arabi et al. (2008) suggested sets of parameter criteria for depicting selected agricultural BMPs in SWAT. White and Arnold (2009) describe an improved filter strip simulation approach that has been incorporated in SWAT2009. White et al. (2009a;b) report methods for improved management of phosphorus loss from pastures and assessment of conservation practice placement for watershed critical source areas (CSAs), respectively. Hunt et al. (2009) provide an overview of key urban BMPs and suggest ways to simulate them in SWAT, including likely needed model modifications.

Plant parameters and crop yield estimation: Reporting of plant parameter choices and SWAT yield/biomass output has been generally neglected in the peer-reviewed literature although some studies are now reporting such results. Hu et al. (2007) and David et al. (2008) report generally accurate SWAT corn and soybean yield predictions for an east-central Illinois, U.S. watershed. Luo et al. (2008) found that SWAT adequately predicted wheat leaf area index (LAI) and biomass adequately for most conditions within the Yellow River basin in China, but overpredicted LAI during senescence and wheat yields in general due to an improper harvest index. Potter and Hiatt (2009) describe vineyard cropping system parameters for northern California, U.S. conditions.

Conclusions

The SWAT model has been adopted and applied by users worldwide. The range of applications and conditions the model has been applied to is rapidly growing and this growth is expected to continue. Clear limitations exist for how the model can be applied for some problems due to lack of data and/or modeling expertise and lack of suitable model algorithms. However, many users are overcoming such barriers by developing improved algorithms and/or obtaining better input and monitoring data. Increased use of modified versions of SWAT can be expected in the future in many regions to address specific simulation needs. Continued developmental support is needed for SWAT and other models to meet worldwide user demands to investigate a wide range of water resource problems.

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SESSION A2

Hydrology (1)

A2-1

Surface Soil Moisture Assimilation with SWAT

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Soil moisture is one of the most critical state variables in hydrologic modeling. Certain studies have demonstrated that assimilating observed surface soil moisture into a hydrologic model results in improved predictions of profile soil water content. With the Soil and Water Assessment Tool (SWAT), however, there is a lack of investigative research as to how the spatial variability of inputs affect the potential capability of data assimilation techniques, especially the assimilation of remotely sensed surface soil moisture data. Therefore, a synthetic experiment is performed to better understand how soil moisture data assimilation affects various hydrologic processes in the model at the watershed scale. The study area for this work is the Upper Cedar Creek Watershed (UCCW) which is located in the St. Joseph Watershed in northeastern Indiana. The predominant land use in the UCCW is agricultural (79%), with major crops of corn and soybeans, and minor crops of winter wheat, oats, alfalfa, and pasture. The area receives approximately 94 cm of annual precipitation and has average daily temperatures ranging from -1°C to 28°C. In the UCCW, the USDA, Agricultural Research Service National Soil Erosion Research Laboratory (NSERL) maintains a hydrometerological network where five years of precipitation and soil moisture data are available. The model is first run with rainfall data from the National Climatic Data Center (NCDC) and the NSERL raingauge network to represent the "true" state. Subsequently, the model is run for the same time period with an intentionally poor set of initial conditions and "limited" forcing data. Instead of using all available rainfall data from data sources, simulation was performed using only the NCDC data. These "limited" inputs are to represent our imperfect knowledge of the true hydrologic processes. By limiting precipitation input, which is the driving force of soil moisture and streamflow, while keeping other model parameters unchanged, we determined how the updated soil water condition with surface measured soil moisture influences model predictions of profile soil water content, runoff and streamflow. Model evaluations were conducted by using time series graphs and standard statistical measures including the correlation coefficient (R), mean bias error (MBE), and root mean square error (RMSE).

Keywords: SWAT, data assimilation, soil moisture

A2-2

The Spatial Analysis between SWAT Simulated Soil Moisture, and MODIS LST and NDVI Products

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This study is to identify how much the Terra MODIS NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) can explain the soil moisture by using the SWAT (Soil and Water Assessment Tool) simulated results. For a 2,694.4 km^2 dam watershed of South Korea, 9 years (2000-2008) monthly MODIS NDVIs and LSTs were compared with the SWAT simulated soil moistures (SM). Before the analysis, the SWAT model was calibrated and verified using the 9 years daily streamflow at 3 gauging stations and 6 years (2003-2008) daily soil moistures at 3 locations with the watershed. The average Nash-Sutcliffe model efficiencies during streamflow validation were 0.7, 0.7, and 0.7 respectively. The correlation of SM with NDVI was on the similar level with LST for the forest leaf growing (March-June) and falling period (September-December). The soil moisture showed an inverse proportion with NDVI and LST during the leaf growing period. The low correlation appeared in case of dispersed storms occurred during the period regardless of the leaf growing or falling periods.

Keywords: SWAT, MODIS, NDVI, LST, soil moisture

Introduction

Soil moisture is an important hydrologic component of water balance, and it would be ideal to use soil moisture for model calibration if measured data are available at study area. It is a state variable to affect the plant and crop actual evapotranspiration (ET), storage capacity for surface runoff and subsurface flow, and recharge to groundwater. However usually due to the lack of measured soil moisture data to represent the spatial soil moisture distribution for an interesting area, we need a pseudo indicator of soil moisture condition.

The soil moisture is highly dependent on the surface temperature and its vegetation vitality under the spatial land cover condition. Recently, researches to evaluate the watershed scale soil moisture have been attempted by using satellite products to overcome the limited information of field scale soil moisture. The monitoring and modelling of land surface and/or vegetation processes by using satellite images viz. NOAA AVHRR (Advanced Very High Resolution Radiometer) and Terra MODIS (Moderate Resolution Imaging Spectroradiometer) is now popular for the assessment of hydrologic behaviour. Many studies to couple the land surface or vegetation condition with soil moisture have been tried. The trace of subsurface soil moisture via surface vegetation condition is useful to prepare data as the initial condition of moisture information for a hydrologic model run and can be used for the warning level of forest fire. Meanwhile, soil temperature is one of the key variables in the physics of land surface processes, which influences energy and water cycles of land–atmosphere system, and largely depends on soil moisture and fractional vegetation cover. Furthermore, soil moisture is a function of soil temperature, so subsurface temperature influences soil moisture transfer in different soil layers (Huang et al. 2007).

A number of studies (Sandholt et al., 2002; Carlson, 2007; Nemani et al., 1993) have suggested that the information from LST and NDVI (Normalized Difference Vegetation Index) can provide better information on vegetation stress and moisture conditions at the surface. Farrar et al. (1994) found that soil moisture and NDVI are well correlated in the plant growing periods. Hutchinson et al. (2006) generated spatially-distributed near surface soil moisture conditions using readily available NOAA AVHRR products on a repetitive basis for Fort Riley, Kansas, and Narasimhan et al. (2005) analyzed the correlation between soil moisture and NDVI in pasture. NDVI also has been used to estimate evapotranspiration (ET) that is strongly related to soil moisture. Ann (2003) calculated soil moisture using ET estimated by NDVI with weather data. Hwang et al. (2006) estimated soil moisture using SWAT model and performed a drought monitoring. Hence, NDVI and LST can be a useful indicator to analyze the soil moisture during the active growing of crop or plant, and to determine the soil moisture condition for drought monitoring (Narasimhan et al., 2005). Thus, this study is to identify how much MODIS NDVI and LST products can explain soil moisture of forest area by using SWAT simulated soil moisture results. The 9 years (2000-2008) monthly MODIS NDVIs and LSTs were prepared, and the spatial analyses were conducted the SWAT simulated forest soil moistures for a 2,694.4 km^2 mountainous watershed of South Korea.

Materials and Methods

Study watershed

A 2,694.4 km^2 forest-dominant watershed located in the northeast of South Korea was adopted. It lies between 127° 45’ E - 128° 32’ E and 37° 39’ N - 38°33’ N. The watershed has 18.9 % deciduous, 53.1 % evergreen, and 21.0 % mixed forests respectively. The Soyanggang Dam at the watershed outlet has important roles to supply municipal water of Seoul metropolitan city and protect flood attack from storms and Typhoons, and is the only multipurpose dam in Bukhan-river basin. The dam of 2.7 billion m^3 of water storage capacity has been operated by K-water (Korea Water Resources Corporation) since 1973. For the proper reservoir water level management especially in case of drought and flood conditions, the dam inflow estimation from the watershed is very important and the accurate estimation largely depends on the soil moisture information of the time. For the dry spring, the forest fires by the spontaneous combustion have been occurred in connection with dryness of soil moisture at first, litters secondly.

The annual average precipitation is 1,359.5 mm, the mean temperature is 9.4 ℃, the relative humidity is 71.0 %, the wind speed is 2.17 m/sec, and the solar radiation is 13.42 MJ/m^2 over the last 30 years (1977-2006). For the analysis, the watershed was subdivided into 3 sub-watersheds, which the division locations are Wontong, Naerincheon, and SoyanggangDam water level gauging stations.

SWAT model and input data

The Soil and Water Assessment Tool (SWAT) is a physical bases and continuous, long-term, distributed-parameter model designed to predict land management practices on the hydrology, sediment and contaminant transport in agricultural watersheds with varying soils, land use, and management conditions (Arnold et al., 1998). SWAT is based on the concept of hydrologic response units (HRUs) which are portions of a subbasin that possess unique land use/management/soil attributes. The runoff, sediment, and nutrient loadings from each HRU are calculated separately using input data about weather, soil properties, topography, vegetation, and land management practices, and then summed together to determine the total loadings from the subbasin.

The model uses spatially distributed data on elevation, soil, land use, and weather data for hydrologic modelling and operates on a daily time step (Narasimhan et al., 2005). For the elevation, 30 m DEM (Digital Elevation Model) was produced from 1:5,000 vector maps supplied by the Korea National Geography Institute. The 30 m land use data were prepared by 2000 Landsat TM (Thematic Mapper) supervised classification with NOAA NDVI. The 1:25,000 soil data were obtained from Korea Rural Development Administration. Loam and loamy sand dominate, covering 52.4 % and 42.4 % of the watershed, respectively.

Weather data of SWAT are precipitation, maximum and minimum air temperatures, wind velocity, relative humidity, and solar radiation. For this study, 11 years (1998-2008) daily precipitation from 18 automatic weather stations (AWS), and other meteorological data at 5 weather stations were obtained from Korea Meteorological Administration.

In the pre-processing of model run, the study watershed was divided into 20 subbasins. In turn, the subbasins were subdivided into 348 HRUs (Hydrological Response Unit). The SWAT model creates input parameters, and performs simulation through HRU.

SWAT soil water routing

The SWAT model runs on a daily time-step. The hydrological component is based on the soil water balance equation as Eq. (1).

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - w_{seep} - E_a - Q_{gw}) \tag{1}$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of returnflow on day i (mm H_2O).

Terra MODIS NDVI and LST data

NDVI is a distributed vegetation condition index, using difference of reflectivity in near infrared light. NDVI not only maps the presence of vegetation on a pixel basis, but also provides measures of the amount or condition of vegetation within a pixel (Wan et al., 2004). The NDVI value is calculated by Eq. 2 for each grid cell.

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{2}$$

where *NDVI* is Normalized Difference Vegetation Index, *NIR* is Near Infrared Ray (MODIS band 2), *RED* is Red band (MODIS band 1).

The MODIS produces the NDVI at 16 days temporal and 250, 500, 1000 m spatial resolutions. To obtain the MODIS NDVI data among the products, the MODIS 250 m NDVI 16-days composite scenes (MOD13Q1) from 2000 to 2008 were downloaded at the Earth Observing System Data Gateway. The 16-days temporal resolution means a composite image using MVC (Maximum Value Composite) during that period. The MVC minimizes the influence of the clouds atmosphere (air molecules, water vapour and aerosols).

LST can be obtained from satellite sensors such as MODIS thermal infrared (TIR) sensors on board the Terra and Aqua satellites. The accuracy of daily MODIS LST products has been validated in more than 20 clear-sky cases with in situ measurement data. The MODIS LST accuracy is better than 1 K in the range from 263 to 322 K (Wan et al., 2002, 2004).

Results and Discussion

SWAT model calibration and validation with streamflow and soil moisture data

The SWAT model was warmed up for 2 years (1998-1999), and calibrated using 5 years (2000-2004) daily streamflow data of three stations (Wontong, Naerincheon, and SoyanggangDam) and 2 years (2003-2004) daily soil moisture data of three locations (Inje, Chuncheon, and Hwacheon).

The model was validated for 4 years (2005-2008) streamflow and soil moisture data. Multisite calibration enhances the calibration results from the viewpoint of spatial variation of the hydrologic response. The calibrated model parameters are shown in Table 1.

Figure 1 shows the comparison of observed and simulated streamflows at Soyanggang Dam of the three stations, and Tables 2 shows the statistical summary of model results. The root mean square error (RMSE) and Nash-Shutcliffe model efficiency (NSE) for validation period were 2.2 mm/day, and 0.7 at Wontong station, 3.0 mm/day, and 0.7 at Naerincheon, and 2.4 mm/day, and 0.7 at Soyanggang Dam station respectively. The NSE value means that the model predicted 70 % better than simply using the average streamflow value during that period. Figure 2 and Table 3 show the comparison of observed and simulated soil moisture at Inje of the three locations, and the statistical summary of model results respectively. The average determination of coefficient (R^2) at Inje, Chuncheon, and Hwacheon were 0.6, 0.5, and 0.6 respectively.

As seen in Figure 1, the error of streamflow in the low flows may come from the uncertainties of forest humus layer function and groundwater parameters during model calibration. Also, the peak runoff errors may be caused by the difference between real and simulated runoff mechanisms in paddy fields. Unlike the unsaturated flow mechanism in a natural environment, paddy has artificial factors such as irrigation scheduling and levee height management that increases the uncertainty of the water budget. During the paddy cultivation periods, farmers control levee heights artificially for their own water management. Irrigating water before rainfall and draining water after rainfall affect the streamflow with significant quantity.

Table 1. The calibrated model parameters at 3 subwatersheds

Parameter	Description	Calibration Range	Wontong Optimal value	Naerincheon Optimal value	Soyanggang Dam Optimal value
CN2	Curve number adjustment ratio	± 20 %	0	10	10
ESCO	Soil evaporation compensation	0.01 ~ 1	0.5	0.3	0.02
SOL_AWC	Available water capacity	± 20 %	10	- 10	5
SFTMP	Snowfall temperature (℃)	-5 ~ 5	1	1	1
SMTMP	Snowmelt base temperature (℃)	-5 ~ 5	0.5	0.5	0.5
SMFMX	Maximum snow melt factor (mm H_2O/ºC-day)	0 ~ 10	4.5	4.5	4.5
SMFMN	Minimum snow melt factor (mm H_2O/ºC-day)	0 ~ 10	4.5	4.5	4.5
TIMP	Snow pack temperature lag factor	0 ~ 1	1	1	1
LAT_TTIME	Lateral flow travel time (days)	-	3	3	2
GW_DELAY	Groundwater delay time (days)	0 ~ 500	180	150	180
CH_K2	Effective hydraulic conductivity of main channel	0 ~ 150	70	20	20

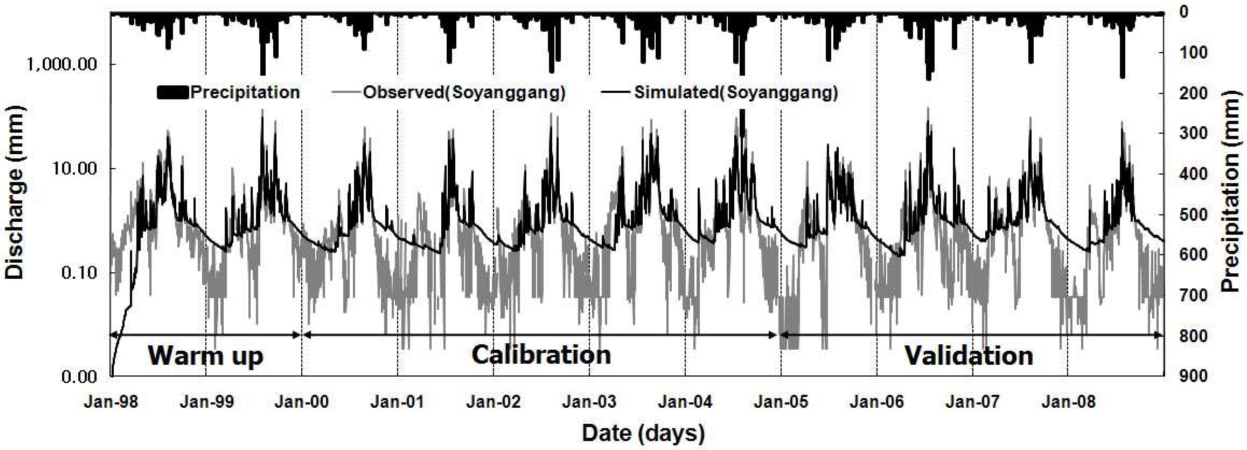

Figure 1. Comparison of observed versus simulated streamflow at Soyanggang Dam

Table 2. The Calibration and verification statistics in Soyanggang Dam station

Period	Year	Precipitation (mm)	Runoff (mm)		Runoff Ratio (%)		R^2	RMSE (mm/day)	NSE
			Obs.	Sim.	Obs.	Sim.			
Calibration	2000	1092.5	676.9	622.9	62.0	57.0	0.89	2.63	0.79
	2001	935.5	515.4	524.5	55.1	56.1	0.92	2.07	0.84
	2002	1280.5	787.7	719.4	61.5	56.2	0.76	3.25	0.69
	2003	1654.7	1276.1	1071.5	77.1	64.8	0.77	2.65	0.72
	2004	1739.0	951.3	1024.2	54.7	58.9	0.62	3.04	0.54
Average		1340.4	841.5	792.5	62.1	58.6	0.79	2.73	0.72
Validation	2005	1149.0	731.8	661.9	63.7	57.6	0.70	1.91	0.68
	2006	1562.2	1125.9	995.1	72.1	63.7	0.86	3.06	0.77
	2007	1336.2	884.6	779.7	66.2	58.4	0.82	2.09	0.70
	2008	1056.1	679.0	594.2	64.3	56.3	0.80	2.72	0.71
Average		1275.9	855.3	757.7	66.6	59.0	0.80	2.45	0.72

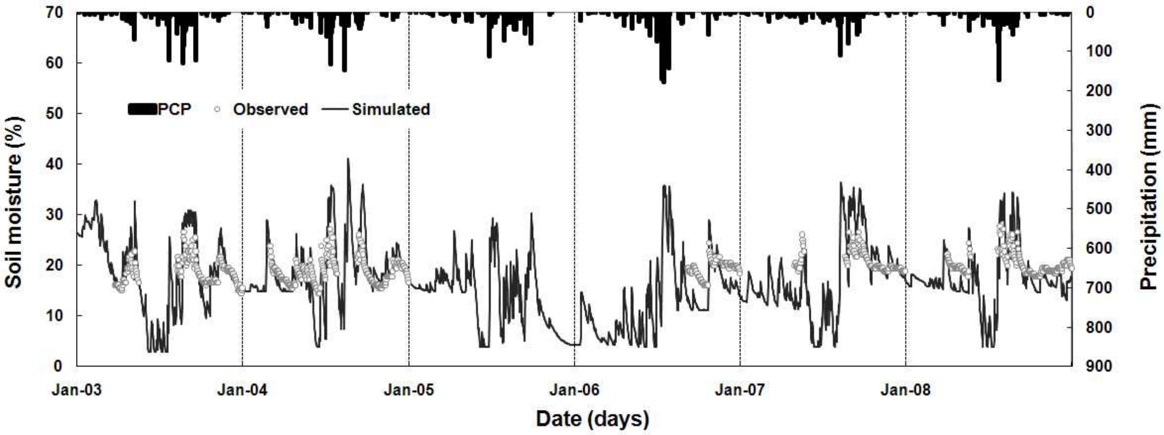

Figure 2. Comparison of the observed versus simulated soil moisture at Inje.

Table 3. The Calibration and verification statistics in three soil moisture station

Period	Year	Inje (%)		Chuncheon (%)		Hwacheon (%)		R^2		
		Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Inje	Chuncheon	Hwacheon
Calibration	2003	17.3	18.7	6.6	17.6	10.6	9.6	0.60	0.55	0.61
	2004	15.6	19.0	12.5	15.3	9.0	9.0	0.60	0.51	0.56
Validation	2005	-	-	11.8	16.1	7.1	9.4	-	0.61	0.62
	2006	14.4	12.8	-	-	-	-	0.72	-	-
	2007	19.8	17.5	-	-	13.4	10.0	0.60	-	0.65
	2008	18.9	17.4	-	-	8.4	8.9	0.64	-	0.56
Average		17.2	17.0	10.3	16.3	9.7	9.4	0.63	0.56	0.60

The correlation analysis between SWAT soil moisture and MODIS NDVI, LST

The temporal correlation analysis was conducted using the 9 years (2000-2008) monthly average data of SWAT simulated soil moisture (SM), MODIS NDVI and LST.

The results show that the soil moisture is in an inverse proportion with NDVI and LST during the leaf growing period. During the leaf growing period of forest, plants need soil water for transpiration. Evaporation from surface also increases because temperature rises from March to June of our country. Therefore the soil moisture is forced to decrease experiencing the wetting and drying process by rainfalls while NDVI and LST increases by the leaf growth. On the other hand, there were little direct proportion between soil moisture and NDVI, and almost no relation between soil moisture and LST during forest leaf falling period.

Tables 4 and 5 show the correlation results of SWAT SM versus MODIS NDVI during forest leaf growing and falling periods of each year respectively. Tables 6 and 7 show the correlation results of SWAT SM versus MODIS LST during forest leaf growing and falling periods of each year respectively.

Looking at the determination of coefficients (R^2) in Tables 4 and 6 of forest leaf growing period, the average R^2 above 0.5 with negative slope for 3 forest types was 4 times between SM and NDVI and 5 times between SM and LST for the 9 years. From Tables 5 and 7 of forest leaf falling period, the average R^2 above 0.5 with positive slope was 3 times each for NDVI and LST respectively.

We could not explain the high R^2 of the years definitely, but we can infer that the values are greatly affected by the rainfall frequency occurred during the period. Soil moisture directly responds to rainfall. Soil moisture increases when rainfall occurs and decreases before the next rainfall. Thus the number of soil moisture fluctuation during the period affected the temporal correlation. The soil moisture continually was decreased by the low rainfall frequency while the air temperature increased. The R^2 of leaf growing period showed the high value with the big inverse slope between two variables among the 9 years. The low R^2 appeared in case of dispersed storms occurred during the period regardless of the leaf growing or falling periods.

Table 4. The temporal correlation between SWAT simulated soil moisture and MODIS NDVI during forest leaf growing period (March-June)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	235.3	13.4	y=-2.1393x+9.7736	y=+0.2865x+8.6856	y=-2.8548x+7.9764	0.21	0.01	0.28
2001	211.5	13.9	y=-25.223x+27.016	y=-20.147x+23.375	y=-17.178x+19.279	0.67	0.58	0.63
2002	286.1	13.7	y=+4.2162x+8.1402	y=+3.0535x+9.7578	y=+0.7755x+7.6458	0.12	0.08	0.01
2003	374.6	12.6	y=-16.213x+28.043	y=-17.309x+28.402	y=-14.574x+22.958	0.76	0.82	0.72
2004	356.6	13.1	y=+6.9717x+7.6368	y=+7.8776x+7.7714	y=+3.9831x+7.2158	0.41	0.51	0.28
2005	383.1	12.8	y=-16.709x+23.950	y=-15.855x+24.347	y=-14.713x+20.488	0.87	0.80	0.78
2006	405.7	12.5	y=+6.0098x+8.5721	y=+5.8201x+8.9483	y=+3.0951x+7.8093	0.68	0.65	0.36
2007	345.4	12.6	y=-23.683x+29.736	y=-21.503x+28.595	y=-21.457x+25.797	0.97	0.97	0.95
2008	290.4	12.6	y=-9.6834x+16.847	y=-3.1432x+13.596	y=-13.221x+16.962	0.42	0.08	0.61
Average	321.0	13.0	y=-4.8919x+17.7461	y=-6.7688x+17.0531	y=-8.4605x+15.1257	0.57	0.50	0.51

Table 5. The temporal correlation between SWAT simulated soil moisture and MODIS NDVI during forest leaf falling period (September-December)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	251.6	8.5	y=+28.532x+2.6753	y=+22.524x+5.0682	y=+28.514x+0.0186	0.53	0.42	0.68
2001	157.4	8.7	y=-7.6178x+18.133	y=-12.189x+21.008	y=-1.522x+11.287	0.09	0.26	0.01
2002	167.9	7.5	y=+18.698x+5.6075	y=+9.1336x+10.486	y=+19.81x+2.7876	0.80	0.43	0.76
2003	452.3	9.0	y=+35.537x-2.2618	y=+29.42x+0.3436	y=+32.665x-2.1686	0.91	0.81	0.92
2004	272.2	9.7	y=+38.851x-5.2091	y=+33.517x-3.1374	y=+36.596x-5.9488	0.92	0.89	0.87
2005	192.6	8.2	y=+18.317x+5.9039	y=+12.434x+8.909	y=+18.333x+2.8593	0.40	0.27	0.46
2006	254.9	9.4	y=-23.788x+29.401	y=-26.003x+30.399	y=-21.302x+26.778	0.69	0.74	0.69
2007	303.2	9.3	y=+38.124x-0.9763	y=+35.385x-1.5646	y=+36.384x-2.5936	0.99	0.99	0.99
2008	142.9	9.4	y=+13.144x+6.031	y=+6.1203x+8.5509	y=+11.297x+5.3715	0.20	0.11	0.16
Average	243.9	8.9	y=+17.755x+6.5894	y=+12.260x+8.8959	y=+17.864x+4.2657	0.61	0.55	0.62

Table 6. The temporal correlation between SWAT simulated soil moisture and MODIS LST during forest leaf growing period (March-June)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	235.3	13.4	y=-0.3067x+98.383	y=-0.259x+85.29	y=-0.3216x+100.42	0.93	0.81	0.94
2001	211.5	13.9	y=-0.9957x+301.32	y=-0.907x+275.08	y=-0.7868x+237.64	0.76	0.72	0.75
2002	286.1	13.7	y=+0.0334x+1.3174	y=+0.0087x+9.3033	y=-0.0446x+21.112	0.01	0.00	0.02
2003	374.6	12.6	y=-0.7597x+239.06	y=-1.036x+319.64	y=-0.8536x+262.53	0.67	0.75	0.60
2004	356.6	13.1	y=+0.2366x-56.321	y=+0.2586x-61.955	y=+0.0517x-5.1168	0.23	0.22	0.02
2005	383.1	12.8	y=-0.3572x+116.13	y=-0.3238x+107.17	y=-0.3257x+104.47	0.97	0.97	0.96
2006	405.7	12.5	y=+0.2779x-68.113	y=+0.2957x-73.039	y=+0.1918x-45.715	0.92	0.96	0.75
2007	345.4	12.6	y=-0.8283x+255.6	y=-0.3016x+101.23	y=-0.217x+73.14	0.77	0.65	0.57
2008	290.4	12.6	y=-0.3577x+115.1	y=-0.2812x+93.117	y=-0.3511x+111.27	0.48	0.55	0.35
Average	321.0	13.0	y=-0.3397x+111.39	y=-0.2828x+95.093	y=-0.2952x+95.528	0.64	0.63	0.55

Table 7. The temporal correlation between SWAT simulated soil moisture and MODIS LST during forest leaf falling period (September-December)

year	Rainfall (mm)	Temperature (°C)	Equation (y = Soil Moisture, x = NDVI)			R^2		
			Deciduous	Mixed	Evergreen	Deciduous	Mixed	Evergreen
2000	251.6	8.5	y=+0.1306x-16.047	y=+0.0682x-0.2731	y=+0.182x-33.171	0.09	0.03	0.19
2001	157.4	8.7	y=+0.0839x-10.406	y=+0.0307x+4.7949	y=+0.124x-24.715	0.08	0.01	0.26
2002	167.9	7.5	y=+0.2633x-56.447	y=+0.1246x-18.914	y=+0.3427x-80.932	0.61	0.24	0.69
2003	452.3	9.0	y=+0.5498x-135.77	y=+0.4562x-111	y=+0.5928x-149.76	0.67	0.47	0.75
2004	272.2	9.7	y=+0.6502x-166.73	y=+0.5242x-132.68	y=+0.605x-156.21	0.69	0.42	0.55
2005	192.6	8.2	y=+0.312x-70.637	y=+0.277x-61.737	y=+0.3178x-75.354	0.92	0.90	0.93
2006	254.9	9.4	y=-0.5224x+163.16	y=-0.6088x+187.86	y=-0.5272x+163.28	0.87	0.91	0.93
2007	303.2	9.3	y=+0.2364x-45.102	y=+0.2573x-53.423	y=+0.2633x-55.208	0.12	0.12	0.12
2008	142.9	9.4	y=+0.1296x-23.155	y=+0.0665x-6.7377	y=+0.1592x-33.288	0.13	0.05	0.14
Average	243.9	8.9	y=-0.3397x+111.39	y=-0.2828x+95.093	y=-0.2952x+95.528	0.46	0.35	0.51

Summary and Conclusions

Due to the lack of soil moisture ground data, we need a pseudo indicator of soil moisture condition. This study was tried to investigate the correlations between SWAT simulated soil moisture (SM) and MODIS NDVI and LST how much the NDVI and LST can explain the soil moisture for the forest leaf growing and falling periods respectively.

For the analysis, a 2,694.4 km^2 forest-dominant dam watershed was selected and 9 years (2000-2009) MODIS NDVI and LST were prepared. For soil moisture preparation, the SWAT model was calibrated and verified using the 9 years daily streamflow data at 3 stations and 6 years daily soil moisture data at 3 locations. The average Nash-Shutcliffe model efficiency for validation period was 0.7 and the average determination of coefficient (R^2) was 0.57.

The temporal correlation between the soil moisture and NDVI and LST showed an inverse proportion during the leaf growing period and a little direct proportion in leaf falling period. The correlation of SM with NDVI was on the similar level with LST for the forest leaf growing (March-June) and falling period (September-December). The 9 years average R^2 between SM and NDVI were 0.57, 0.50, and 0.51 for deciduous, evergreen, and mixed forests during the leaf growing period, and 0.61, 0.55, and 0.62 during the leaf falling period respectively. Meanwhile, the 9 years average R^2 between SM and LST were 0.64, 0.63, and 0.55 during the leaf growing period, and 0.46, 0.35, and 0.51 during the leaf falling period respectively. The soil moisture showed high correlation with the big inverse slope for NDVI and LST during the forest leaf growing period among the 9 years. The low correlation appeared in case of dispersed storms occurred during the period regardless of the leaf growing or falling periods.

In this study, we derived the simple relationship between model simulated soil moisture and vegetation index and surface temperature from satellite image. To understand the relationship between the variables, we need spatial correlation analysis and discuss with the soil because the soil moisture is dependent on the soil physical properties. In addition, we can try the multiple regression including rainfall amount or frequency as dependent variables. Other MODIS products such as LAI (leaf area index) can a candidate indicator to be analyzed.

Acknowledgements

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A2-3

Evaluation of SWAT Model for Irrigation Reservoir Operation

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The objective of this study is to evaluate SWAT-K model in paddy irrigation area in korea. SWAT model was applied to Idong reservoir watershed which represents a typical korean rural watershed in Yongin city. Field data to assess irrigation water are monitored from irrigation district, reservoir, stream. Several reservoirs with small size in upper stream area of Idong reservoir such as Yongduck, Misan, Nogok which are working on irrigation area of approximately 800ha. Also, Return flow and spillway release water make an effect on streamflow of inlet stream to Idong reservoir.

Simulation results compared with HOMWRS model are calculated as 2.2 Mm^3 and 1.7 Mm^3 in 2007, 1.3 Mm^3 and 1.6 Mm^3 in 2008. Irrigation amount by SWAT are 918 mm/year and monitored data are 875mm in the irrigation district. As a result of this study, Irrigation water balance can be calculated by SWAT model. As a result of this study, Misan subbasin without reservoir effect had a good result with the daily and monthly streamflow comparison. It has a very similar trend with observed data with reservoir effect. It is necessary to study reservoir effect, return flow and water use which are influencing rural watershed streamflow.

Keywords: SWAT-K, HOMWRS, Agricultural reservoir, Reservoir operation

SESSION B2

InStream Sediment and Pollutant Transport

B2-1

Using SWAT for Estimating Impact of Sediment and Pollutant Export in the Chungju Dam Watershed, Korea

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Abstract

The SWAT model has been used to estimate the impact of sediment, nitrogen, and phosphorus export flowing into the Chungju Dam of the Han River basin in Korea, which is a multi-purpose dam with the storage capacity of 2.75 billion ㎥, approximately 0.6 billion ㎥ of flood regulation, and the annual power generation of 844 millions kWh. The watershed area is 6,648 ㎢ that accounts for 19.3% of the entire area of the Han River basin. The model was calibrated against measured daily flows using Nash-Sutcliffe model efficiency and R squared, and calibrated against water quality data sampled infrequently using temporal-window statistics. After calibration and validation, simulated data from the model for the period 1980~2009 were used in order to investigate the in-stream sediment and pollutant transmission characteristics. Using transmission ratios of each sub-watershed stream, the total transmission ratios of pollutant loads to the Dam site were estimated. Downstream areas had higher transmission ratios than upstream areas, which indicated the application of practices to reduce pollutant export into the stream waterbodies near the mouth of the watershed would be more effective than application of the same practices on upstream areas near the head of the watershed. For the whole watershed, non-point sources accounted for 99.6% of sediment, 88.0% of T-N, and 73.8% of T-P loads into the Dam.

KEYWORDS: SWAT, Chungju Dam, In-stream, Transmission characteristics, sediment, Nitrogen, Phosphorus

Introduction

In Korea, TMDL program is being performed for the Geum River, Yeongsan River, Seomjin River, and some areas of the Han River basin. This program started on the Nakdong River basin August of 2004. TMDLs are quantitative objectives and strategies needed to achieve water quality standards by controlling the discharged loads from the upstream areas. To decide the way and the amount of discharged loads to be reduced, it is necessary to understand the impact of the loads from the upstream areas on the water quality standards at the downstream point of interest.

Not all the generated or discharged loads from the upstream areas have an effect on the downstream water quality, which is actually affected by the loads delivered to the lower areas

(Lee and Cho, 2001). In the SWAT model, sediment and nutrient yields into reaches are calculated for each subbasin and then routed through each reach. In other words, the SWAT does not simulate the generated loads, instead, it simulates the loads into a reach and out of a reach. Therefore, we can assess the impact of sediment and nutrient loads from the upstream areas on the downstream point of interest using a stream routing process.

This study was conducted to simulate the discharged pollutants to stream reaches, and to quantitatively estimate how much the pollutants are delivered to the downstream areas and actually contribute the total loads at the Chungju Dam using a transmission ratio defined as the ratio of the delivered load to a downstream reach to the discharged load from an upstream reach.

Methods and Materials

Study area and model input data

The SWAT was set up for the Chungju Dam upstream area of 6,648 ㎢ that accounts for 19.3% of the entire area of the Han River basin in Korea. The watershed was divided into 11 sub-watersheds where hydrological and water quality data have been monitored (Figure 1). The DEM (30m×30m), landcover map (1/25,000) obtained from the Ministry of Environment, and detailed soil map (1/25,000) from the National Academy of Agricultural Science were used as the GIS input data for the model simulation. Daily weather data from five stations were applied in order to calculate the potential evapotranspiration. Discharged wastewater and pollutant loads to streams estimated by the National Institute of Environmental Research (NIER) (2001) were used as the point source load of each sub-watershed.

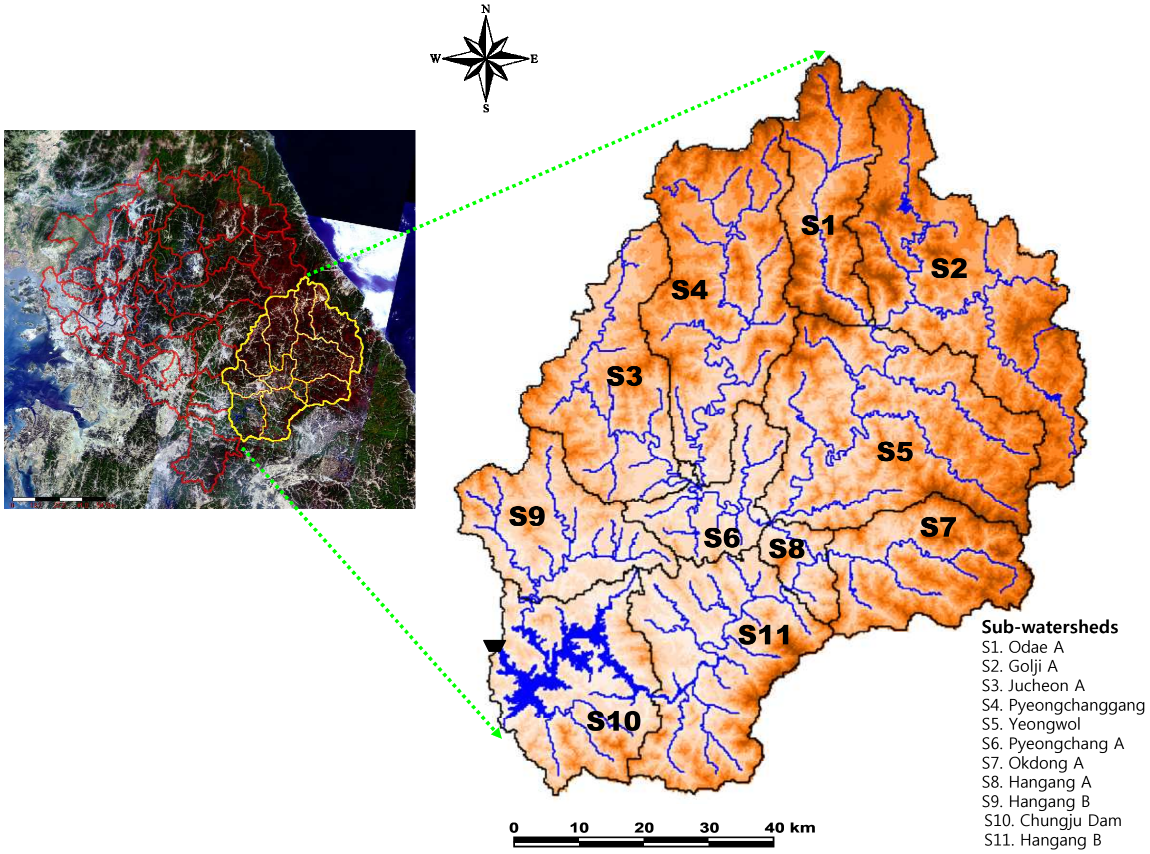


Figure 1. The Chungju Dam watershed.

Model calibration and validation

Multi-site calibration and validation were performed since simulation accuracies in several sites within a watershed are prerequisite for a semi-distributed model such as the SWAT. The same data period from January 2005 to December 2009 were used for the calibration and validation. Daily inflow data at the Chunju Dam were used for calibration, and the daily streamflows at the Yeongchun and the Jucheon stations located in the upper region of the watershed were applied for validation. For total nitrogen (T-N) and total phosphorus (T-P), a temporal window approach (Kim et al., 2007) was adopted for estimating 'observed' nutrient loads from the streamflow and the nutrient concentrations which were sampled in every eight days. Using this approach, data of the Hangang A (S8) were used in calibration process and other sites were used for validation.

Figure 2 shows the calibration result for flow at the Chungju Dam during 2005~2007. Although there were some discrepancies between the observations and simulations, overall the simulated daily flows matched well with the observed flows (R^2=0.73 and Nash-Sutcliffe (1970) ME=0.72). This implies sufficient applicability of the model for the long-term simulations.

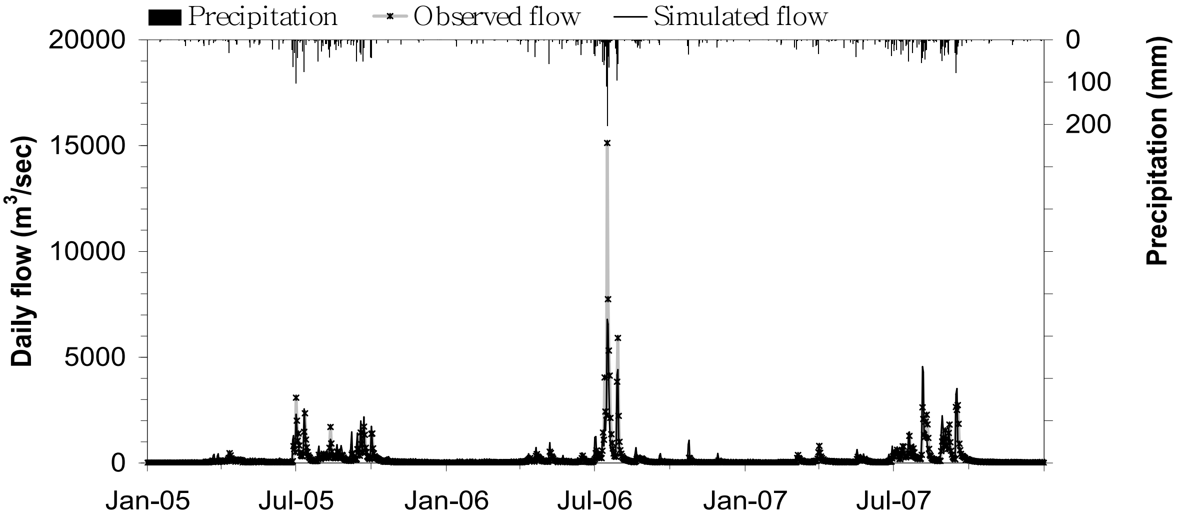
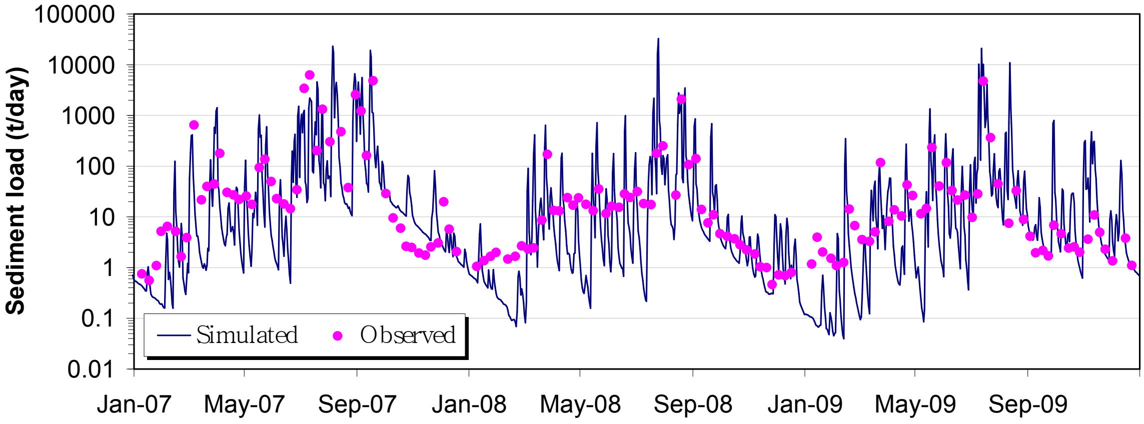
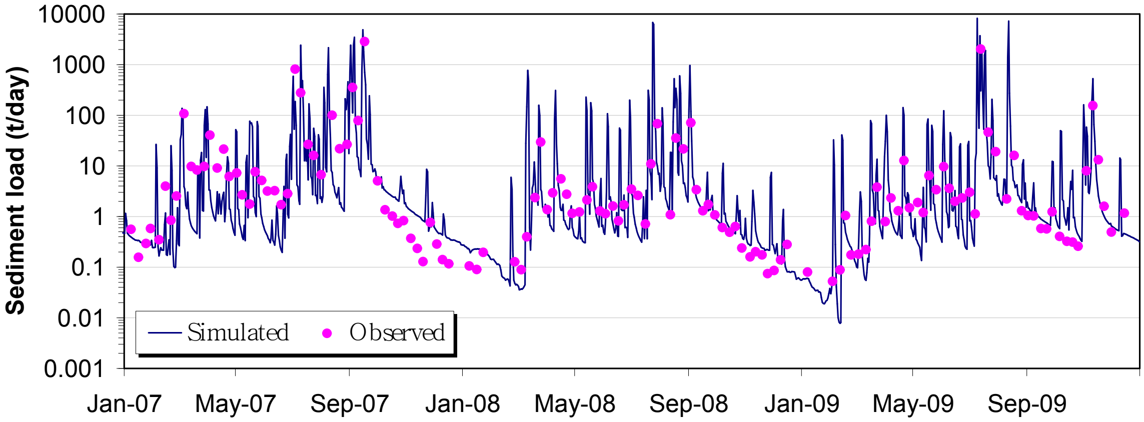


Figure 2. Observed and simulated daily inflows at the Chungju Dam during 2005~2007.

Figure 3(a) and (b) compare the observed sediment loads with the simulated loads for the Hangang A (S8) and the Golji A (S2) stations, respectively.



(a) Hangang A



(b) Golji A

Figure 3. Observed and simulated daily sediment loads at the Hangang A and the Golji A.

Results and Discussions

Transmission ratios for sub-watersheds

The transmission ratio is defined as the delivered load to the discharged load. And the discharged load is the sum of point and nonpoint loads, and sometimes plus upstream load. To estimate transmission characteristics of the watershed, 30-year (1980~2009) simulation results from the model were analyzed. Using the transmission ratio for each sub-watershed, the total transmission ratio to the Chungju Dam was calculated. Figure 4 indicates that sub-watersheds located at downstream areas had greater impacts compared to the sub-watersheds at headwater areas. That means the application of practices to reduce pollutant export into the stream waterbodies near the mouth of the watershed would be more effective than application of the same practices on upstream areas near the head of the watershed.

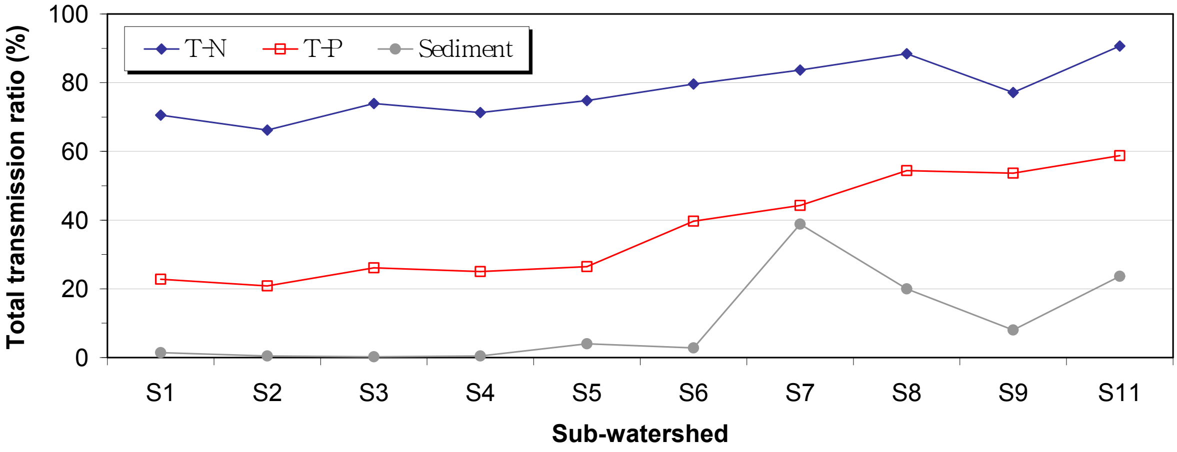


Figure 4. Total transmission ratio to the Chungju Dam from each sub-watershed.

Contribution of each pollutant source to total loads

As shown in Figure 5, about 99.6%, 88.0%, and 73.8% of the total pollutant loads were contributed by nonpoint source pollution for sediment, T-N, and T-P, respectively. That indicates the contribution of point and nonpoint pollutants within the watershed on the total delivered loads to the Chungju Dam, the main outlet of the study area.

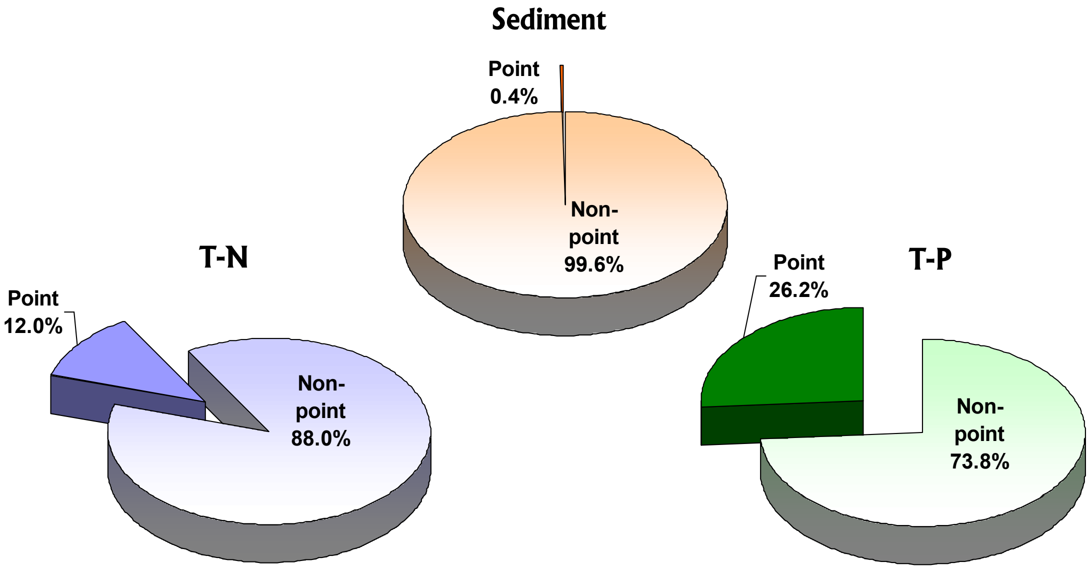


Figure 5. Contribution of point and nonpoint sources to the total loads at the Chungju Dam.

Conclusions

This study was conducted to simulate the discharged pollutants to stream reaches such as sediment, nitrogen, and phosphorus, and to quantitatively estimate how much the pollutants are delivered to the downstream point of interest and actually contribute the total loads. The ratio of the delivered load to a downstream reach to the discharged load in an upstream reach was defined as the transmission ratio, which may qualitatively depict the characteristics of the movement of pollutants along the stream reach. The SWAT model was applied to the

Chungju Dam watershed in order to simulate hydrology and pollutant loads for all sub-watersheds, and to define the transmission ratios.

Estimated contribution of pollutant load to the Chungju Dam showed that sub-watersheds located at downstream areas had greater impacts compared to the sub-watersheds at headwater areas. And, about the total pollutant loads by point and nonpoint source (NPS) pollutions, 99.6%, 88.0%, and 73.8% of the total loads were contributed by NPS for sediment, T-N, and T-P, respectively.

Acknowledgement

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B2-2

Assessing the Impacts of Land use/ Land cover Changes and Practices on Water Discharge and Sedimentation using SWAT: Case study in Dong Nai watershed – Vietnam

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The Soil and Water Assessment Tool (SWAT) has been widely applied for modeling watershed hydrology and simulating the movement of non-point source pollution. The SWAT is a physically – based continuous time hydrologic model with Arcview GIS interface developed by the Blackland Research and Extension Center and the USDA-ARS (Arnold et al., 1998) to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex basins with varying soil type, land use and management conditions over long periods of time. This study is aimed at assessing factors contributing to reservoir sedimentation, water discharge using SWAT model in Dong Nai watershed as case study. It is especially important in the Dong Nai watershed where the soil is highly erodible and forest conversion for agricultural cropping is in serious condition. This study was also focused on how surface runoff and sediment yield was impacted when land use in the watershed resource is changed. The SWAT model was applied to evaluate the effect of main input data of SWAT (land use, soil, human practices) to sediment yield in Tri An reservoir, Dong Nai watershed, Vietnam.

Keyword: Land use/Land cover change, Surface discharge, Sedimentation, SWAT, Dong Nai watershed

Introduction

Impact assessment of land use change, population growth and watershed development to soil loss, water quality and quantity is one of the most important topics in a watershed. The rapid increase of population and the driving force of economic growth further accelerate the need for various land uses within the watershed. To contemplate the scope of such problems, as experienced in many other developing countries, the efforts of pursuing integrated optimal planning to achieve the sustainable uses of these watershed resources becomes critical. Many studies have been made of multi-objective land-use planning under various conditions, such as those applied in an industrial complex, a watershed, a river basin. However, very few of them focus on the evaluation of the optimal balance between economic development and environmental quality within a watershed. Hence, this research attempts to solve the selected Dong Nai watershed in context of surface runoff, sediment yield through the SWAT (Soil and Water Assessment Tool) approach.

Objectives

To provide decision makers with a scientific tool for supporting them in making decisions on reservation of water and soil resources by delivering appropriate policies about land use allocation, the details of objectives as follows:

1. To apply SWAT model to assess the impact of land use change and practices in Dong Nai watershed on surface runoff, sediment yield to the Tri An reservoir;

2. To make policy recommendations to policy maker on land use change impact to surface runoff, sediment yield.

Methodology

Location of the study area

The Dong Nai watershed locates in the southern part of the country including 10 provinces and Ho Chi Minh City. It is situated between $10^{0}31^{'}$ - $11^{0}35^{'}$ latitude and $106^{0}42^{'}$ – $107^{0}35^{'}$ longitude. The region occupies an area of approximately 3,878,787 ha as shown in Figure 1. Three forms of topographical formations can be identified in the area: a mountainous area in the north, a basaltic plateau in the south, and between them is a transition zone of alluvial valleys. The average elevation is about 500 msl. The major part in the North is only slightly undulated with a slope of less than 10^{o}, resulted from the layers of basaltic deposition while high slopes are found in the Northeastern mountainous part near the border with Lam Dong province. The lowland areas of the Dong Nai watershed are subject to annual flooding in the wet season and salinity intrusion in the dry season while mountainous highland areas goes up to 1,600 m. The Dong Nai watershed has 5 major river systems: the Dong Nai mainstream, the Be, the Sai Gon, and the La Nga as major tributaries, and the Vam Co Dong system that joins the Dong Nai just before the outlet into the Sea.

Brief description of SWAT model

The Soil and Water Assessment Tool (SWAT) has been widely applied for modeling watershed hydrology and simulating the movement of non-point source pollution. The SWAT is a physically – based continuous time hydrologic model with Arcview GIS interface developed by the Blackland Research and Extension Center and the USDA-ARS (Arnold et al., 1998) to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex basins with varying soil type, land use and management conditions over long periods of time. The main driving force behind the SWAT is the hydrological component. The hydrological processes are divided into two phases, the land phase, which control amount of water, sediment and nutrient loading in receiving waters, and the water routing phase which simulates movement through the channel network. The SWAT considers both nature sources (e.g. mineralization of organic matter and N-fixation) and anthropogenic contributions (fertilizers, manures and point sources) as nutrient inputs (Somura, H. et.al. 2009). The SWAT is expected to provide useful information across a range of timescales, i.e. hourly, daily, monthly, and yearly time-steps (Neitsch et al., 2002).

Figure 1. Dong Nai watershed map

Data collection

Available data and information related to the SWAT modeling in Dong Nai watershed such as maps, statistic data, forest area, forest cover, population, soil erosion parameter, precipitation, water quality and other the related data was collected by the offices of local authorities and relevant professional institutions and our team. The types of data and their sources are shown in Table 1.

Table 1. Data collection and their sources for SWAT model

Types of data	Sources of data
1. Physical Data	Department of Land Development, Dong Nai Province
Topography	
Precipitation	Dong Nai Meteorological Department
Soil erosion	Institute of Water Resource Research in HCMC
Parameter	Department of Land Development, Dong Nai Province
2. Biological Data	
2.1. Land use maps	
2.2.Forest, Agriculture	Department of Agriculture and Rural Development, Dong Nai Province
3. Socio-economic Data	
Population	Dong Nai Statistical Department
Income	
4. Water quality (BOD, COD, DO, SS, . . .)	Department of Natural Resources and Environment, Dong Nai province

The Scenario Planning Process for SWAT Model

The SWAT model approach applied to the case study area of Dong Nai watershed is shown in Figure 3, 4. The principal planning task is aiming at the efficient planning of future in Dong Nai watershed. The objectives of each plan will assist in deciding upon the socio-economic, physical and environmental data that required formulating the different planning scenarios. The derived objectives are also used later in the methodology to evaluate the efficiency of each proposed planning scenario.

The next step of the planning process is to formulate possible land-use scenarios. Two land-use planning scenarios are formulated for Dong Nai watershed as input of SWAT model.

Scenario A: Dong Nai watershed Land use map in 2000.

Scenario B: Existing land use map (2008).

Impact assessment of changes in land use practices and human practices in Dong Nai watershed on surface water, sediment contribution to the Tri An reservoir during the period from 2000 – 2008.

The SWAT model requires methodological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity, and solar radiation data. Spatial data sets including digital parameter layers such as parameters (R, K, C, P) and topography (LS) was digitized from the associated maps. LS factor of the watershed is derived from digital elevation model (DEM) obtained from topography.

The SWAT model was applied in Dong Nai watershed as shown in Figure 2, 3.

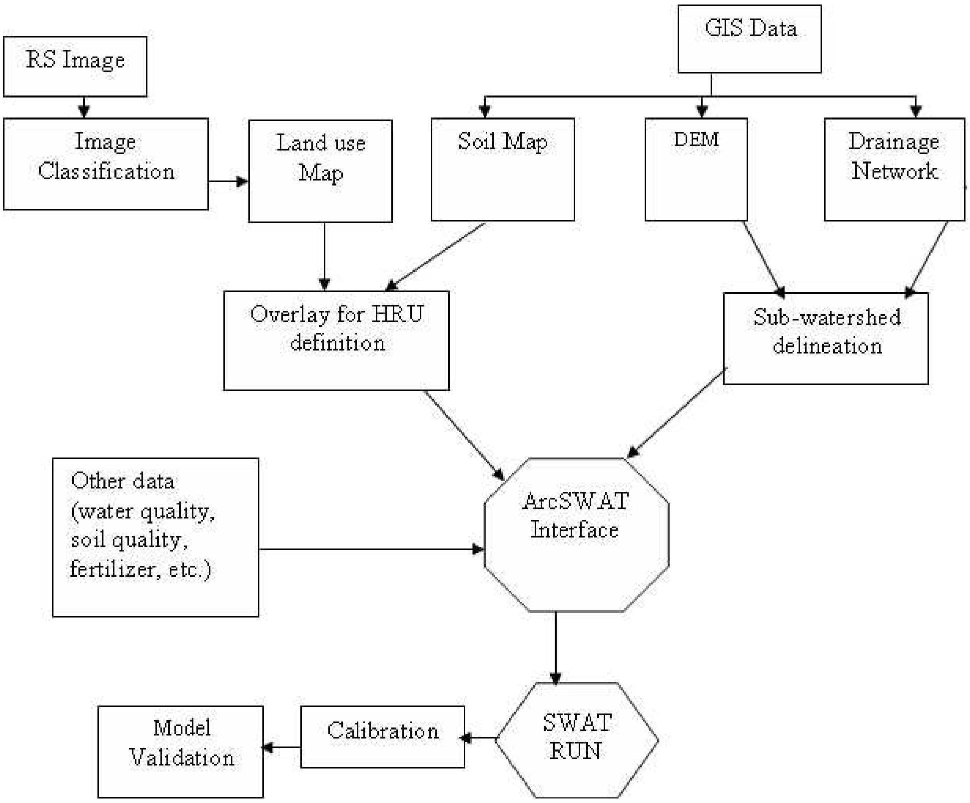

Figure 2. The SWAT model

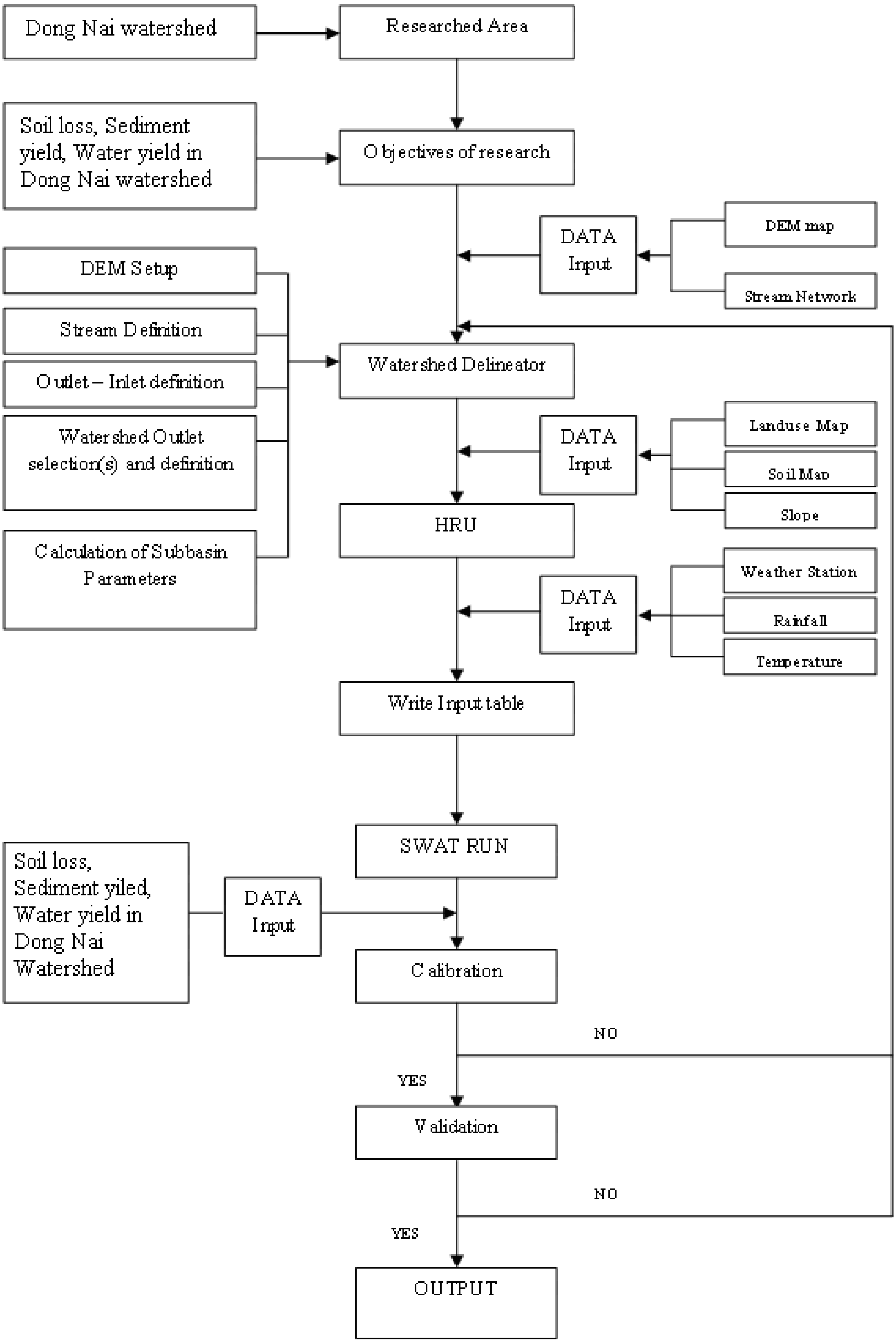

Figure 3. Application of SWAT model in Dong Nai watershed

Results and Discussions

Land Use and Land Cover Change (LUCC) between 2000 and 2008

The LUCC between 2000 and 2008 is conducted by matrix operation as shown in Table 2. The interaction of land use and land cover types pattern can be explained as shown in Figure 4 which be able to briefly describe as follows:

Forest: about 21% forest area in 2000 were converted to agriculture in 2008, and about 2.7% forest area were changed to bare land.

Agriculture: 10% of agricultural land in 2000 were changed to urban / settlement in 2008.

Urban / Settlement: area of urban / settlement in 2000 did not changed to other types in 2008.

Bare land / Open land: about 34% areas of bare land / open land in 2000 were mainly changed to forest areas and special land in 2008, while about 2.8% area of bare land in 2000 were changed to agriculture.

Special land: about 23% of special land in 2000 was converted to agriculture and bare land.

Table 2. Probability coincident matrix of land use/land cover change between 2000 and 2008, Dong Nai Watershed

2000\1995	Forest	Agriculture	Urban	Bare land	Special	Total
Forest	0.7600	0.2130	0.0000	0.0270	0.0000	1.0000
Agriculture	0.0050	0.8888	0.1005	0.0011	0.0019	1.0000
Urban	0.0000	0.0000	0.9908	0.0000	0.0000	1.0000
Openland	0.3401	0.0276	0.0000	0.2869	0.3455	1.0000
Special	0.0006	0.0810	0.0084	0.1501	0.7600	1.0000

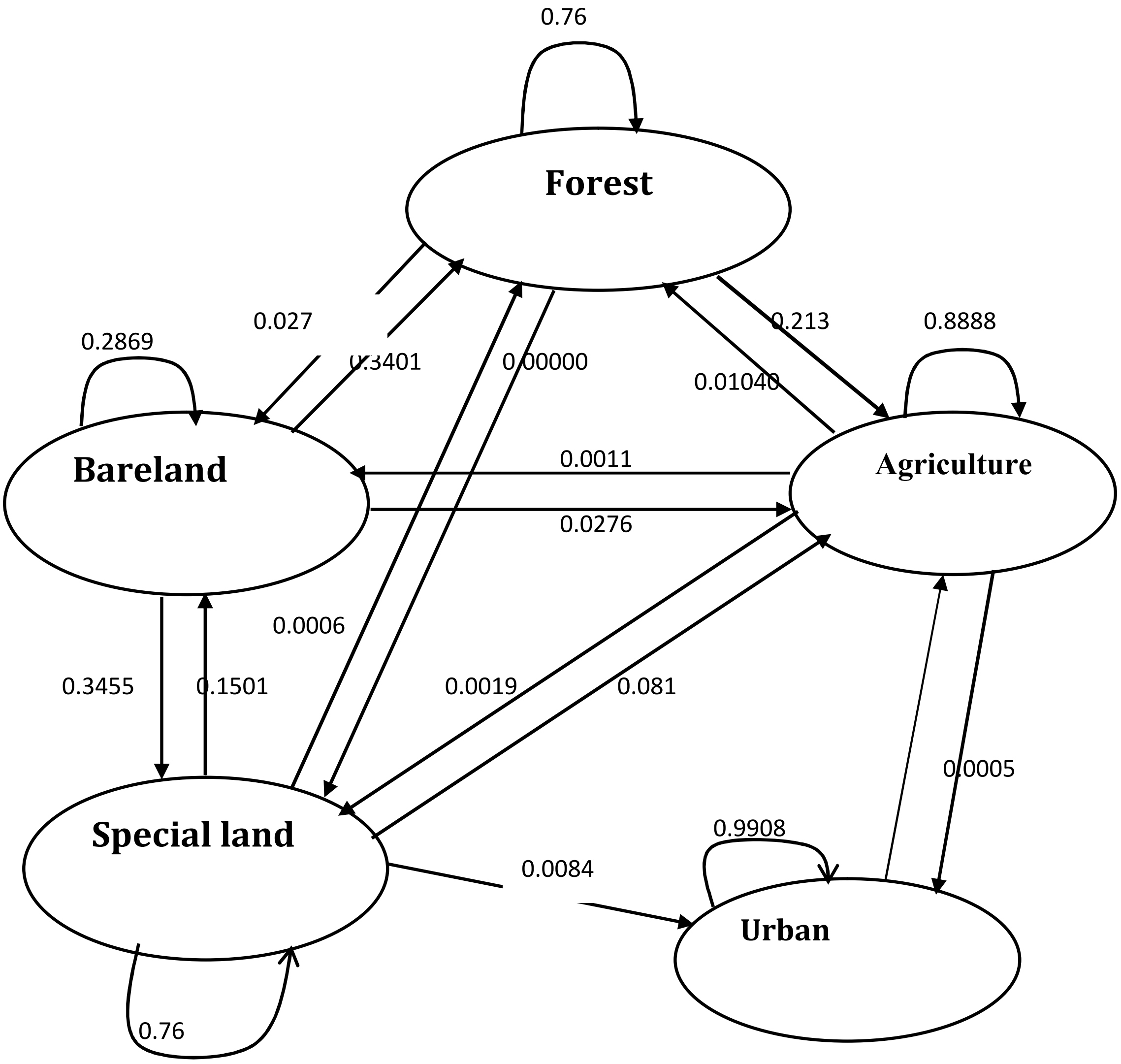

Figure 4. Probability land use / land cover change pattern between 2000 and 2008 in Dong Nai Watershed.

The result derived from the remaining land use in Table 2 imply that between 2000 and 2008 forest area was decreased about 24 percent of the forest area, while the others classes were increased. The largest increased category was agricultural, because the upland of Dong Nai watershed has been a place suffered a rapid increase in population, resulting of massive immigrations since the end of the war in 1975.

Evaluation of land use change effect on surface runoff and sediment yield

In Dong Nai watershed have 13 sub-basins as shown in Figure 5 based on SWAT model. In order to develop sound management schemes of protecting the Dong Nai watershed and to have clear picture of the impact of land use changes specifically on surface runoff, and sediment yield. The calibrated model was run to simulate two land use change scenarios. Land use change scenarios are:

Scenario A: Dong Nai watershed Land use map in 2000.

Scenario B: Existing land use map (2008).

For developing the scenarios, the key processes and related model parameters such as P factor of USLE, infiltration rate were modified in the appropriate SWAT input files. An

USLE P factor of 0.6 to 1.0 was used in simulations to reflect the condition of the watershed with and without soil conservation intervention. The predicted surface runoff and sediment yield in 2000 and 2008 were summarized in Table 3. The daily simulated surface runoff and sediment yield in the watershed is shown in Figure 6, 7.

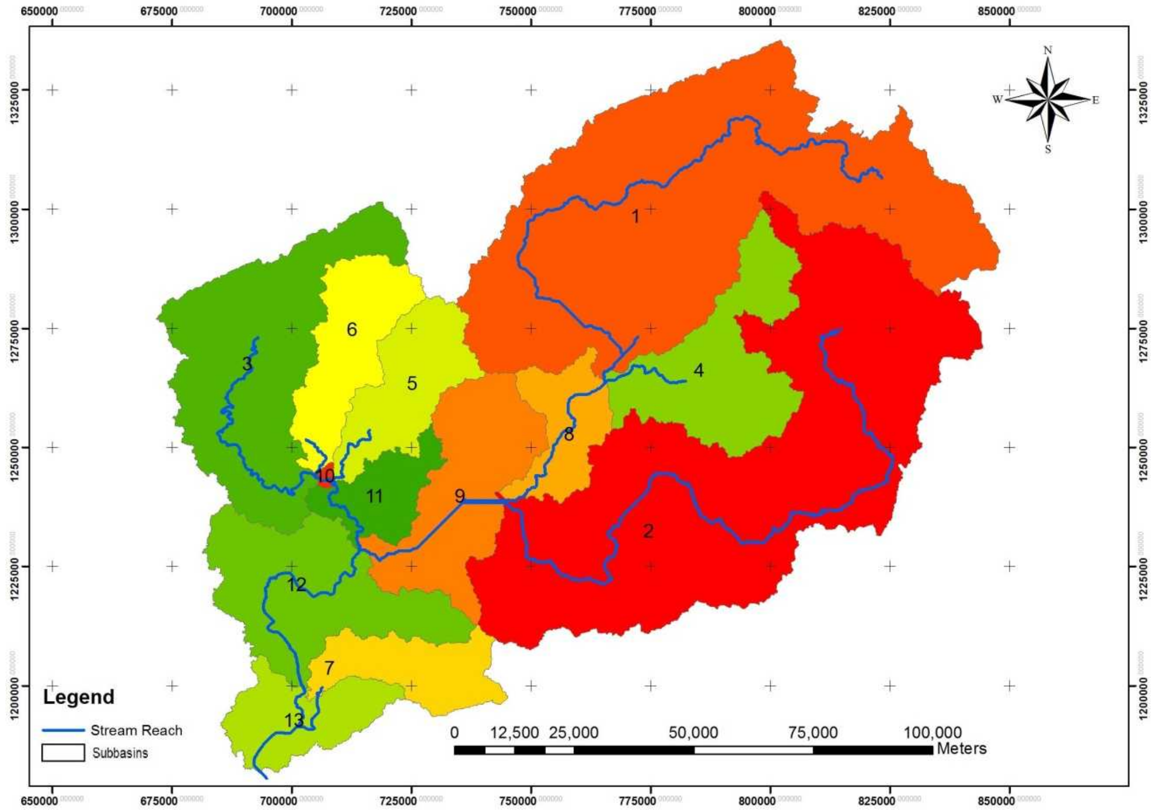

Figure 5. The Dong Nai watershed along with its sub-basin automatically delineated

Table 3. The SWAT output (monthly) with different land use scenarios

Month	Rainfall (mm)		Surface runoff Q (mm)		Sediment yield (ton/ha)	
	Scenario A	Scenario B	Scenario A	Scenario B	Scenario A	Scenario B
1	11.90	21.10	0.01	0.70	0.00	0.59
2	81.01	26.90	17.03	0.26	91.74	0.26
3	66.96	71.78	7.19	11.03	18.42	13.65
4	183.50	70.37	49.18	0.79	45.50	1.41
5	195.47	138.95	37.69	16.41	19.62	8.94
6	126.83	114.55	29.84	19.08	11.50	5.40

7	28.80	89.20	1.53	25.34	0.23	15.48
8	235.76	259.88	90.40	110.54	61.08	130.04
9	93.16	362.71	21.34	176.34	13.56	256.40
10	82.41	59.70	30.65	12.87	28.82	18.87
11	28.80	35.60	0.32	1.87	0.16	1.91
12	68.35	58.15	8.05	7.50	8.84	10.95

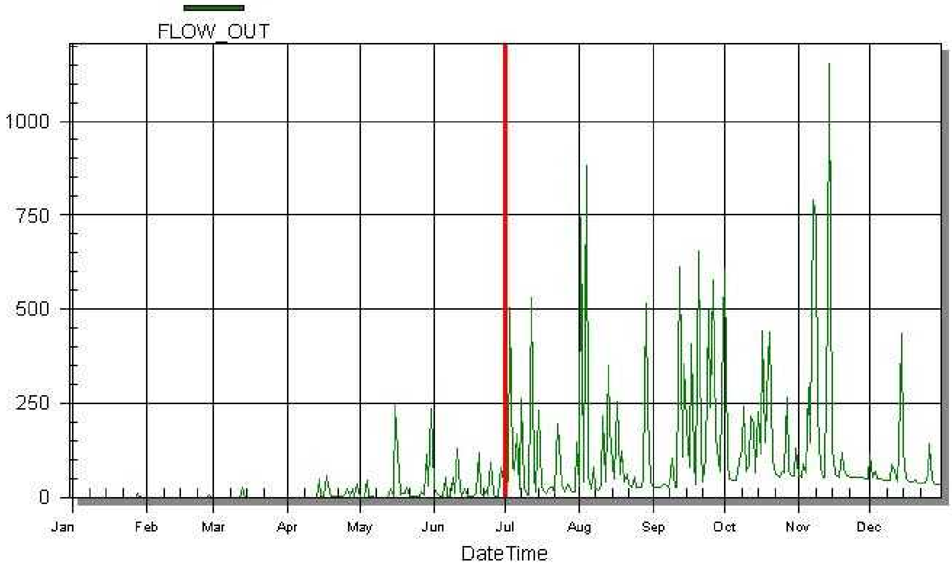

Figure 6. Simulated water flow in sub-basin 4 in Dong Nai watershed

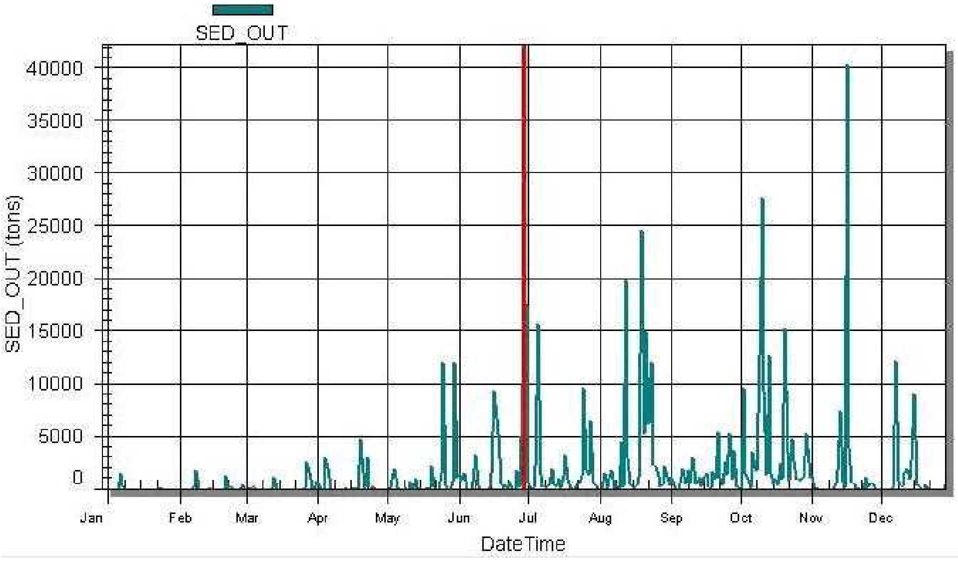

Figure 7. Simulated Sediment yield loading to Tri An reservoir in Dong Nai watershed

Table 4. The SWAT simulated statistics for Dong Nai watershed using land use scenario A (2000) and land use scenario B (2008)

Year	Precipitation (mm)	Surface runoff (mm)	Sediment yield(ton/ha)
2008	1308	31.89	38.66
2000	1202	24.44	24.96

To assess the effects of land use change in the study area, the SWAT model was run to simulate two scenarios of land use changes on surface runoff, sediment yield. Results of the simulation shown that surface runoff increase when forest converted to agricultural land (Table 3&4). An increase about 30% in surface runoff occurs when 21% of the forest area converted to agricultural land. Meanwhile, sediment yield increase about 54.8% compared between 2000 (24.96 ton/ha) and 2008 (38.66 ton/ha).

Conclusions

This research is just the first step apply SWAT in Dong Nai watershed. The SWAT model performed well in simulating the general trend of surface runoff, sediment yield, at watershed over time for daily, monthly time intervals. The results shown that the land use change and practices was affected surface runoff, sediment yield loading to Tri An reservoir. Results of the simulation shown that surface runoff increase when forest converted to agricultural land. An increase about 30% in surface runoff occurs when 21% of the forest area converted to agricultural land. Meanwhile, sediment yield increase about 54.8% compared between 2000 (24.96 ton/ha) and 2008 (38.66 ton/ha).

These simulated effects of forest conversion to agricultural crops clearly indicate an alarming situation of watershed elsewhere having the same land use pattern. In Dong Nai watershed, we recommend that policies addressing this problem should be formulated both at the local and national level. Parallel to this, an intensive information and education campaign on the consequences of forest conversion and ways of rehabilitating the watershed should likewise be done. Finally, alternative livelihood opportunities for upland farmers should be considered in policy implementation.

While simulation results are subject to further validation, this study showed that the Soil and Water Assessment Tool (SWAT) model can be a useful tool for modeling the impact of land use changes in Vietnam watershed.

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SESSION B3

BMPs

B3-1

Evaluation of Watershed Management Practices on receiving water quality using SWAT model

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To implement water quality management in upper watershed of portable water resource, it is necessary to assess point and non point source pollution loads, identify critical watershed pollution sources which are regional management priority missions, and act on best management plans. The SWAT model would be applied to evaluate the pollutant removal capacity with various best management practices (BMPs) in Kyeongan stream watershed which plays an important role in water quality conservation and improvement of Paldang reservoir. The methods for the representation of various BMPs scenarios with SWAT is developed and evaluated. Riparian buffer strip, agricultural conservation practices to reduce fertilizer, sediment, and nutrients occurring from farm field (Grassed swale, Contour farming/Parallel terrace, Field border, Farm retention pond, Grade stabilization structure), and wash land such as wetland and pond to extend detention and improve water quality are represented in SWAT. And to represent the expansion of existing Waste Water Treatment Plants in SWAT model, reduction effect for point source pollutants was simulated. As the result of simulation, the removal rates of SS, TN, TP from scenarios of Kyeongan stream watershed are the average annual SS yield by 4.4% to 64.3%, the average annual TN yield by 1.0% to 32.2%, and the average annual TP yield by 1.3% to 38.7%, respectively. This study has demonstrated that the SWAT is a very reliable and useful water quality and quantity assessment tool, and the BMPs representation in SWAT for watershed management is able to effectively simulate in Kyeongan Stream watershed.

Keyword: BMPs representation, BMPs evaluation, NPS pollution, Pollutant removal capacity, SWAT, Watershed management

Introduction

For watershed environmental management, multiple pollution sources contribute to environmental problems, so single management measures are not equipped to overcome the pollution. Consequently, watershed best management practices (BMPs) has been developed in response to regional environmental issues, especially NPS water pollution. BMPs is routinely used to reduce NPS pollution resulting from rainfall runoff of urban and agricultural activities and improve water quality. Benefits of BMPs are Habitat protection, reduced risk of flooding, ground recharge through infiltration, water quality improvement, community value (i.e. increased aesthetics), and cost savings. Many studies have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, wetlands, sand filters, dry detention, grade stabilization structures, field borders, parallel terraces, etc.) to reduce pollutant concentrations and loadings in stormwater. Studies have demonstrated how structural management practices can improve water quality, but the duration of their effectiveness and performance is largely unknown. Watershed modeling is helpful approach to analyzing the water quality impact, long term, of BMP implementation. Watershed models including HSPF and SWAT have been used for decades to identify critical land and to analyze discharge and degradation of pollution, but a limited number of studies have examined the structural BMP simulation using watershed models in Korea. The objectives of this study are to analyze the long-term water quality impact of structural BMPs using SWAT model, one of the most widely used watershed models in Kyeoungan Stream watershed (KSW) for the complex land-use, that is to present a stepwise procedure for the representation and evaluation of water quality impacts of several agricultural conservation practices and reduction of point source pollutant load. The practices discussed in this study have a long history of use around the world, we expect the measures will be widely applied for selection and implementation of pollution control strategies at the watershed scale in Korea.

Description of the Study Area

The KSW is about 589.3 km^2 in size, 49.5 km in stream length, and populated by 380,000 people. Land uses in the watershed are 64.9% forest, 16.5% agriculture, 11.1% urban or built-up land, 3.1% pasture, and 4.4% others. The KSW has thirteen public WWTPs and a larger residential land-use than other upper watersheds around the Paldang Reservoir. The average annual rainfall is 1,299 mm and show typical Asian Monsoon Climate. The Kyeongan Stream flows into the Paldang reservoir, which is an important for a supplying drinking water to the Seoul capital, Kyeonggi, Kangwon, and chungcheong provinces (Figure 1). And the stream has a shot flow length and a low flow rate (about 5.4 m^3 s^{-1} of mean flow; 470,000ton day^{-1} of total flow) compared with the others (the South Han River and North Han River), but worse water quality. Water quality in the Kyeongan Stream was extremely deteriorated by treated wastewater discharge at near sewage wastewater treatment plant located in the upstream in a low water season; therefore, it is need to manage water quality in this period particularly. Recently, along the KSW, 3 sewage treatment plants have been newly built and 5 enlarged for water quality protection, maintaining water supply, local community improvement (MOE, 2007).

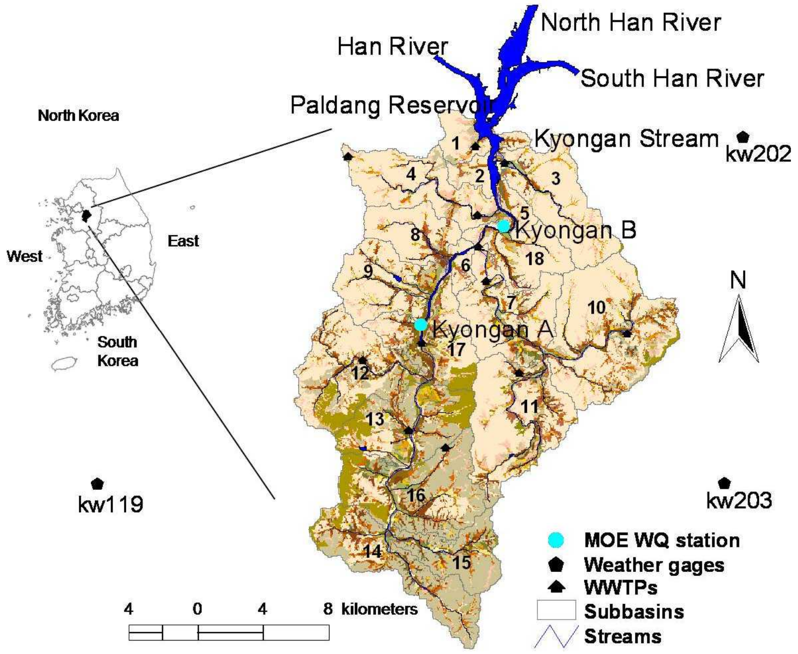

Figure 1. KSW and locations of monitoring stations.

Model Application

Model inputs

Data needs for SWAT can be extensive and SWAT is a continuous simulation program and requires continuous data to drive the simulations. Hydrologic boundary conditions can present by watershed boundary, stream network, and digital elevation model (DEM). Watershed boundary and stream network received from Nation Geographic Information Institute and a digital elevation model (DEM) data layer from the MOE was prepared at 30 m x 30 m resolution. The Based on the topography and stream network of the watershed and burn-in options (digitized streams) using the BASINS tool, the study area was divided into 18 smaller, hydrologically connected sub-basins and their stream reaches. We used a land-use map (1:25,000 scales in shape-polygon format) from the Environmental Geographic Information System (EGIS) and a detailed soil map (1:25,000 scales in shape-polygon format) from the National Institute of Agricultural Science and Technology (NIAST), with soil textures also generated. SWAT resulted in 155 HRUs considering all possible combinations of soil types and land-use covering more than 8% area. SWAT required daily time-series for precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity, which we obtained from the three stations of Suwon, Icheon, and Yangpyeong (Figure 1). In all cases, the input time series should be available at intervals equal to or less than the simulation time step.

Model performance

SWAT were fitted to the observed daily streamflow, sediment, and nutrient data from stations Kyeongan A and B for a 7-year period (2002–2008), with the first two years (2002–2003) used to stabilize the model runs. The study period of about 3 years was divided into a calibration period (August 2004–December 2006), and the remaining years (2007–2008) were used for model validation. For model calibration, a stepwise trial-and-error approach was used. SWAT ran on a daily time step, with output also generated on a daily basis. SWAT parameter values were approximated based on the sensitive analysis, the characteristics of each sub-basin, and calibration guidelines were derived from the reports of Neitsch et al. (2002) and Santhi et al. (2001). The simulated values were evaluated using graphical observations and quantitative statistics. Quantitative measures of agreement were based on daily observed and simulated mean values; percent difference (*% diff.*) index, Nash-Sutcliffe model efficiency (*NSE*; Nash and Sutcliffe, 1970), and R^2. Table 1 lists the general guidelines for calibration tolerances or targets from HSPF training workshops over the past 10 years (Donigian, 2000).

Table 1. General simulation targets or tolerances for model applications.

Daily basis		Very Good	Good	Fair	Poor
% difference	Water flow	< 10	10 - 15	15 - 25	-
	Sediment	< 20	20 - 30	30 - 45	-
	WQ/nutrient	< 15	15 - 25	25 - 35	
NSE (R^2)	Water flow	0.9 - 0.8	0.8 - 0.7	0.7 - 0.6	0.6 - 0.5

Streamflow was calibrated first, until *% diff.* values for average observed and simulated streamflow were within 25%, and *NSE* was more than 0.6. Sediment and nutrient were calibrated after the flow calibration and was continued until average observed and simulated sediment values were within 30% and 25%, respectably. Model simulated streamflow satisfactorily within the simulation targets (both *% diff.* and *NSE*). Sediment showed somewhat poor fits with the observed values of the simulation period. But their reliability and performance were within expectations, considering the complexity of the watershed and pollutant sources. TN and TP showed that, in general, SWAT was in good agreement at both station A and B, within the range of the simulation target mentioned above.

BMPs Representation

A key strength of SWAT is a flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer/manure application rate and timing, cover crops (perennial grasses), filter strips, grassed waterways, and wetlands. SWAT model has been applied to simulate pollutant reduction using BMPs (Arabi et al., 2007), effect of riparian buffer zone for reduction of NPS pollutants (Zhongwei, 2006), agricultural management practices by parameter changes (Arabi et al., 2007; Bracmort et al., 2006; Ouyang et al., 2008; Santhi et al., 2003; Vache et al., 2002). Also, in South Korea, Kang (2005) simulated best management practices with contour tillage, parallel terrace, field border, and grade stabilization structure and have been studied watershed management such as riparian buffer zone and reduction of soil erosion (Heo et al., 2005, Kim, 2007; Lee, 2005). In this chapter, to analyze the long-term water quality impact of structural BMPs in the complex land use watershed and present a stepwise procedure for the representation within model and the evaluation of hydrologic and water quality impacts of several agricultural conservation practices and point source pollutant controls, practicable control measures including point and nonpoint source pollutant control were performed on the KSW with SWAT model.

In this study, each control measure is described in Table 2. Constructing buffer strip in riparian zone (scenario 1), BMPs for control of agricultural activities (scenario 2), constructing retention ponds and wetlands (scenario 3) were assessed to simulate watershed management with SWAT model and point source pollutant load reduction (scenario 4) was also applied to assess water quality improvement in the KSW according to Government Plan 2010 (MOE, 2007). Also, for assessment of combined scenario (scenario 5), the management of water quality and pollutant load for the KSW is analyzed under the assuming that all scenarios are applied.

Table 2. BMPs measures in SWAT model.

Scenario	Description
Scenario 0	Current condition
Scenario 1	Constructing buffer strip in riparian zone
Scenario 2	Control of agricultural activities
Scenario 3	Constructing retention ponds and wetlands
Scenario 4	30~50 % reduction of WWTPs effluent
Scenario 5	Scenario 1 + Scenario 2 + Scenario 3 + Scenario 4

Riparian buffer zone

Riparian buffer zones, also referred to as vegetated filter strips or buffer strips, are vegetated areas located between the pollutant sources and surface water bodies (Narumalani et al., 1997). The function of riparian buffer zone have NPS pollution control, decrease flood and drought impacts on streamflow, and ecological preservation. Most of the research on buffer design is focused on the width. Trapping efficiency generally is improved when the width of the buffer is increased (Barfield et al., 1998; Chaubey et al., 1994; Magette et al., 1989). The riparian zone in the KSW composed from Paldang Reservoir to the origin of stream, and the Ministry of Environment has the control of within 1 km both banks. Riparian zone is about 35.8 km^2 in size as notified, which takes 6.1% of the KSW and grassland is 0.85 km^2 in size consists of pasture and wetland (Table 3). Therefore, the impact of water quality improvement is simulated assuming 10% of the changeable farmland and barren, 10.8 km^2 in size and the creation of 100 m buffer zones along the stream banks can be changed into grassland (MOE, 2007). Buffer function and spatial analyst extension in ArcView GIS tool were used to change the riparian zone of riparian zone into pasture and wetland land use types.

Table 3. Land use distribution in riparian zone of the KSW.

Land-use	Resi.*	Agri**	Forest	Pasture	Barren	Wetland	Water	Total
Area (km^2)	2.80	9.75	21.04	0.81	1.05	0.04	0.33	35.82

*: Residential area
**: Agricultural area

Agricultural management practices

Fertilizer control: The green revolution in Korea (1981~1990) helped increase the economic value, however, much use of pesticides and fertilizers accelerated soil pollution, water pollution, and ecosystem collapse. As the NPS management plan was introduced to control pesticides and fertilizers, general management skills like slow release fertilizer and nitric acid restraint fertilizer have made an effort. Agricultural management operation of SWAT was used to simulate the effect of reducing fertilization. A series of agricultural activity data, such as the cultivation, planting, fertilizing, irrigation, and harvest of major farm produce like cabbage, corn, soybeans and rice, were input to SWAT model to describe agriculture (Table 4 and 5). According to the research of Wastewater Reuse for Agriculture as part of Alternative Water Resources Project, if treatment water is used for irrigation, the same crop yields can be harvested as 40% of standard amount of fertilizer (Ministry of Science and Technology, 2006). Because in current domestic agriculture, manures and conventional fertilizers are most used, the effect of management techniques is simulated assuming that wastewater reuse for agricultural can reduce the standard amount of fertilizer up to 60% in Scenario 2.

Table 4. Upland activities: fertilizer operation of cabbage, corn, and soybean.

Land-use	Application date (month/day)			Item	Fertilizer operation (kg/ha)				Crop
	Basal	Additional fertilizer			Basal	Additional fertilizer		Total	
		First	Second			First	Second		
Upland	4/10 8/10	4/25 8/25	5/10 9/10	N	220	50	50	320	Cabbage
				P	34	-	-	34	
	4/20	6/10	7/10	N	90	45	45	180	Corn
				P	150	-	-	150	
	5/25			N	30	-	-	30	Soybean
				P	30	-	-	30	

Table 5. Paddy activities: fertilizer operation.

Landuse	Application date (month/day)			Item	Fertilizer operation (kg/ha)				Remarks
	Basal	Tillage	Panicle		Basal	Tillage	Panicle	Total	
Paddy	5/17	6/7	7/26	N	55	33	22	110	Jeon (2005)
				P	20	-	-	20	
	5/15	6/15	7/25	N	74	42	7	123	Oh (2004)
				P	25	-	2	27	
	5/25	6/20	7/30	N	55	33	22	110	This study
				P	45			45	

Soil and water conversion practices: Soil and water conversion practices in all cropland was simulated by modifying the channel cover factor and channel erodibility factor in SWAT model building grassed channel and filter strip, contour farming and parallel terrace, sediment trap, retention pond, and grade stabilization structures so that pollutants like soil and chemicals from terraced field by shear and erosion cannot wash off. The impact of filter strips on sediment and nutrient reduction was simulated as a function of filter strip width. As soil erosion distribution of farmland from NIAST (2005), simulated annual sediment load from basins is "Lower" (6< ton/ha) (Table 6), however, to analyze the soil conservation effects, above-mentioned BMPs were applied sub-basins where upland farming is practiced. Input variables were referred to Arabi et al. (2007), Bracmort et al. (2006), Gassman et al. (2007), and Santhi et al. (2006); building grassed swales along farmland if sediment discharge is under 2 ton ha^{-1} and creating various best management practices like grassed water, contour farming, parallel terrace, and sediment trap if yearly sediment discharge is 2~4 ton ha^{-1}. No.18 of sub-basins which contains upland had heavy rainfall relatively, which made yearly sediment discharge 4.61 ton ha^{-1}. Thus, grassed swales, contour farming, parallel terrace, and sediment trap, in addition to waterway stable structures are represented in SWAT.

Table 6. Soil erosion yield in sub-basins which contains upland.

Sub-basin	2	4	5	7	8	12	13	16	17	18
% Upland	11.4	10.6	19.8	12.8	10.4	13.7	12.7	13.9	15.0	14.4
SYLD*	0.50	1.10	3.64	2.29	2.91	2.51	2.85	3.17	3.18	4.61

*: sediment yield, ton ha^{-1} yr^{-1}

Table 7. Representation of agricultural managements in SWAT.

BMP	Function	Representative SWAT parameter		
		Variables	No BMPs	BMPs in good condition
Grassed swale	Increase channel cover	CH_COV	1.0	0.25
	Reduce channel erodibility	CH_EROD	0.6	0.15
	Increasing channel roughness	CH_N2	0.14～0.28	0.24
Contour farming/ Parallel terrace	Reduce overland flow	CN2	83	62
	Reduce sheet erosing	USLE_P	1.0	0.54
Field border	Increase sediment trapping	FILTERW	0	5
Farm retention pond	Present pothole	POT_FR	0	0.3
		POT_TILE	0	0.1
		POT_VOLX	0	0.05
Grade stabilization structure	Reduce gully erosion	CH_EROD	0.6	0.15
	Decrease cover factor	USLE_C	Assigned by SWAT	0.05

Retention pond and wetland: Scenario 3 was simulated retention basins at the tributaries and main stream with 0.3~0.5 m in water level and 50 m × 400 m (2 ha) in size of wetland and 1.5~2.0 m in water level and 50 m × 100 m (0.5 ha) in size of pond according to the ecological wetland construction plan. Pond-wetland system was assumed to simulate type of the pre-treatment of pond and the additional treatment of wetland referring to Kim (2008) and Ham (2005). It was assumed that wetland have a storage capacity of 0.6×10^4 m^3, normally and 1.25×10^4 m^3 in rainy season and for pond, 0.75×10^4 m^3, normally, 1.0×10^4 m^3 in rainy season. It was also assumed that 1,000 m^3 ha^{-1} day^{-1} for hydraulic loading rate, sedimentation in wetland occurs monthly, and initial concentration of sediment in wetland and pond was 20 mg/L, which is the average SS concentration of Kyeongan A and B. According to Mitsch and Gossolink (2000), settling rate of wetland is 0.25~0.76 m yr^{-1}. This research set the setting ratio of phosphorus as 0.7 m yr^{-1} and 0.3 m yr^{-1} for nitrogen. The others input factors were given in Table 6.27 and 6.28 using *.pnd of SWAT.

WWTPs discharge reduction: In scenario 4, the expansion of existing capacity and newly advanced treatment plant were used to improve the rate of sewage treatment according to water quality management plans in the KSW (MOE, 2007). Treatment efficiency of WWTPs nationwide is about 95% of SS, about 60% of nutrients (MOE, 2008). The treatment of SS and nutrients was set additional reduction of 50% possible. The high effluent concentration of Yongin, Opho, and Kwangju WWTPs will be reduced to 50% for SS and 30% for TN and TP; and Konjiam and Kyeongan WWTPs where the capacity is over 20,000 m^3 day^{-1} will be reduced 50% of SS because of expansion (Table 8). For the lack of data, the expansion and newly build plan were not reflected in the simulation.

Table 8. WWTPs effluent reduction with SWAT.

Sub-basins	Treatment plants	Capacity (m^3 day^{-1})	Extension capacity	Advanced treatment
13	Yongin*	48,000	SS : 50%	TN : 30%, TP : 30%
12	Ohpho*	7,000	SS : 50%	TN : 30%, TP : 30%
7	Konjiam**	20,000	SS : 50%	-
18	Kwangju*	5,000	SS : 50%	TN : 30%, TP : 30%
4	Kyeongan**	25,000	SS : 50%	-

*: High effluent concentration of WWTPs

**: WWTPs are above 20,000 m^3 day^{-1} of wastewater treatment capacity

Results and Discussions

BMPs evaluations and recommendations

When analyzing applicable BMPs effects from SWAT as building residence facilities and environmental infrastructures, there was an improvement in water quality. Yearly SS, TN, and TP pollutant load in basins from 2004 to 2008 was analyzed and, the reduction effects according to each scenario are compared (Figure 2, Table 9~11). In case of SS, reduction effect on each scenario never past yearly sediment load 12,483 ton yr^{-1}, and TN and TP were showed a similar result. According to Table 9~11, SS, TN, and TP were reduced to 10,894 ton yr^{-1} (efficiency 12.5%) average, 1,691,642 kg yr^{-1} (efficiency 5.5%) average and 75,816 kg yr^{-1} (efficiency 5.9%) average when applied Scenario 1. Scenario 2 was the most efficient among a single scenario reducing SS 9,198 ton yr^{-1} (efficiency 27.9%) average, TN 1,627,892 kg yr^{-1} (efficiency 9.3%) average, TP 68,332 kg yr^{-1} (efficiency 14.8%) average. Scenario 3 was the least efficient reducing SS 12,002 ton yr^{-1} (efficiency 4.4%) average, TN 1,775,987 kg yr^{-1} (efficiency 1.0%) average, TP 79,489 kg yr^{-1} (efficiency 1.3%) average. Scenario 4 was the most efficient reducing SS 10,094 ton yr^{-1} (efficiency 20.3%) average, TN 1,492,383 kg yr^{-1} (efficiency 16.7%) average, TP 66,686 kg yr^{-1} (efficiency 17.3%) average. Jung (2008) reported that if the proposal efficiency of sewage disposal plant is improved 30%, BOD, TN, TP can be reduced to 14~20%, and when improved 50%, 19~31% can be reduced), using HSPF model. Scenario 5 showed that removal measures on point and non-point pollution should be considered at the same time to have efficient water quality management, reduced to SS 4,088 ton yr^{-1} (efficiency 64.3%) average, TN 1,087,913 kg yr^{-1} (efficiency 32.2%) average, TP 49,221 kg yr^{-1} (efficiency 38.7%) average.

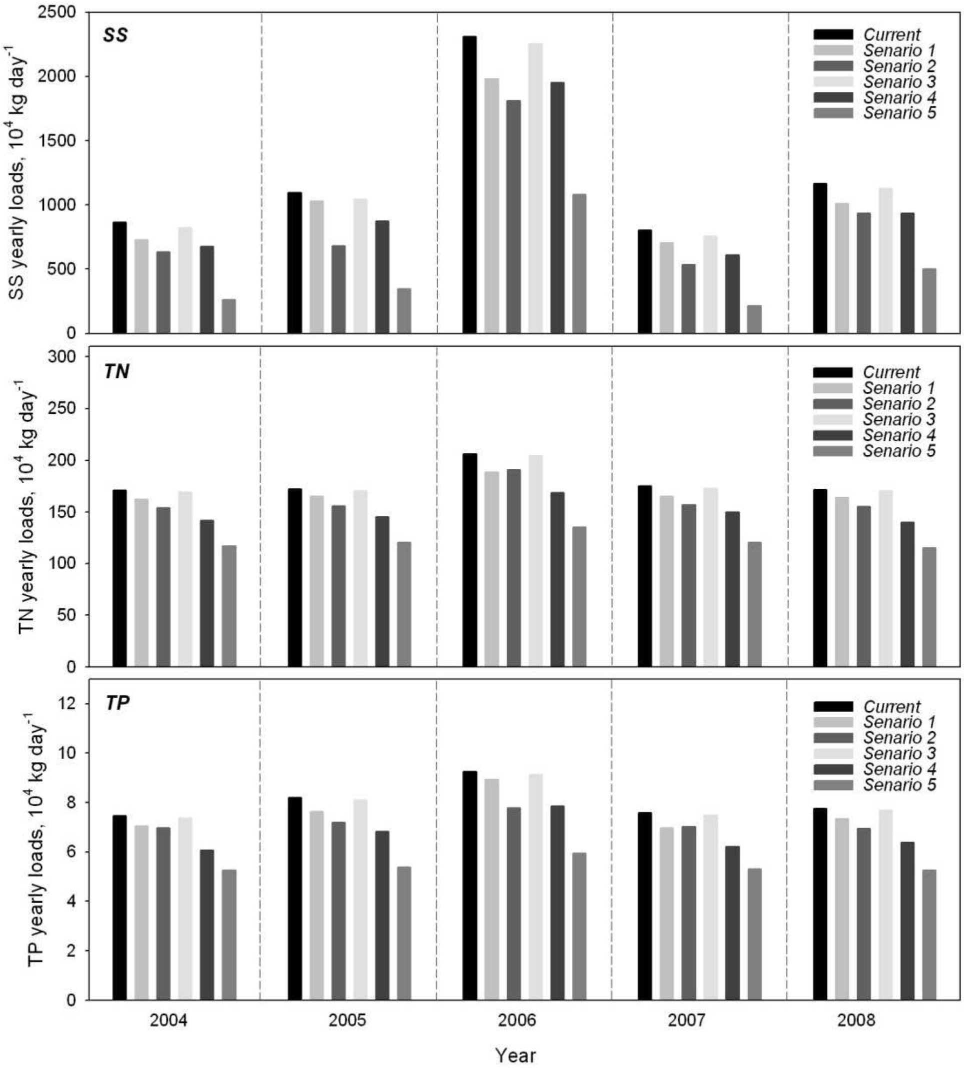

Figure 2. SS, TN, and TP yearly loads before and after BMPs

SS, TN, and TP with respect to concentration were 12.72 mg/L, 4.86 mg/L, and 0.245 mg/L average, respectably, for 5 years before BMPs. In case of agricultural activities control (Scenario 2), SS concentration went down to 10.27 mg/L average, and it went down to 7.36 mg/L average which was about 2 times lower than current condition after point and non-point pollution reduction measures (Scenario 5). TN concentration after Scenario 2 and 5 decreased by 4.50 mg/L and 3.61 mg/L, respectably and for TP decreased by 0.216 mg/L and 0.169 mg/L, respectably. SS concentration after Scenario 5 was meet Grade III of the water quality standard, while were far exceeding the Grade V for TN and TP. Therefore, further study on nitrogen and phosphorus control is needed for improving the quality of Paldang Reservoir.

Table 9. SS pollutant load after BMPs application.

		Scenario 0	Scenario1	Scenario2	Scenairo3	Scenario4	Scenario5
2004	Load(kg day^{-1})	8,663,202	7,259,052	6,340,354	8,202,834	6,742,974	2,606,596
	Conc.(mg L^{-1})	12.18	10.60	9.57	11.66	10.02	5.37
	Efficiency (%)	-	16.2	26.8	5.3	22.2	69.9
2005	Load(kg day^{-1})	10,969,965	10,294,415	6,815,542	10,445,046	8,741,259	3,447,507
	Conc.(mg L^{-1})	13.15	12.50	9.17	12.65	11.01	5.94

	Efficiency (%)	-	6.2	37.9	4.8	20.3	68.57
2006	Load(kg day^{-1})	23,092,556	19,794,256	18,122,281	22,536,972	19,532,113	10,788,414
	Conc.(mg L^{-1})	15.13	13.40	12.52	14.84	13.26	8.68
	Efficiency (%)	-	14.3	21.5	2.4	15.4	53.28
2007	Load(kg day^{-1})	8,032,811	7,037,650	5,352,519	7,551,998	6,111,293	2,155,030
	Conc.(mg L^{-1})	11.20	10.09	8.21	10.66	9.05	4.64
	Efficiency (%)	-	12.4	33.4	6.0	23.9	73.2
2008	Load(kg day^{-1})	11,655,571	10,082,462	9,361,565	11,271,506	9,343,427	5,041,962
	Conc.(mg L^{-1})	11.96	10.67	11.86	10.25	6.65	12.18
	Efficiency (%)	-	13.5	19.7	3.3	19.8	56.7
Ave.	Load(kg day^{-1})	12,482,821	10,893,567	9,198,252	12,001,671	10,094,213	4,087,902
	Conc.(mg L^{-1})	12.72	11.45	10.27	12.01	10.00	7.36
	Efficiency (%)	-	12.5	27.9	4.4	20.3	64.3

Table 10. TN pollutant load after BMPs application.

		Scenario 0	Scenario1	Scenario2	Scenairo3	Scenario4	Scenario5
2004	Load(kg day^{-1})	1,710,008	1,624,265	1,543,388	1,693,181	1,421,449	1,169,743
	Conc.(mg L^{-1})	4.57	4.38	4.21	4.53	3.95	3.41
	Efficiency (%)	-	5.0	9.7	1.0	16.9	31.6
2005	Load(kg day^{-1})	1,723,271	1,655,207	1,558,774	1,705,722	1,453,961	1,201,630
	Conc.(mg L^{-1})	5.09	4.93	4.70	5.04	4.45	3.85
	Efficiency (%)	-	4.0	9.6	1.0	15.6	30.3
2006	Load(kg day^{-1})	2,062,025	1,886,301	1,911,411	2,044,587	1,687,974	1,352,644
	Conc.(mg L^{-1})	4.66	4.34	4.38	4.62	3.98	3.37
	Efficiency (%)	-	8.5	7.3	0.9	18.1	34.4
2007	Load(kg day^{-1})	1,751,336	1,651,274	1,570,416	1,728,625	1,498,458	1,200,510
	Conc.(mg L^{-1})	4.80	4.59	4.41	4.75	4.25	3.60
	Efficiency (%)	-	5.7	10.3	1.3	14.4	31.5
2008	Load(kg day^{-1})	1,718,160	1,641,160	1,555,474	1,707,821	1,400,074	1,150,047
	Conc.(mg L^{-1})	5.21	5.02	4.81	5.18	4.44	3.83
	Efficiency (%)	-	4.5	9.5	0.6	18.5	33.1
Ave.	Load(kg day^{-1})	1,792,960	1,691,642	1,627,892	1,775,987	1,492,383	1,214,915
	Conc.(mg L^{-1})	4.86	4.65	4.50	4.83	4.21	3.61
	Efficiency (%)	-	5.5	9.3	1.0	16.7	32.2

Table 11. TP pollutant load after BMPs application.

		Scenario 0	Scenario1	Scenario2	Scenairo3	Scenario4	Scenario5
2004	Load(kg day^{-1})	74,552	70,381	66,435	73,638	60,743	48,435
	Conc.(mg L^{-1})	0.230	0.219	0.210	0.227	0.196	0.165
	Efficiency (%)	-	5.6	10.9	1.2	18.5	35.0
2005	Load(kg day^{-1})	82,019	76,245	68,394	80,918	68,233	48,921
	Conc.(mg L^{-1})	0.255	0.241	0.221	0.252	0.221	0.173
	Efficiency (%)	-	7.0	16.6	1.3	16.8	40.4
2006	Load(kg day^{-1})	92,375	89,248	73,155	91,231	78,585	54,631
	Conc.(mg L^{-1})	0.255	0.248	0.213	0.252	0.224	0.172
	Efficiency (%)	-	3.4	20.8	1.2	14.9	40.9
2007	Load(kg day^{-1})	75,897	69,732	67,387	74,960	62,023	46,789

	Conc.(mg L^{-1})	0.227	0.212	0.207	0.225	0.194	0.157
	Efficiency (%)	-	8.1	11.2	1.2	18.3	38.4
2008	Load(kg day^{-1})	77,665	73,477	66,288	76,695	63,847	47,328
	Conc.(mg L^{-1})	0.258	0.247	0.228	0.256	0.221	0.177
	Efficiency (%)	-	5.4	14.7	1.3	17.8	39.1
Ave.	Load(kg day^{-1})	80,501	75,816	68,332	79,489	66,686	49,221
	Conc.(mg L^{-1})	0.245	0.233	0.216	0.242	0.211	0.169
	Efficiency (%)	-	5.9	14.8	1.3	17.3	38.7

There is a difference in removal efficiency according to water quality criteria, thus Scenario 5 > Scenario 2 and Scenario 4 > Scenario 1 > Scenario 3 was the order. All scenarios including Scenario 5 which is a complex water quality management measure on point and nonpoint source pollution can reduce sediment discharge efficiently; especially sediment discharge as well as nutrient can be reduced by Scenario 2 and 4. Mulch plants and structural measures for protecting erosion are efficient for reduction of SS and nutrient and the best management practices have been encourage for they can maximize the productivity of agriculture and preserve agricultural ecosystem (Lee and Choi, 2002). Therefore, agricultural management must be demanded to control non-point pollution (sediment and chemical pesticide/fertilizer) and these various management techniques suggested can be applied in SWAT model. On the other hand side to think like non-structural BMPs, in general, the more pollution control effort a farmer makes, the more water quality improves. Reducing pollution loads from agricultural sources is a key objective of plans for the restoration and protection of Kyeoungan Stream. Even if the regulations are currently enacting in the Water protection area, achieving them will required changes in the way farmers produce and, therefore, aggressive public intervention in farm decision making as following measures. As an incentive to voluntarily adoption technologies, cost-sharing and incentive payments are commonly used financial incentives, while education and technical assistance are commonly used voluntary incentives. Taxes levied on a polluting input (such as a chemical pesticide and fertilizer) will also cause the farmer to use it less.

In the KSW being appeared characteristic of point source pollution significantly, water quality improvement and load reduction due to control point source pollution are very effective and it can be known that a simulation and evaluation within the model can be handled easily. And WWTPs supply and environmental infrastructures establishment are required to consider along with sustainable urban development policies in the KSW. Overall, to reach the effective result of watershed management, the control measures for point source and non-point source pollution should be considered at the same time.

Limitation and Suggestions

The riparian (buffer strip) to pass through the reduction of pollutants, rather than being simply a change in land-use of watershed (HRU property), which is the effect of grassland can be increased. Pollution occurred from the basin cannot be to evaluate how much removal through the riparian and this is a structural limitations on distributed model. SWAT-REMM prototype version has been developed using analysis of riparian effects in small river basins (Im et al., 2008). For accurate evaluation of Scenario 3, the exact location, characteristics, and capacity of wash land and long-term information of monitoring data should be sufficiently supported. In addition, the analysis of river flow change and water quality improvement must be followed to assess the sustainability of wash land as a BMP and the REMM model is needed to compare with SWAT result for uncertainty and ambiguity.

Some management practice requires small costs to reach a desired management effect, while others require large payments. In general, the more pollution management measures, the more facilities costs. Therefore, cost-effect analysis should be accompanied by the proposed each scenario and BMPs.

Conclusions

In this study, we discussed the long-term effects of implementing the water quality management practices using SWAT model in the KSW. These scenarios are implemented on several measures and each scenario represented well within SWAT model and the removal effects are reasonably simulated within given functions at the watershed level.

For BMP evaluations of SWAT model, constructing buffer strip in riparian zone (scenario 1), BMPs for control of agricultural activities (scenario 2), constructing retention ponds and wetlands (scenario 3) were assessed to simulate watershed management and water quality control and point source reduction (scenario 4) was also applied to assess water quality improvement in the KSW according to Government Plan 2010 (MOE, 2007). And the last combined scenario (5) in the KSW is analyzed assuming that all scenarios are applied.

According to this study, nonpoint source control can be expected to reduce high level of sediment yields and adequate level of nutrient yields. The scenario of point source pollution control for advance treatment and expansion WWTPs was also evaluated and can be expected to bring more significant improvement in water quality than non-point source pollution control in the KSW. To control point source is more necessary rather than non-point source for the KSW, occupied significant point sources, but all the scenarios should be applied to ultimately improve water quality of the Kyeongan Stream. Overall, we can expect that both point and nonpoint source management should be demand for the reduction of pollutant impacts and development of TMDL to the Kyeongan Stream for management of water quality. In the future study, the cost-effect evaluation should be additionally considered economical approach for establishment, operation, and management.

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B3-2

Estimation of Pollutants Removal Efficiency in the Buffer Strip Using SWAT Model

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Abstract

The construction of buffer strip is one of nonpoint sources pollutants controls. SWAT model would be applied to estimate the pollutant removals through the buffer strip. According to measures for the water quality, the non business purpose land would be changed into the grass as the buffer-strip and the changes of landuse effects on the results of the model. Under the rainfall conditions in 2007, the removal rates of SS, BOD, TN, TP are 11.5%, 9.5%, 1.2%, 4.5%. During the rainy days the removal rates of the buffer strip resulted in 92.3% of SS, 91.2% of BOD, 82.4% of TN, and 83.5% of TP. The pollutants from nonpoint sources were effectively removed by over 80% through the buffer strips.

KEYWORDS: SWAT, buffer strip, nonpoint sources

Introduction

The water quality in the artificial construction reservoirs was considered with the controls of pollutants in the only point sources. The pollutants from nonpoint sources would not be controlled to improve the water quality in the past years. However, the pollutants in the nonpoint source have been recently focusing on the improvement of the water quality. According to the measures of water quality in the Daecheong reservoir, buffer strips were constructed along the reservoir and new constructions areas were excluded within the buffer strips. This policy was the turning points to control the pollutants for the water quality.

The roles of buffer strips in the U.S. have been studied to improve the water quality. Maurizio and Elisa(2002) studied the removals of nitrogen by the plants and Mersie et al(2003) researched the runoff and the removals of pollutants with two different types of plants. Additionally, Leeds-Harrison *et al.*(1998) reported the nitrogen removals of the grasses in the buffer strips.

In this country, many studies have been started with the related of the buffer strips in 2000. The proper width of the buffer strips was simulated with the use of model by Hong in 2000. AGNPS(Agricultural Nonpoint Source Pollution Model) model was simulated to construct the plant belt by Jaehoon Kim in 2000. AGNPS with the GIS tool was used to set the boundary conditions for the buffer strips (Haejin Han, 2000).

In this study, SWAT made by USDA Agricultural Research Service, was simulated to remove the water pollutants by the changes of the landuse.

Methods

Study Sites

The research area was digitized from the source of Geum River to the inlet of Yongdam reservoir. The study area was 299.5 ㎢ and the characteristics and landuse patterns of watershed were shown in Table 1 and Table 2.

Table 1. Characteristics of study area.

Type	Slope (%)	Height (EL.m)	Density (L/L^2)	Factor (L/L)
Status	34.59	539.93	2.97	1.25

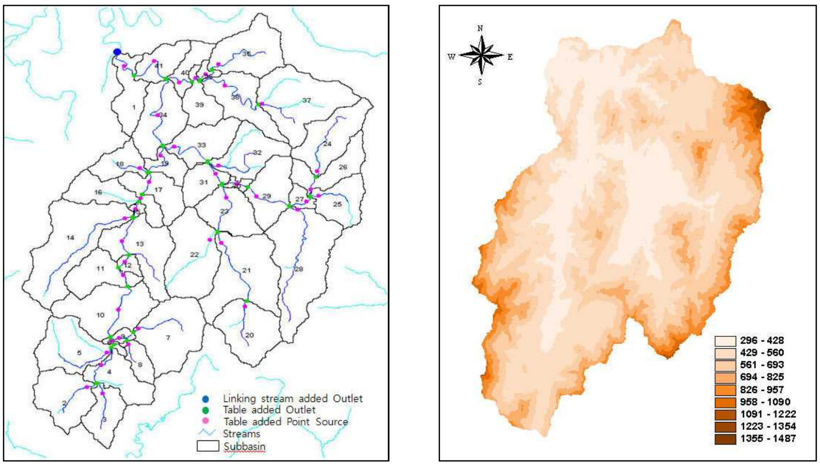
Table 2. Landuse pattern in the study area.

Landuse	Field	Paddy	Forest	Upland	Others	total
Area(㎢)	24.1	30.2	218.1	13.1	14.1	299.5

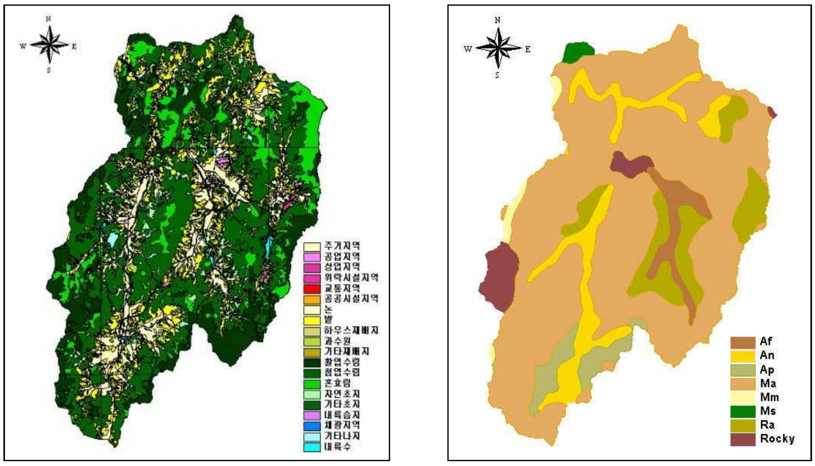
SWAT model input data

The data of contour lines were made by the 30 X 30m DEM in Arcview with the map scale of 1:25,000. These data would be utilized to set the boundaries of the small watersheds in the SWAT inputs. The threshold area input of small watershed in the SWAT was 91 and this input provided the network of streams by using the flow directions and flow accumulations. Geographical input data were taken based on the small watersheds within the SWAT such as areas, slopes, the lengths and width of streams, and so on. Soil maps and landuse patterns data were provided by the Ministry of Environment, Republic of Korea.

The runoff and the evapotranspiration would be simulated with meteorological data such as rainfall, wind velocity, and temperatures. These data were provided by the 5 adjacent meteorological stations of the study areas. Daily meteorological data were used from Jan. 1 of 1996 to Dec. 31 in 2008. Figure 1 shows the geographical DEM, landuse patterns and soil maps within the study areas.



(a) Delineation (b) DEM



(c) Landuse (d) soil

Figure 1. Input data of SWAT model in the study area.

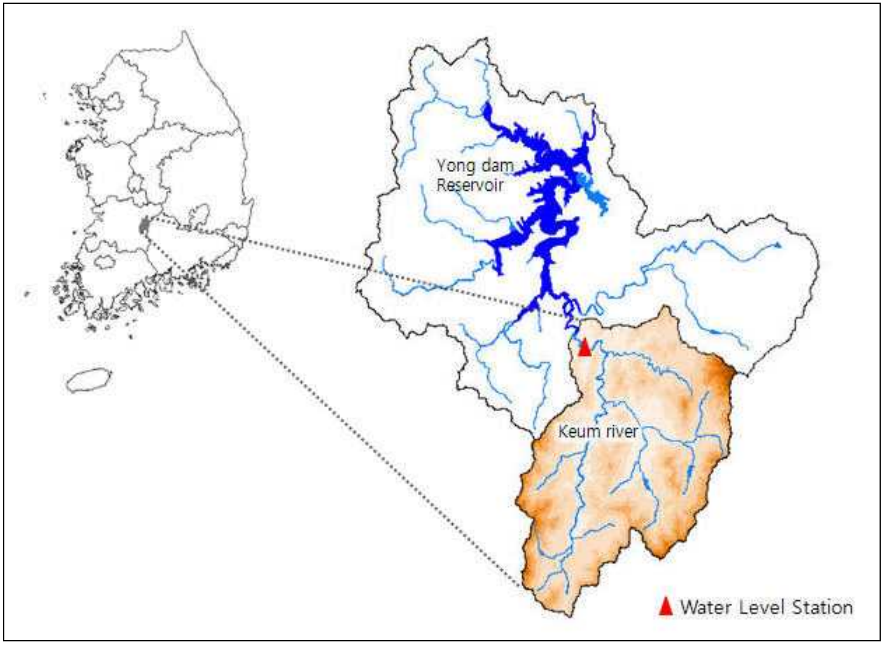


Figure 2. The monitoring stations in the study area

Runoff and water quality

The runoff and water quality were measured for the calibration and validation of the model. The water level stations were shown in Figure 2 and the daily runoff data were also supplied in these stations. The Geum River environment research center has been analyzing the water qualities for 30 times at that point. The measurement data in 2007 were used for the model calibrations. The runoff and water quality in 2006 were verified by the model.

Results and Discussion

Calibration and Validation

Runoff

The data of water level station within the watershed in 2007 was used for the calibration of the model. The R^2 of runoff calibration was estimated by 0.96. The results of runoff validation in 2006 led to the 0.92 of R^2. The simulation data were similar with the measurement data.

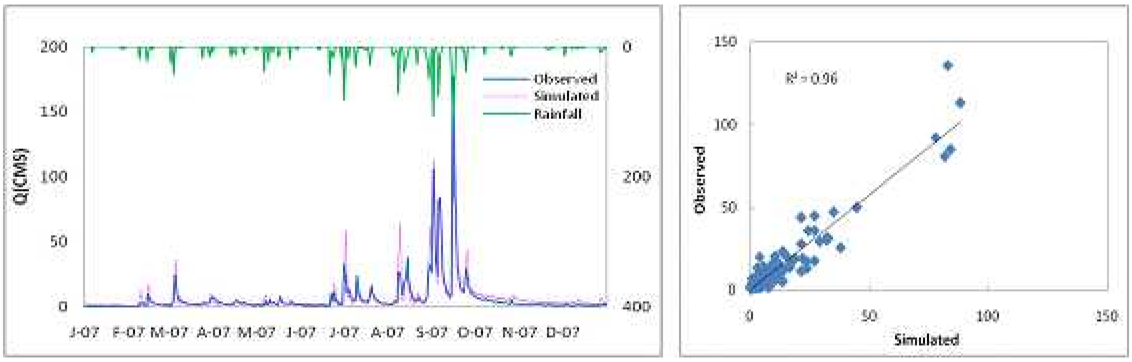


Figure 3. Calibration of runoff.

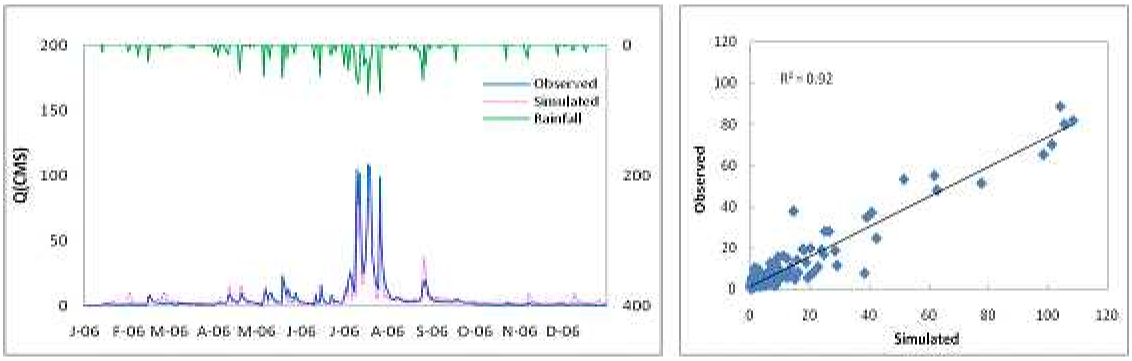
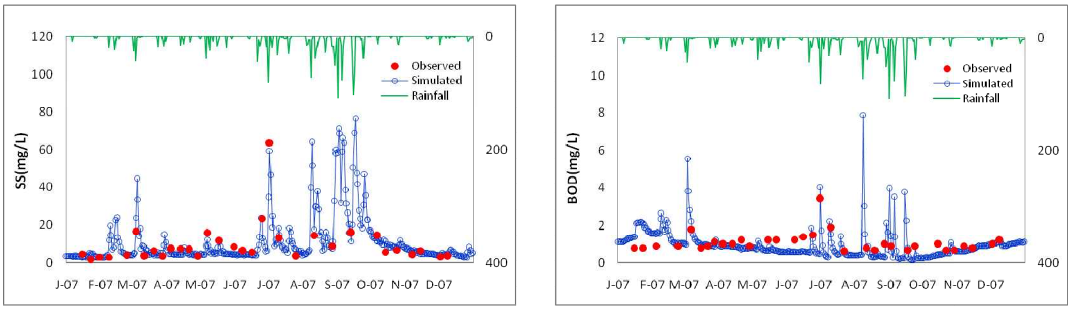


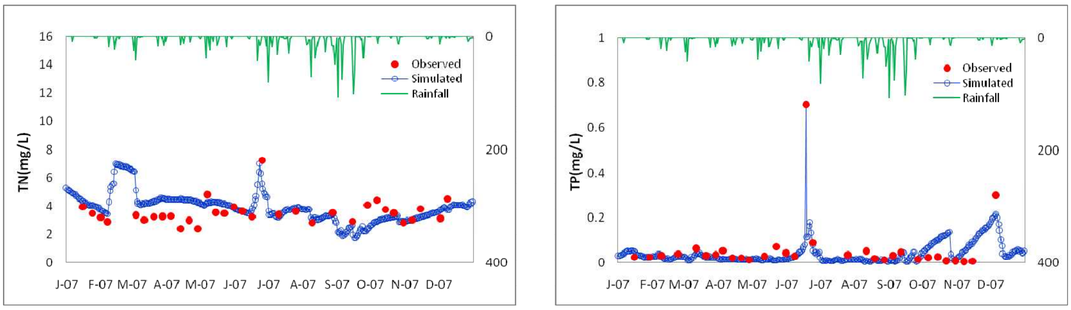
Figure 4. Validation of runoff.

Water quality

The SS was chosen at the first calibration parameter and then BOD, TN and TP were calibrated as the order of the calibration process. Since the SS were influenced by the sedimentation, the SS data were calibrated with the measurement data during the rainfalls. The other outputs such as BOD, TN, TP were calibrated with the adjustments of coefficients. The calibration results of R^2 showed 0.91 of SS, 0.59 of BOD, 0.42 of TN and 0.90 of TP. However, the validation of water quality parameters resulted that R^2 presented the 0.49 of SS, 0.72 of BOD, 0.22 of TN, and 0.26 of TP. There was the difference between calibration and validation data but pattern of water quality in the simulation was similarity to that in the measurement data.

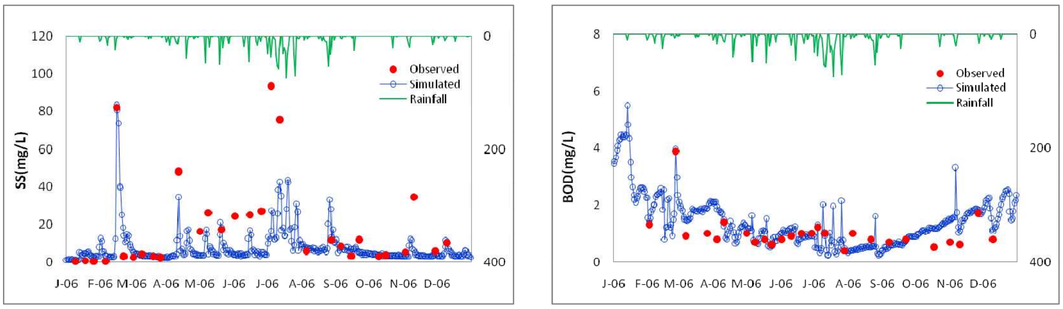


(a) SS (b) BOD

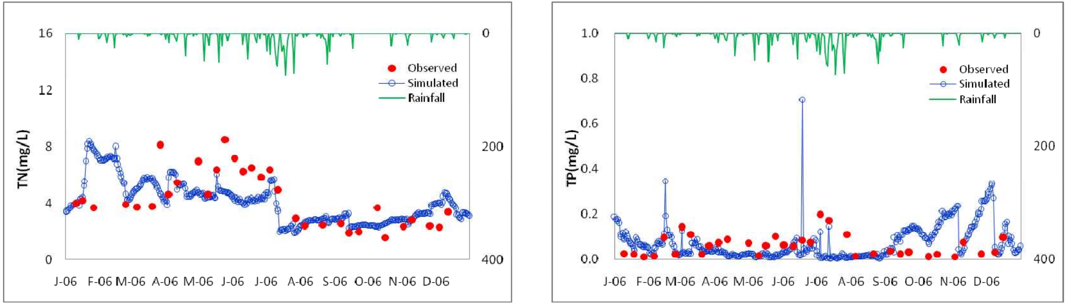


(c) TN (d) TP

Figure 5. Calibration of water quality.



(a) SS (b) BOD



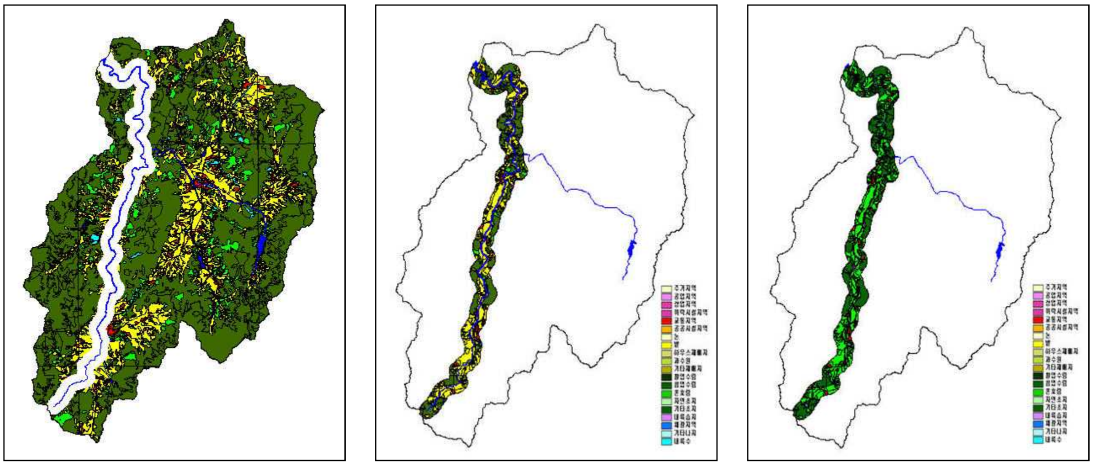
(c) TN d) TP

Figure 6. Validation of water quality.

The removal rates of nonpoint source pollutants in the buffer strips

The status of buffer strips in the study area

The objective of the study was to estimate the removal rates of nonpoint source pollutants in the buffer strips. The create buffer function in the ArcView GIS 3.2a was utilized for the construction of buffer strips in Figure 7. The widths of buffer strips were designed with 500m along the rivers. The buffer strips were constructed excluding the sewage treatment areas, urban areas, the limit areas of construction, and military protection areas. The capacity of pollutant removals was shown with the various change of landuse in Figure 7. The landuse pattern was changed in the several assumptions. Excluding the construction of buffer strips, woodland areas were not changed within the study areas and agricultural areas were changed into the grass areas. The SS, BOD, TN, and TP in SWAT model were simulated with the consideration of landuse pattern changes.



(a) Riparian buffer strip (b) Composition of buffer strip (c) Modifying of buffer strip

Figure 7. Buffer strip in the study area.

Table 3. Landuse pattern of buffer strips in the study area.

(Unit : ㎢)

Landuse	Before	Proportion(%)	After	Proportion(%)
Paddy	7.97	26.49%	0.00	0.00%
Field	6.40	21.22%	0.00	0.00%
Forest	13.21	43.87%	27.64	91.81%
Wetland	0.61	2.03%	0.61	2.03%
Mining area	0.00	0.00%	0.00	0.00%
Bare patches	0.07	0.23%	0.00	0.00%
Others	1.85	6.16%	1.85	6.16%
Total	30.11	100.00%	30.10	100.00%

Simulation results of pollutants removals

The removal rates of pollutants in the buffer strips were estimated with the runoff and nutrients by the comparisons of before and after the buffer strips constructions. The results of pollutants removals were shown in table4, and Figure 8~9.

The removal rates were 11.5% of SS, 9.5% of BOD, 1.2% of TN, and 4.5% of TP. During the rainy, SS was removed by 92.3% and the removals of BOD, TN, TP were 91.2%, 82.4%, and 83.5%. This meant the pollutants were removed over 80% by the buffer strips. Under the dry days, the removal rates were 9.5% of SS, 9.2% of BOD, 7.1% of TN, and 6.9% of TP. The role of buffer strips was the effectively removal of pollutants during the rainy days. Especially, the removal rate of TN was low. This resulted from the inflows of TN in the ground water. The SS was effectively removed by the decrease of surface flow and protection of sediment inflows although the areas of buffer strips were not big enough to remove the SS. Buffer strips made the role of protection of soil erosions.

Table 4. The pollutants removal efficiency of the buffer strip.

(Unit : ton/yr)

Type	SS	BOD	TN	TP
Before buffer strip structure	8,215.3	435.8	547.9	10.1
After buffer strip structure	7,270.5	394.4	541.3	9.6
Removal efficiency (%)	11.5	9.5	1.2	4.5

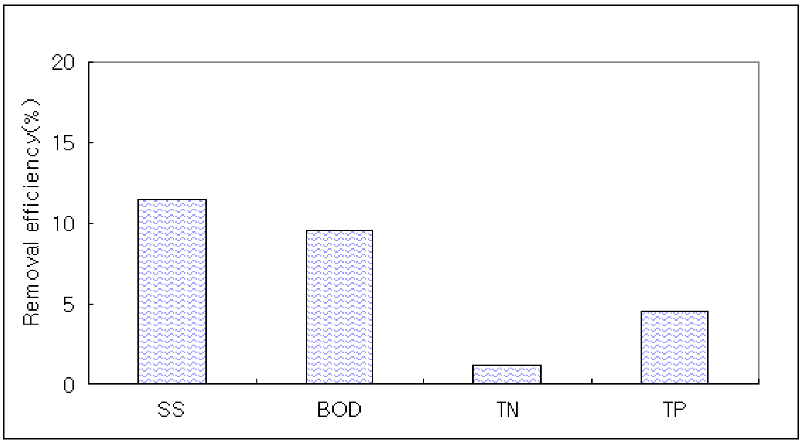


Figure 8. The pollutants removal efficiency of the buffer strip.

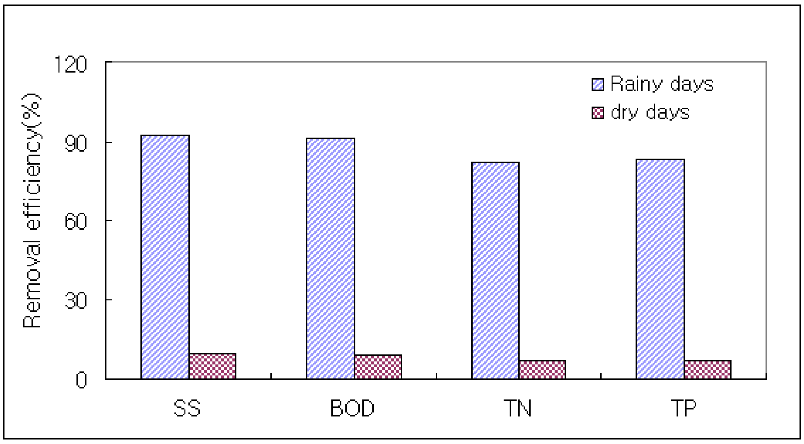


Figure 9. The pollutant removal efficiency in the buffer strips during the rainy season.

Conclusions

To protect the direct inflows of pollutants into the streams, buffer strips were constructed to improve the water quality with the consideration of self purification in the streams. The SWAT was simulated with the areas from the source of Geum River to the inlet of Yongdam reservoir.

1. If the buffer strips were constructed by the study assumptions, removal rates were 11.5% of SS, 9.5% of BOD, 1.2% of TN and 4.5% of TP under the rainfall conditions of 2007.

During the rainy days, most water quality parameters were removed over 80% such as 92.3 % of SS, 91.2% of BOD, 82.4% of TN, and 83.5% of TP.

2. Rainfall resulted in the soil erosions and led to increase the SS concentrations. Thus, the construction of buffer strips protected the SS inflows into the streams. TN concentrations would be influenced by the inflows of ground water.

Acknowledgements

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SESSION A2

Hydrology (2)

A2-4

Analyzing Water Resources in a Monsoon-driven Environment – an Example from the Indian Western Ghats

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Abstract

In India water availability is typically dominated by a pronounced seasonality resulting from the monsoon-driven rainfall regime. Besides this environmental situation, many regions show an increasing water demand due to rapid population growth, industrial development, and intensified (irrigation) agriculture. Such a situation is particularly the case in the meso-scale catchment of the Mula and the Mutha river (2036 km²), located in the Western Ghats upstream of the fast growing city of Pune.

In this study a coarse resolution (1 km) general and a high resolution (30 m) current land use map were used to derive recent land use changes and their impacts on the catchment hydrology, particularly evapotranspiration. SWAT was used to set up two watershed models based on the different land use maps. A focus is set on the use of freely available data from international archives and remote sensing.

Our first findings show the relevance of using high resolution remotely sensed data to evaluate land use changes. Based on these data SWAT allows to evaluate impacts on water availability, especially in agricultural areas. Crop specific evapotranspiration rates and leaf area development were reasonably modeled. However, further improvements regarding soil parameterization and forest transpiration are necessary.

KEYWORDS: SWAT, remote sensing, land use change, evapotranspiration, India

Introduction

Monsoon-driven environments are characterized by a pronounced seasonality of water and energy fluxes. This seasonality has an important impact upon the regional water availability. Many regions in India show rapid population growth and industrial development, which result in an increasing water demand as well as in changes in land use patterns and land management procedures. The recent changes in land use and land management may lead to increasing water shortage and conflicts of interest between different stakeholders as well as between upstream and downstream water users. This situation is particularly the case in the meso-scale catchment of the Mula and the Mutha river (2036 km²), located in the Western Ghats upstream of the fast growing city of Pune (18.533° N, 73.85° E; Figure 1). It is a sub-basin and source area of the Krishna river, which drains towards the east and into the Bay of Bengal.

The catchment has a tropical wet and dry climate that is characterized by seasonal rainfall from June to October and low annual temperature variation with an annual mean of 25° C in

Pune. There is a pronounced west (2500 mm) to east (750 mm) decline of annual precipitation in the catchment (Biggs et al. 2007, Immerzeel et al. 2008), likewise the relief declines from 1300 m on the top ridges in the Western Ghats to 550 m in Pune. Agriculture in the Mula-Mutha catchment is characterized by complex spatio-temporal patterns of land use and land management. Land use patterns are dominated by small fields (< 1 ha) with rain-fed agriculture during the monsoon season and irrigation during dry season. Typically two crops per year are harvested. Kharif crops are grown from June to October, Rabi crops from November to March. In a few locations, where irrigation water supply is sufficient in April and Mai, summer crops are grown.

The aim of our research is to analyze the impact of changes in land use on the water resources and to investigate the relevance of using up to date remote sensing data to assess changes in water fluxes. The specific goal of this study is to analyze the effects of utilizing different data sources upon the modeled water fluxes. To this end, we used freely available land use data from international archives and compared these with results obtained using our land use classification.

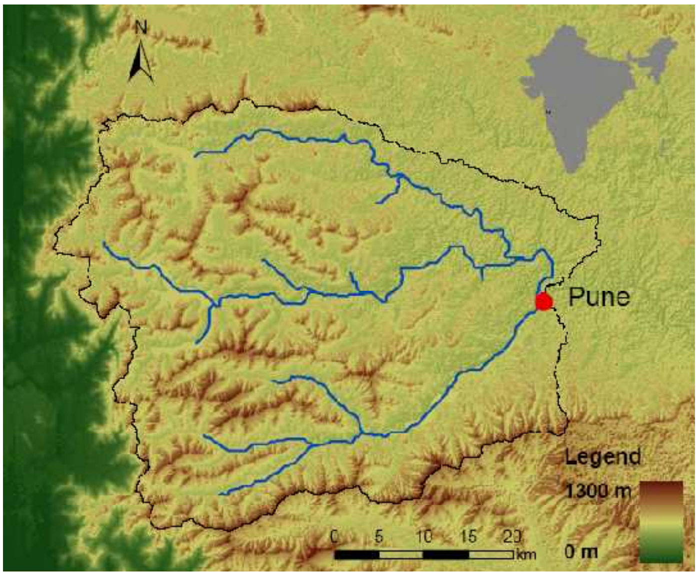

Figure 1. Mula-Mutha catchment

Optical remote-sensing data for 2009 were used to derive current land use information. The land use classification derived from LISS-III data was validated with field measurements. Field surveys during Kharif and Rabi season served to derive typical crop rotation patterns. By comparing the model results obtained using generally available land use data with the model results obtained using our land use classification, we investigate if the recent land use change has lead to significant changes in water fluxes, particularly in evapotranspiration (ET). The study was carried out with the help of the Soil and Water Assessment Tool (SWAT, Arnold et al. 1998). The derived model was not calibrated, to assess the potential of hydrological modeling under limited data availability.

Materials and Methods

The SWAT model has proven its capability to model water fluxes also in regions with limited data availability (Ndomba et al. 2008; Stehr et al, 2008). Although environmental data is generally available in India, data access is sometimes limited and often time consuming. Due to the rapid change of the environment in India available data are quickly outdated. Moreover, generally available data are often limited with respect to spatial resolution, timeliness and level of accuracy and detail. The following sections provide information on the input data including pre-processing details and model specifications.

Digital elevation model

A suitable digital elevation model (DEM) is an essential prerequisite for hydrological model studies. We used a DEM which is based on ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite data with a spatial resolution of 30 m. Four readily processed DEMs, calculated from stereo images of the near infrared band, were acquired from U.S. Geological Survey. To cover the entire study area these four ASTER DEMs were merged. Water surfaces are poorly represented in DEMs derived from optical satellite data. To determine water surfaces a Landsat 7 ETM+ scene was used and the water levels were derived from the ASTER elevations of the reservoir banks.

Compared to the 90 x 90 m SRTM DEM the ASTER DEM has a mean offset in elevation of 13.6 m. After correcting for this offset the mean absolute error, which indicates the mean deviation from the SRTM DEM, is 8.78 m, while the root mean square error is 15.29 m. The most pronounced differences can be observed in the mountain ranges, which typically result from the different spatial resolutions. The major advantage of the higher spatial resolution is a more accurate representation of slopes and the possibility to derive a more detailed stream network. The accuracy of the calculated stream network was confirmed by the drainage maps acquired from Groundwater Department Pune.

Soil map

The soil map and parameterization was derived from the digital Soil Map of the World (FAO 2003). Two soil types can be identified in the catchment. 92.5 % of the study area is covered by a sandy clay loam (Hh11-2bc, Haplic Phaeozem) and 7.5 % by a clay (Vc43-3ab, Chromic Vertisol). Texture, layer depth, saturated hydraulic conductivity, available water capacity and water conductivity were adapted from Immerzeel et al. (2008). Bulk density and organic carbon content were derived from the FAO Soil Map of the World (2003).

Weather data

Weather data from the Indian Meteorological Department (IMD) weather station in Pune (ID 430630, 18.533° N, 73.85° E, 559 m) were used for the model. In addition, three rainfall measurement stations that are maintained during the rainy season by Tahasil (sub-district administrative division) offices complete the record of precipitation in the catchment. Due to the significant and systematic differences of rainfall (east to west rainfall gradient, Biggs et al. 2007, Immerzeel et al. 2008) in the catchment, using the standard method of assigning the nearest station to represent the precipitation in the sub-catchment leads to large errors. Therefore virtual weather stations were generated for each sub-basin and the precipitation for these virtual stations was estimated from the four measurement stations (Figure 2) using the relationship of precipitation and elevation. First a linear trend of elevation and mean daily rainfall amount was calculated from the four measured stations. Using this trend and the mean elevation of every sub-basin the mean daily rainfall amounts for every sub-basin were estimated. The residual of daily rainfall (daily rainfall – mean daily rainfall) was calculated for every wet day and every measurement station. These residual values were interpolated to the centre of each sub-basin using an inverse distance weighting scheme. Finally, by adding the interpolated residuals to the mean daily rainfall values calculated from the regression equation a consistent precipitation record has been produced for every sub-basin. To account for temperature differences in the catchment, temperature values were adjusted for every sub-basin using the adiabatic temperature gradient of 0.98°C/ 100 m on a dry day (no precipitation) and of 0.44°C/ 100 m on a wet day (Weischet 1995). Using the sub-basin specific temperature record relative humidity values were calculated from the specific humidity measured in Pune. Solar radiation and wind speed data from Pune was used for the whole catchment. In the two sub-basins where measured data was available, the measured data was used instead of the interpolated data from the virtual stations.

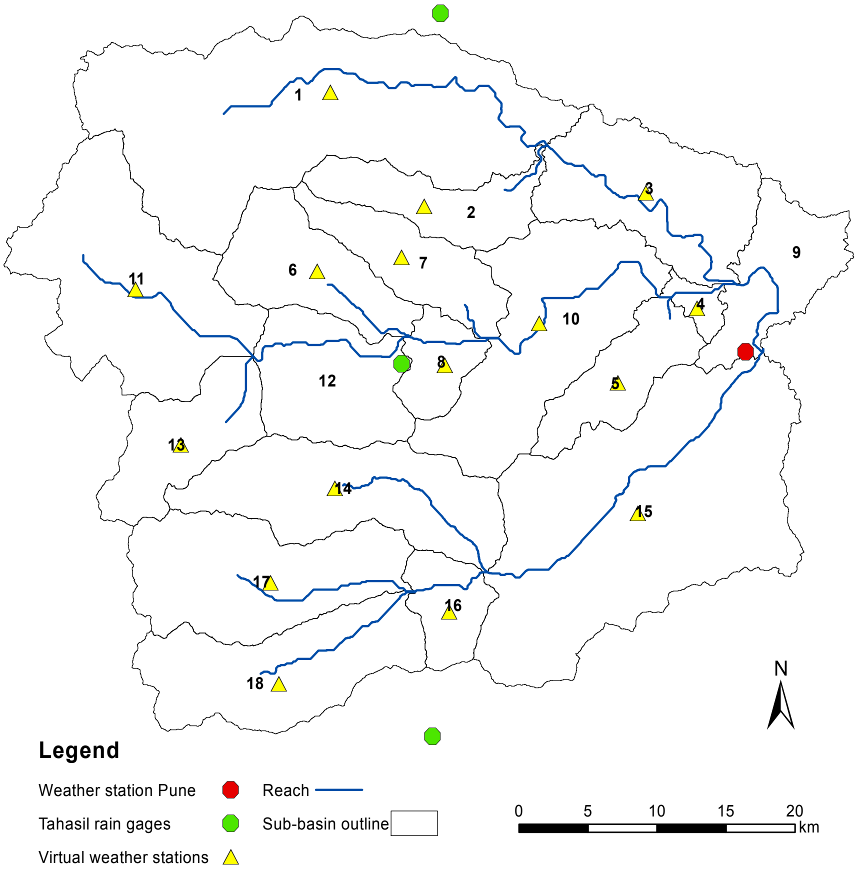

Figure 2. Locations of weather stations and virtual weather stations in the Mula-Mutha catchment

Land use maps

The current land use map was derived from satellite data. The satellite image was taken by the Linear Imaging Self-Scanning Sensor III (LISS-III) on the Indian satellite IRS-P6. LISS-III is a medium resolution multispectral sensor with two bands in the visible, one in the near infrared and one in the shortwave infrared region. All bands provide a resolution of 23.5 m. For the classification all four bands of a LISS-III image dated from 30th November 2009 were used. A stratified knowledge-based classification approach, using a Maximum Likelyhood classifier was applied. Thresholds of elevation (800 m) and slope (10 %) have been set for agriculture to avoid false classification in the mountain ranges. Pixels classified as agriculture in areas exceeding these thresholds were converted to grassland.

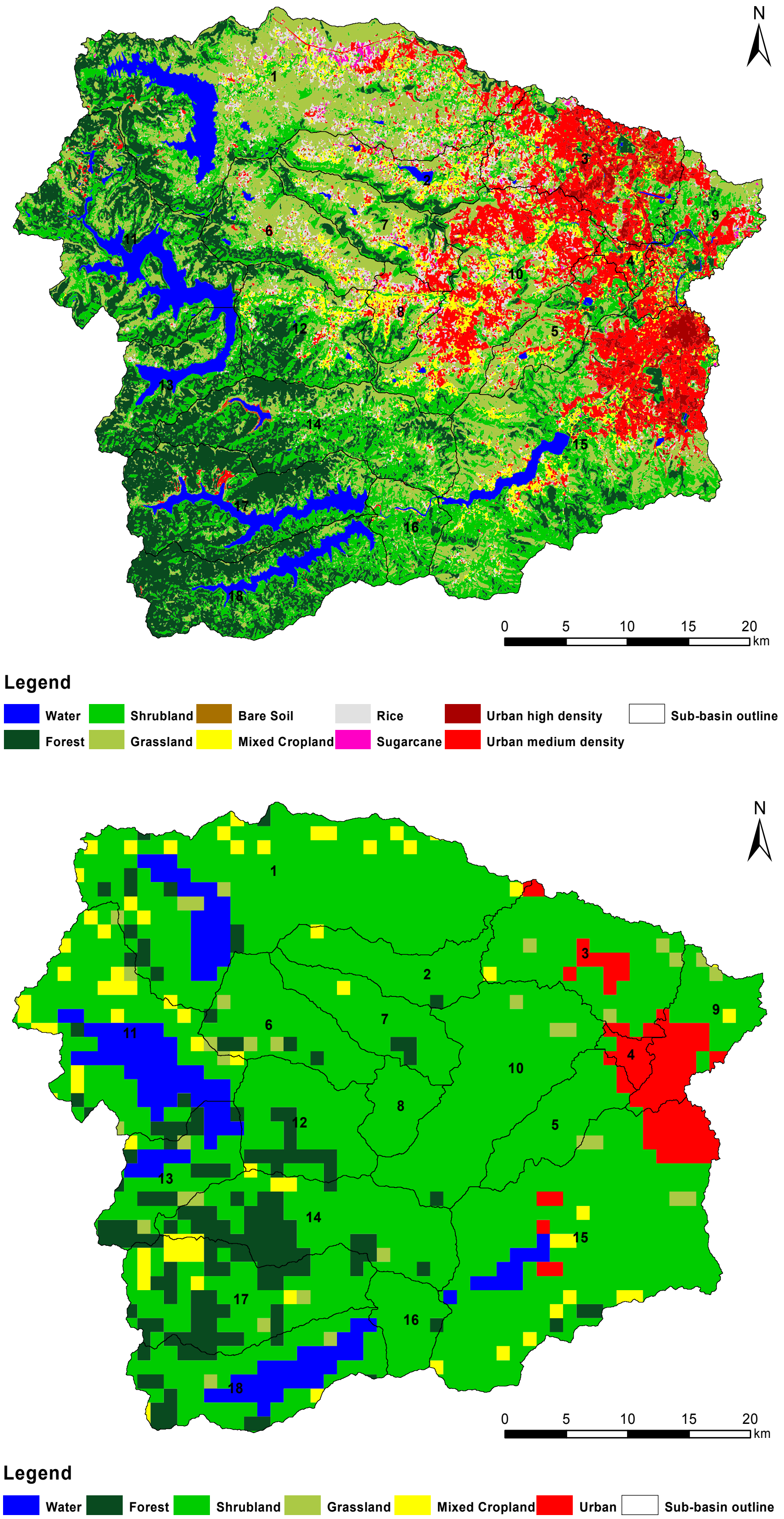

Figure 3. Current (above) and general (below, data adapted from Hansen et al. 1998) land use map of the Mula-Mutha catchment

Finally a majority analysis has been applied to remove spatially singular pixels. Ground truth mapped between 20th September and 9th October 2009 was used from three test sites. The time gap between ground truth and satellite image resulted from the need for a cloud-free image. Despite this the classification has a good quality with an overall accuracy of 79 %. For this study we have distinguished rice and sugarcane from the general agricultural class. Consequently the overall accuracy decreased to 65 % due to the higher level of detail.

A global land cover classification (Hansen et al., 1998) was used as a general land use reference. It is based on AVHRR satellite images that were acquired between 1981 and 1994 and has a spatial resolution of 1 km. To obtain categories that are congruent with our land use map the classes wooded grassland, closed shrubland, open shrubland were combined to one shrubland class. The woodland class is the only forest type in the catchment and was therefore reclassified as forest. General and current land use map are shown in Figure 3.

Model specifications

For both land use maps a model was set up. Apart from the land use input the model specifications are the same for the GEN (using the general land use map) and the CUR (using the current land use map) model. The confluence of the Mula and Mutha river in Pune was chosen as the catchment outlet. The 2036 km² catchment was divided into 18 sub-basins. The drainage network was calculated from the DEM. Canals and reservoirs were not modeled and the model was not calibrated. Three slope classes were distinguished: 0-5 %, 5-10 % and above 10 %. Minimum thresholds of 10 % were set for soils and slopes, resulting in 250 Hydrological Response Units (HRUs) in the GEN and 610 HRUs in the CUR model. The default value for Manning's n (0.014) was applied. Heat units to bring a plant to maturity were calculated and adjusted to the growing periods of the local crops. For runoff generation the SCS curve number method was applied and potential ET was calculated using the Penman-Monteith equation. The model was run for eight years from 2000 to 2007. Only seven years of the simulation period (2001-2007) were analyzed, allowing for a one year model spin-up phase.

The chosen model plant types and management of the vegetation land use classes are given in table 1. Shrubland is modeled as a mixture of forest and grassland to account for the percentage of trees. The maximum LAI for deciduous forests was modified (BLAI = 6) using the LISS-III satellite image and relations of NDVI and LAI observed by Madugundu et al. (2008). To diminish the effect of the modeled dormancy period for trees which is modeled by SWAT to occur at the wrong time of the year, the LAI during dormancy parameter was set to the highest possible value (0.99). Two of the general crop classes in SWAT (AGRL, AGRR) contribute equally to the modeling of mixed cropland. The bare soil class was split between agriculture and grassland, as some fields were harvested and bare, when the satellite image was taken. For the rice fields the typical crop rotation of growing rice in Kharif season and wheat in Rabi season was implemented. This rotation was the only crop rotation pattern that was clearly observable from the field surveys. A growing period of 18 month was realized for the modeling of sugarcane. For all crops auto-irrigation has been initialized. The irrigation procedure is based on plant water demand, triggering irrigation when plant growth falls below 95 % of potential plant growth. The water for irrigation is taken from the reaches. A fraction of two thirds is allowed to be used for irrigation purposes, which is in agreement with the percentage of surface water used for irrigation in Pune Division (districts of Pune, Sangli, Satara, Solapur and Kolhapur) (Bhagwat 2006). Apart from stream flow, wells and reservoirs are water sources for irrigation in the study area. Therefore the applied irrigation management is strongly generalized, but within the scope of this study a reasonable first approximation. To evaluate the effectiveness of this methodology a second model run was performed applying sufficient water from an outside source (40 mm per month in Kharif, 100 mm per month in Rabi season). For auto fertilization elemental nitrogen has been used.

Table 1. Model setup for the land use classes

Land use	SWAT-Plant-Code and management details
Forest	FRSD, modified BLAI, ALAI_MIN, BIO_LEAF
Shrubland	70 % BERM: see grassland, 30 % FRSD: see forest
Grassland	BERM: two growth cycles in rainy season, one in dry season
Bare soil	50 % BERM: see Grassland, 50 % AGRL: see mixed cropland
Mixed Cropland	50 % AGRR, 50 % AGRL: all grown as Kharif and Rabi crop, auto irrigation, auto fertilization
Rice	RICE as Kharif crop, SWHTas Rabi crop: auto irrigation and fertilization in both seasons
Sugarcane	SUGC: 18 month period of growth, auto irrigation, auto fertilization

Results

Land use changes in the Mula-Mutha catchment

Table 2. General and current land use in the Mula-Mutha catchment

Land use	General	Current
Forest	8.49 %	20.61 %
Shrubland	74.76 %	26.60 %
Grassland	1.87 %	22.78 %
Water	6.94 %	5.78 %
Mixed Cropland	3.63 %	11.17 %
Urban	4.32 %	13.07 %

A comparison of the two land use maps shows the effects of land use change within the last 15 years as well as effects of different degrees of detail of the used data sets. Figure 3 and table 2 indicate an increase of urban area and a higher percentage of agriculture in the current land use map. Whereas the urban increase is linked to the fast growing of the city of Pune, the agricultural increase is most likely in part a result of the different spatial resolutions of the two maps. Small fields, which are very common in the study area, are often separated by tree lines and obviously hard to identify at a 1 km resolution. With regard to forests, grasslands and shrublands there are similar percentages in the current land use map, while forest and grassland percentages are significantly smaller in the general land use map. The prevalence of shrubland in the general land use map could be seen as a lack of detail. The class of shrublands includes characteristics of forests and grasslands. On a coarse resolution this could lead to an overestimation of shrublands. The finer 30 m resolution allows for the determination of these classes more accurately. While the differences between the two land use maps regarding forests, grasslands and shrublands probably arise from the different classification methodologies and should not be interpreted as land use changes, the difference of their sum can be related to land use change. Forests, shrublands and grasslands account for 85.12 % in the general land use map and for only 69.98 % in the current land use map. This 15.14 % decrease is mainly due to urbanization and in part related to an increase of agricultural area.

In summary increase of urban and cropland and a consequential decrease of semi-natural vegetation can be identified as the main land use change. Due to the different methodologies in generation of the maps and their different spatial resolutions, these changes can be only partly linked to real land use change. Therefore the results of this study show the impact of land use change and the impact of using more detailed land use data on catchment hydrology.

Impact on the catchment hydrology

First results show that the water balance of the two model runs agrees well with results for similar catchments in the Western Ghats region. The runoff coefficient, which is the fraction of precipitation that appears as runoff, is similar to observed runoff coefficients in the upper

Krishna basin (GEN 0.61, CUR 0.63, upper Krishna 0.68). The catchment of the upper Krishna used for this comparison is located about 100 km south of the study area (Biggs et al. 2007). The plant development indicated by the leaf area index (LAI) is reasonable for crops and grassland. Due to the dormant period for deciduous trees, LAI of forests is very low during the dry season (0.99). The time trees enter dormancy in the SWAT model is linked to latitude and daylength (Neitsch et al. 2005). The shortest day of the year triggers the beginning of tree dormancy in the model. However in our region dormancy is related to water and temperature stress, which occur at another time of the year. This may result in an underestimation of forest evapotranspiration. Compared to the ET sums calculated by Immerzeel et al. (2008) for the dry season, our results are about 250 mm lower. Two reasons contribute to this difference: The coarse land use map used by Immerzeel et al. shows mainly forests in our study area, which are modeled as evergreen or mixed forests in his model and obviously allow for higher ET during the dry season, than grass- or shrublands. On the other hand the soils in our model dry up by December. Thereafter the ET of forests is close to zero.

Focusing on the two different model runs and the impact of land use changes, the water balance components do not show eminent differences on the catchment level. Though, we observe differences, when comparing land use specific ET rates and their annual distribution. Figure 4 shows mean monthly ET rates for the different land use classes in the crop year 2004/05. As these were very similar in both runs, only data from the CUR model is shown. In October and November the ET of mixed croplands and the rice-wheat rotation is lower than the ET of grasslands, due to harvesting at the end of Kharif and sowing at the beginning of Rabi season. In January and February it is higher, resulting from the growth of Rabi crops.

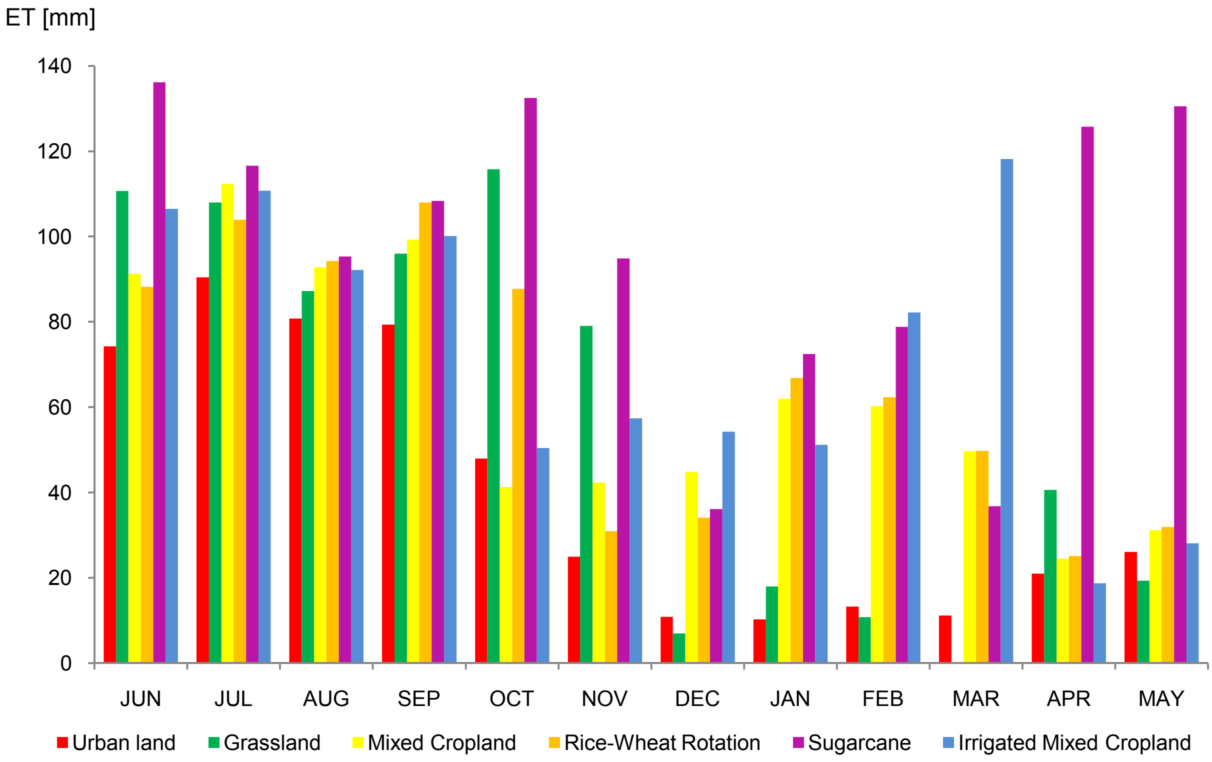

Figure 4. Mean monthly evapotranspiration (ET) rates for different land uses from June 2004 to May 2005 modeled with the current land use data set

A change from grassland to cropland therefore results in a change of evapotranspiration patterns and a slightly higher annual ET. In our study this effect is compensated by the comparatively low ET rates of urban land. The increase of cropland (7.54 %) and the increase of urban land (8.75 %) take a balancing effect on annual ET in our model comparison. ET rates from cropland are higher during the dry season, if the irrigation amount is not limited by water availability in the reach of the sub-basin (see Irrigated Mixed Cropland in Figure 4). Still the effect on the catchment level is limited due to the small increase of cropland and the compensating increase of urban land. Sugarcane shows the highest ET rates but has a negligible effect on total ET, as it covers only 0.75 % of the study area. Nevertheless, the ET rates from sugarcane show the increased water demand of a crop that is grown year-round. The large sugarcane fields downstream of Pune rely on irrigation water from the Mula-Mutha catchment. This year-round water demand has to be met by water provided by the dams in the catchment.

Conclusion

In this study two models were set up to evaluate the impact of land use change on ET in a meso-scale catchment in the Indian Western Ghats. The SWAT model runs were capable of reasonably representing ET for most land use classes in this monsoon-driven environment. Runoff coefficients were in agreement with a similar nearby catchment. Reasonable LAI development and ET rates indicate a successful incorporation of local crop rotations and irrigation management. As the model was not calibrated and a very coarse soil map was used, the representation of soils and groundwater is probably not very accurate. This model limitation becomes obvious during dry season, when the soils dry up completely and do not allow for forest growth and ET.

The comparison of the two land use maps shows an increase in agriculture and in urban land. The higher percentage of agricultural area in our land use map is not only a result of real land use change but is most reasonably an effect of using more detailed land use data. The small fields, which are very common in the study area, are often separated by tree lines and hard to identify at a 1 km resolution. High resolution data is needed to investigate the recent changes and answer questions on recent and future water availability. The observed differences of the land use maps do not show a strong effect upon the annual water balance due to compensatory effects of an increase in ET, resulting from increased agriculture in some areas, and a decrease of ET, resulting from urbanization in other regions. While the changes at the catchment scale are small, they are significant at the sub-catchment scale. Also, it can be assumed that the effect of the significant area increase of sugarcane cultivation downstream of our study area results in an increase in water demand and aggravates conflicts of interest between upstream and downstream water users.

Furthermore, we expect a significant increase in model accuracy and degree of spatial detail by assimilating remote sensing data to better assess vegetation effects. Our future work will focus on the derivation of more detailed land use maps (30 m resolution) from historical satellite scenes (Landsat), which allow investigation of recent land use change and its impacts on the water balance components. Moreover, multi-temporal satellite data will be used to improve the current land use map and to provide spatially detailed information on crop rotations. The representation of the soils in the model needs further examination, including calibration of groundwater parameters. Plant growth will be optimized by validation of LAI development with satellite data using NDVI – LAI relationships and by a shift or deactivation of the dormancy period implemented in SWAT. Implementation of reservoirs is essential for a better representation of the catchment hydrology, especially for irrigation management during the dry season and for runoff modeling. This is particularly important with regard to questions of water distribution between agricultural (food crops or cash crops), industrial and residential use, that are becoming more relevant with increasing water demand.

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A2-5

Evaluation of Mixed Forest Evapotranspiration and Soil Moisture using Measured and SWAT Simulated Results in a Hillslope Watershed

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Abstract

This study is to evaluate the SWAT soil moisture, evapotranspiration and streamflow by comparing with the measured data in a 8.54 km^2 hillslope watershed of South Korea. By using 2007 daily streamflow at the watershed outlet, 3 months daily evapotranspiration and 6 months soil moisture data measured at mixed forest, the SWAT model was calibrated. The uncertainty of soil moisture parameters, available soil water capacity, soil bulk density, and soil evaporation compensation coefficient, and the evapotranspiration parameters, plant uptake compensation factor, soil evaporation compensation factor, and maximum canopy storage were interpreted by the measured data during the calibration. The model was validated with 2008 streamflow, evapotranspiration and soil moisture, and 4 years (2003-2006) streamflow. The coefficient of determination (R^2) for soil moisture and evapotranspiration were 0.67 and 0.57, and the R^2 and Nash-Sutcliffe model efficiency for streamflow were 0.76 and 0.77 respectively.

KEYWORDS: soil moisture, evapotranspiration, streamflow, measured data, SWAT

Introduction

The typical parameter calibration of hydrological models has been accomplished by using the measured streamflow with temporal events and multi-site data if available. This kind of calibration method was generally accepted to lumped models as the state variables such as evapotranspiration (ET) and soil moisture (SM) are treated as averaged values in a watershed. In many SWAT modeling researches, the streamflow was the single most commonly used watershed response variable (Arnold and Allen, 1996). However, considering numerous sources of uncertainty and the complexity of recently developed models, the approach often has errors to generate consistent parameter sets (Bastidas et al., 2003).

One of possible methods to reduce calibration uncertainty is to utilize of additional observation data (Ambroise et al., 1995). Bastidas et al. (2003) used point measurements of near-surface soil moisture and temperature as well as heat fluxes to constrain the land surface model parameters via multi-objective calibration. The compromise solution was found from a set of Pareto optimization results. They found that additional data increased the model consistency but the accuracy of soil moisture and temperature simulations deteriorated with depth. As the recent models have been developed to reflect spatially distributed information of the watershed viz. elevation, soil, and land use, the model calibration became possible with the measured state variables in addition to the measured streamflow. To utilize additional observation in the process of spatial model calibration can reduce the uncertainty of model parameters related with the state variables, and explain the hydrological behaviors more confidentially within the watershed.

This study is to evaluate the SWAT model by using measured ET and SM in addition to the streamflow at the watershed outlet, and discuss the model parameters that were identified through the spatial calibration. The evaluation is expected to improve the ability of model predictions.

Material and Method

SWAT model description

The SWAT is a physical bases and continuous-time, conceptual, long-term, distributed-parameter model designed to predict of land management practices on the hydrology, sediment and contaminant transport in agricultural district. The watershed is subdivided into subbasins based on the number of tributaries. Size and number of subbasins is variable, depending on stream network and size of the entire watershed. The subbasin is further disaggregated into classes of Hydrological Response Units (HRUs), whereby each unique combination of the underlying geographical maps (soils, land use, etc.) forms one class (Ullrich et al., 2009). The hydrologic components (e.g. streamflow, evapotranspiration, soil moisture, etc.), sediment, and nutrient loadings from each HRU are calculated and predicted separately using input data about weather, soil properties, topography, vegetation, and land management practices, and then summed together to determine the total loadings from the subbasin (Neitsch et al., 2001a). The hydrologic routines within SWAT account for vadose zone processes (i.e., infiltration, evaporation, plant uptake, lateral flows, and percolation), and ground water flows.

Study watershed description

The forest-dominant Seolma-cheon watershed (8.54 km^2) located in the northwest of South Korea within the latitude-longitude range of 37°55′25″N-37°56′50″ N and 126°55′30″E-126°57′30″E was adopted as a study area. The watershed stream is one of the main tributaries of Imjin river basin. Elevation ranges average elevation of 247.8 m and average slope of 2.0 %. The watershed consists of 88.1 % forest, 4.6 % upland crop field, 2.2 % urban area, and 5.1 % pasture and bare field. The dominant soils are sandy loam (76.4 %). The annual average precipitation of the watershed is 1,210.0 mm, and the mean temperature is 10.3 ℃ over the last 10 years (1999-2008).

Input and measured data for model simulation

The SWAT model basically requires elevation, land use, soil and meteorological data at desired locations of watershed. The elevation data was rasterized to a 30 m that was supplied by the KNGI (Korea National Geography Institute). The soil information was from 1:25,000 vector map that was supplied by the KRDA (Korea Rural Development Administration). The land use was prepared by classifying the Landsat TM (3rd June 2004) satellite images. The HRUs were created using the spatial information. The daily meteorological data for 6 years

(2003-2008) from 1 weather station and 4 rainfall stations were collected. The mean, maximum, minimum temperature (℃), precipitation (mm), relative humidity (%), wind speed (m/sec), and sunshine hour (hr) were prepared for Penman-Monteith ET calculation. The 2 years (2007-2008) daily soil moisture (SM), evapotranspiration (ET) and the 6 years (2003-2008) daily streamflow (Q) were prepared for model calibration and verification. The data measurement has been managed by Korea Institute of Construction Technology and Department of Atmospheric Sciences, Global Environment Lab. of Yonsei University. The soil moisture was measured by Waveguide of TDR (Time Domain Reflectometry) system buried at sandy loam of mixed forest area with 10 cm, 30 cm, and 60 cm depth from surface. The evapotranspiration was measured by Eddy Covariance observation system at the upper part of mixed forest. It was set on the top of tower (20 m) that is over twice the height of vegetation (9 m).

Results and Discussion

Sensitivity analysis of model parameters for Q, SM and ET

Usually model calibration is undertaken to reduce the uncertainties and inefficiencies associated with the estimation of model parameters. To ensure efficient calibration, a sensitivity analysis is conducted to identify the most sensitive parameters (Kannan et al., 2007). The sensitivity analysis was conducted by LH-OAT (Latin Hypercube -One-factor-At-a-Time) method which combines the One-factor-At-a-Time (OAT) design and Latin Hypercube (LH) sampling. The SCS curve number (CN2) was sensitive to the peak flow and amount of discharge (Q). Increasing CN2 by 20 % resulted in 1.4 % increase of Q and 5 % peak flow. The GW_ DELAY, GW_ REVAP, and Surlag affected the recession phase of hydrograph. The 20 % increase of CANMX increased 1.9 % ET. The 20 % decrease of ESCO decreased ET by 3.8 % and SM by 1.7 %. The EPCO had an inverse relationship with ESCO.

Model calibration and verification

Model calibration is the adjustment of model parameters, within recommended ranges, to optimize the agreement between measured data and model simulation results. The calibration was carried out using 2007 daily streamflow at the watershed outlet, and 4 months (September to December) daily ET and 6 months (June to November) SM data measured at mixed forest area by the personal interpretation of data quality of soil moisture. The winter soil moisture from December to February could not be observed by the frozen field condition. Tables 1 and 2 show the summary of 2007 calibration results for Q, ET, and SM respectively, and Figure 1 shows the comparison of the measured versus simulated Q, ET, and SM. The average coefficient of determination (R^2) and the Nash-Sutcliffe model efficiency (Nash and Sutcliffe, 1970) (E) for streamflow were 0.77 and 0.75, and the R^2 for SM and ET were 0.71 and 0.61 respectively. The model verification was conducted with 2008 streamflow, ET and SM, and 4 years (2003-2006) streamflow data. The results are shown in Tables 1, 2. The average R^2 for SM and ET were 0.67 and 0.57, the average R^2 and the E for streamflow were 0.72 and 0.71 respectively. The difference between model performance in calibration and verification period is because the hydrologic conditions in validation period may change and do not look exactly like the hydrologic conditions during the calibration period (e.g. Beven, 2006; Liu and Gupta, 2007; Zhang et al., 2009a).

Table 1. Summary of streamflow for calibration and verification periods

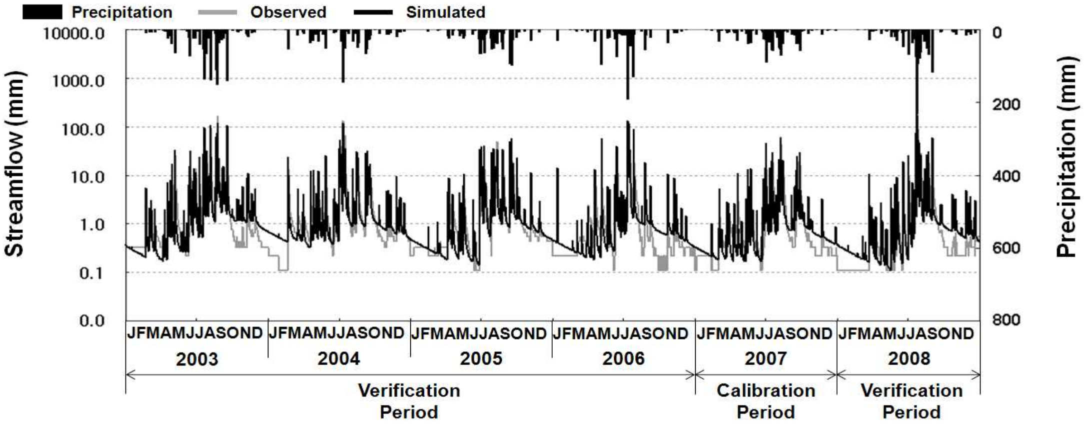
Year	P(mm)	Q (mm)		QR (%)		*E*	R^2	Note
		Obs.	Sim.	Obs.	Sim.			
2007	1262.2	761.0	706.0	60.3	55.9	0.69	0.66	C
2003	1885.0	1534.5	1334.6	81.4	70.8	0.71	0.74	V
2004	1232.5	1091.3	996.1	88.5	80.8	0.73	0.74	V
2005	1300.5	868.1	859.2	66.8	66.1	0.63	0.54	V
2006	1223.0	970.5	982.9	79.4	80.4	0.85	0.85	V
2008	1498.3	941.7	922.8	62.9	61.6	0.83	0.83	V
Mean	1392.9	1029.3	965.0	73.9	69.3	0.76	0.77	-

P: Precipitation, Q: Streamflow, QR: Runoff Ratio, *E*: Nash-Sutcliffe Model Efficiency, R^2: Coefficient of Determination, C: Calibration, and V: Verification

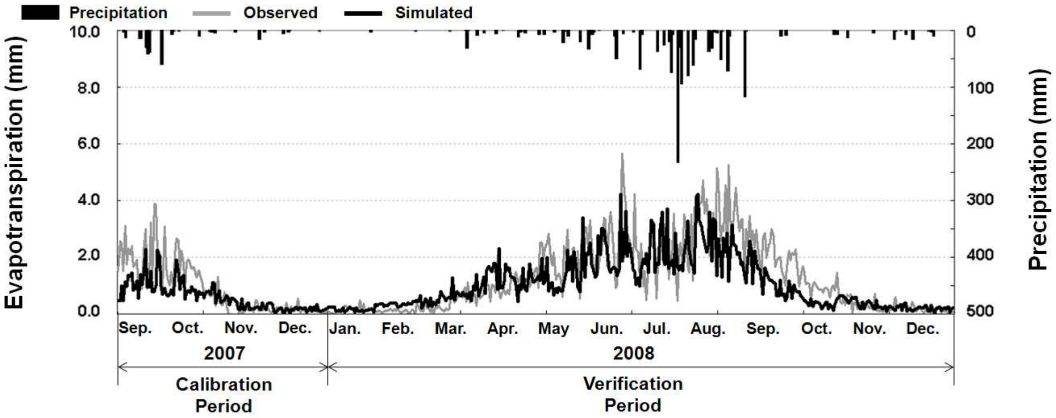
Table 2. Statistical summary of soil moisture and evapotranspiration for calibration and verification periods

Year	P(mm)	SM (%)			ET (mm)			R^2		Note
		Period	Obs.	Sim.	Pedriod	Obs.	Sim.	SM	ET	
2007	1262.2	Jun.-Dec.	13.6	15.2	Sep.-Dec.	109.0	85.7	0.71	0.61	C
2008	1498.3	Jan.-Dec.	10.3	14.0	Jan.-Dec.	471.7	421.1	0.67	0.57	V
mean	1392.9	-	11.9	14.6	-	290.4	203.4	0.69	0.59	-

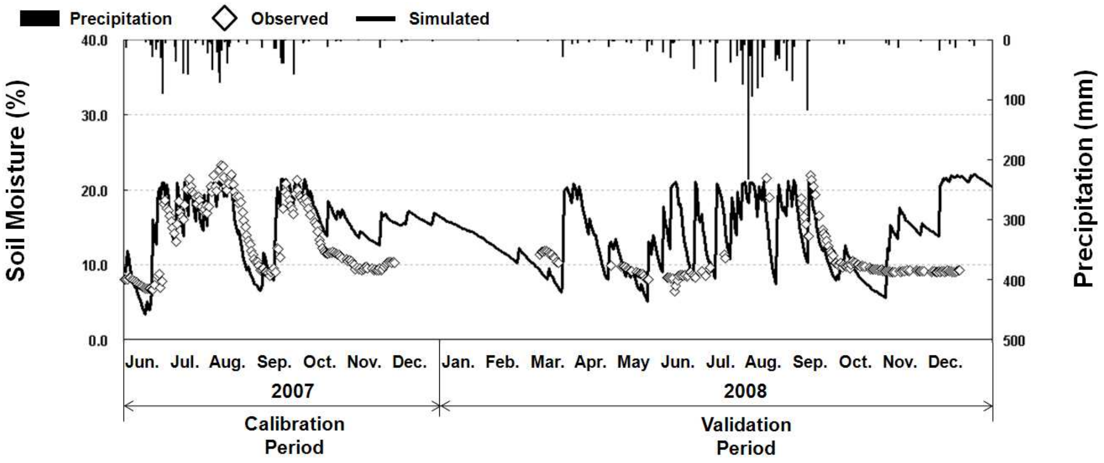
P: Precipitation, SM: Soil Moisture, ET: Evapotranspiration, R^2: Coefficient of Determination, C: Calibration, and V: Verification



(a) Streamflow



(b) Evapotranspiration



(c) Soil Moisture

Figure 1. Comparison of the measured versus simulated streamflow (a), evapotranspiration (b), and soil moisture averaged in depth (c).

Summary and Conclusion

This study was tried to identify the uncertainty of SWAT model parameters by evaluating the model using measured evapotranspiration and soil moisture data. For a 8.54 km^2 hillslope watershed of South Korea, the SWAT model was calibrated using 2007 daily streamflow at the watershed outlet, 3 months daily evapotranspiration and 6 months soil moisture data measured at mixed forest.

The calibration range of soil moisture parameters viz. available soil water capacity, soil bulk density, and soil evaporation compensation coefficient, and the evapotranspiration parameters viz. plant uptake compensation factor, soil evaporation compensation factor, and maximum canopy storage were judged and narrowed by referencing the measured data. The model was well validated with 2008 streamflow, evapotranspiration and soil moisture, and 4 years (2003-2006) streamflow. The coefficient of determination (R^2) for soil moisture and evapotranspiration were 0.67 and 0.57, and the R^2 and Nash-Sutcliffe model efficiency for streamflow were 0.72 and 0.71 respectively.

Application of the uncertainty estimation model indicates that the streamflow simulation is fairly consistent in that the uncertainty bounds are ‘narrow’. In contrast, evapotranspiration and soil moisture prediction of SWAT model was found to involve a great deal of uncertainty. However, this study relies on a relatively short duration of measured data due to the lack of sufficient data for the study watershed. The capability of the behavior of the simulation model and uncertainty analysis methodology could be more effectively tested if the calibration and verification could be applied to a ‘data rich’ watershed.

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A2-6

Integrated Surface-groundwater Analysis Considering Groundwater Use in Pyoseon Region, Jeju Island, Korea

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The surface runoff characteristics of Pyoseon region in Jeju island are quite different from those of inland. Most of streams show dried characteristics by means of large portion of recharge which goes to the deep aquifer. It means that there is no baseflow in the upper area of watershed. However groundwater discharge is more and more increasing as approaching to the downstream near to sea. The quantity of groundwater use in this area is very large enough to affect the hydrologic component. For this reason, the integrated SWAT-MODFLOW model is used to simulate the complex runoff structure including groundwater recharge/discharge as well as the effect of water use by pumping with 198 wells. Statistical analysis shows that SWAT-MODFLOW produces a reasonable water budget which shows similar pattern of observed one. Hydrologic component variation due to the well pumping in the area is analyzed by using the Well package in MODFLOW. The comprehensive results show that the most of groundwater discharge is moved to the sea, so careful management of groundwater is needed for reasonable groundwater planning.

Keywords: SWAT-MODFLOW, Jeju island, groundwater discharge, well pumping

SESSION B4

Database and GIS Application and Development (1)

B4-1

The MVC Client Server Architecture of the BSC-OS Portal to Digest, Manage, and Query SWAT Data Collections

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Abstract

The EC FP 7 enviroGRIDS project (http://www.envirogrids.net/) is the first truly trans-national effort to address many socio-economic and environmental issues in the Black Sea region, involving 15 European countries for a total of 27 partners. During the project, a Black Sea Catchment Observation and Assessment System (BSC-OS) portal will be developed. This will expose a shared information system based on a set of loosely coupled web applications. The Collaborative Working environment (CWE), to be developed in Task 2 of Work package 6, is the front end for the SWAT reporting production mechanism and data visualization of the BSC-OS portal that will provide an easy access to contents and services.
The CWE framework, that operates on the boundary between production and research, aims at bridging the gap between public water protection agencies, scientific/technical partners, stakeholders and citizens. On this regards we will address the need to build local, national and regional capacity also through active interaction between the partners and cooperation to the GEOSS and INSPIRE initiatives.
Such framework exploits the Model View Controller (MVC) architectural pattern. This isolates "domain logic" (the application logic for the user) from input and presentation (GUI), permitting the massive use of Velocity Templates stored in the database of the portal. Such paradigm allows the enabled users to write, share and expose on the WEB their Templates in the portal as Applications. Each Template is a stand-alone script (written in VTL - Velocity scripting language) that combines data such as SWAT simulations, maps, users' roles, to produce a web page (in a HTML format). Applications for the reporting production, in this way, will use the full features of the web browser, so it is possible to integrate JavaScript / AJAX objects in the same developing environment.

Introduction

The Black Sea Catchment Observation and Assessment System (BSC-OS portal) is being developed in the 4-year EnviroGRIDS project under the EC Seventh Framework Programme [Gorgan et al., 2010]]. The project aims at addressing the subjects of environmental unsustainable development and inadequate water and soil resource management in the Black Sea Catchment area. In recent years the progress in network based technologies, data analysis, and high performance computing, let us imagine new way in which territorial management systems can operate. Earth scientists, public and private agencies are moving ever more to the Internet client-server paradigm, searching for reliable data, models and applications.

Currently, the SWAT model is being exploited using the AVSWAT [Di Luzio et al., 1995] or ArcSWAT [Francisco et al., 2006] interfaces, which are 2 programs that work on the desktop GIS environment ESRI ArcVIEW and ESRI ArcGIS respectively. Such environments are convenient to set up the model and, for its calibration, but are not optimized to share results between scientist and to expose them on the Internet. Still, AvSWAT and ArcSWAT projects cannot be easily moved and show some instability due mainly to the ESRI GIS environment they run on. The AVSWAT interfaces relies on a datafile system paradigm while the ArcSWAT interface relies basically on the Microsoft Access personal Geodatabase. Both choices are not portable and in general cannot be easily extended.

The use of WEB based innovative interactive tools such as SPRITE and SWATSL within the BASHYT environment for data manipulation and report production is expected to increase data interpretation abilities at present exploited for the SWAT model with the above mentioned technologies.

The report production mechanism of the BSC-OS portal, based on the BASHYT [Manca et al. 2009] (www.eraprogetti.com) software, will be farther developed to meet the challenges of such complex enlarged working environment.

The BASHYT Interface and the MVC Paradigm

The CWE front end which will be part of the enviroGRIDS BSC OS Portal is based on the BASHYT framework. BASHYT is a software on the WEB, based on the SWAT [Jayakrishnan et al., 2005] model to support decision makers in the field of sustainable water resources management. It works in tandem with the AvSWAT and ArcSWAT interface. The portal, for the general user, exposes hydrological applications based on the SWAT model to quantify the impact of point/non point pollution. Results are exposed through a “user friendly” interface, which supports a coherent management of Drivers - Pressure, State, and Impact indicators as distributed (in space and time) catchment’s variables. This procedure encourages the user to increase the awareness of the effects of subjective judgments or misjudgments on the final result.

Within an experimental environment, modules have been developed to run real-time applications, run pre- and post-processing codes, query and map results through the web browser. It is based on a client server architecture and works directly in any WEB browser without any external programs or plugin.

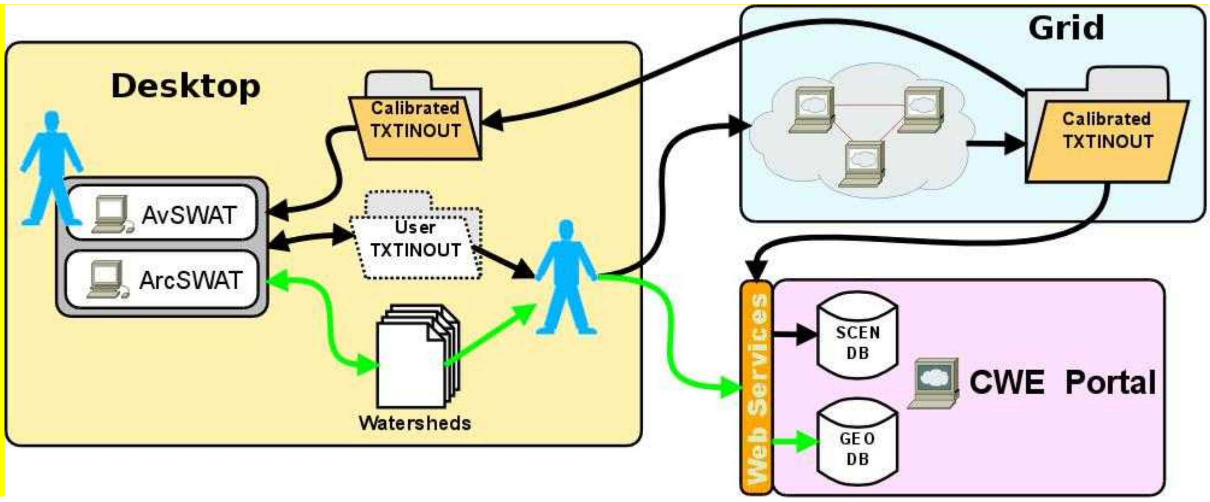


Figure 1. Operational Workflow. The CWE environment will work with the GRID and with the desktop environment of earth specialists to digest SWAT simulations.

The CWE environment exploits the Model View Controller (MVC) architectural pattern. This isolates "domain logic" (the application logic for the user) from input and presentation (GUI), permitting the massive use of Velocity Templates stored in the database of the portal. Such paradigm allows the enabled users to write, share and expose on the WEB their Templates in the portal as Applications. Each Template is a stand-alone script (written in VTL - Velocity scripting language) that combines data such as SWAT simulations, maps, users' roles, to produce a web page (in a HTML format). Applications for the reporting production, in this way, will use the full features of the web browser, so it is possible to integrate JavaScript / AJAX objects in the same developing environment.

SPRITE and SWATSL Application

Sprite and SWATSL are two programs that work in tandem to process a SWAT project, upload it to a server and import it to a Spatialite (http://www.gaia-gis.it/spatialite/) DB file to be exposed in the WEB environment.

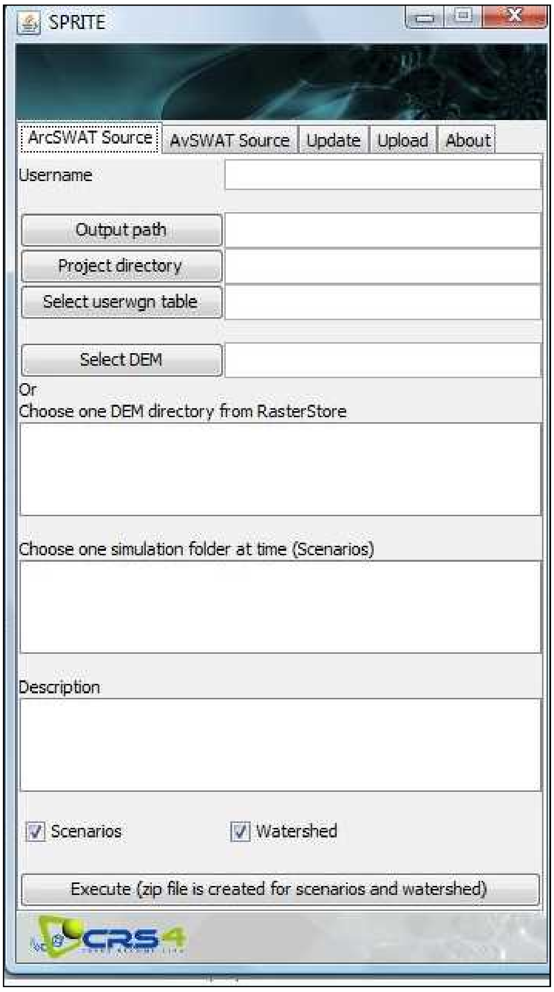
Sprite is a Java stand alone program that works as a standard Extract, Transform and Load (ETL) procedure. It process AvSWAT and ArcSWAT projects to derive the necessary information to be fed to the BASHYT application. Once a project has been processed, the SPRITE application can upload the data to any server reachable on a LAN or on the Internet.

The main tasks performed by SPRITE are:

1. Extract: process a SWAT project (AvSWAT or ArcSWAT) extracting a minimum dataset
2. Transform: normalize its content and archive the data in 2 zip folders:
    a. Watershed
    b. Scenarios
3. Upload the data to any BASHYT server When the 2 zip files are created, a metadata xml file gives the information about: project name, user name, SWAT version (2000, 2005, 2009), date of creation, etc.

SWATSL is the server side application and works also as a standard ETL. It is programmed in C and its purpose is:

1. Extract the data,
2. Transform it to fit operational needs
3. Create an empty logical schema of the geo-relational database (a spatialite db file). Such schema is fixed.
4. Populate it. SWATSL will import the data within the schema.



☑ Scenarios ☑ Watershed

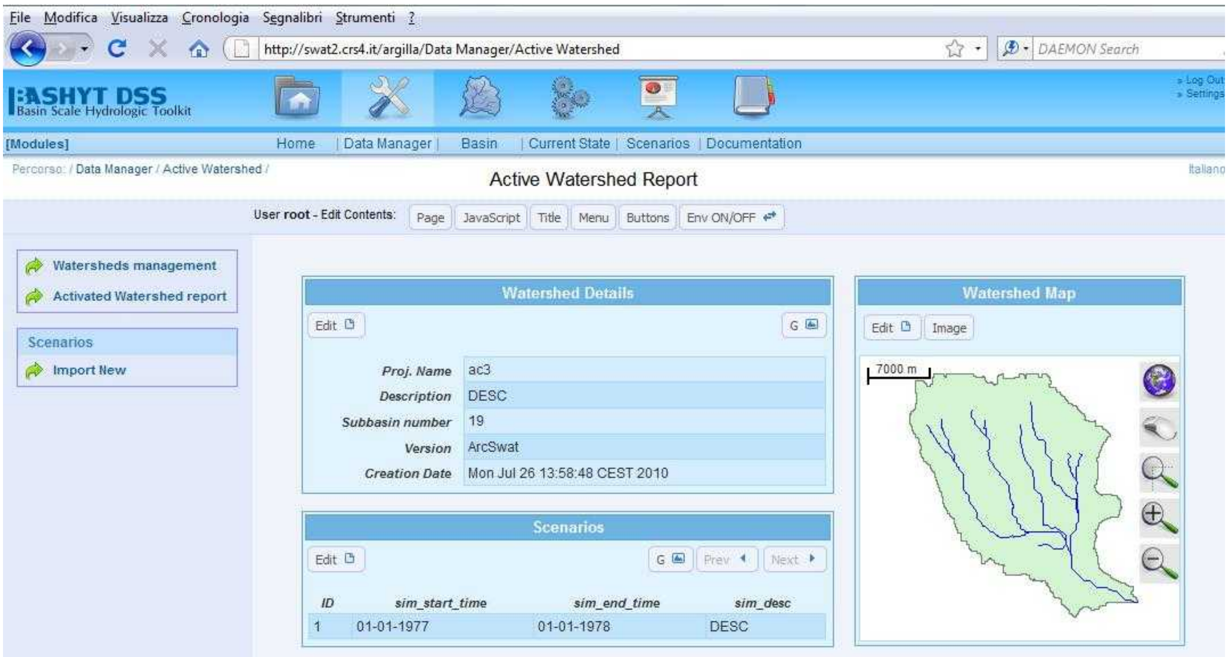
Figure 2. The Sprite client interface.

The transform stage applies a series of rules and functions to the extracted data from the source to derive the data for loading into the db file. Some data require very little or even no manipulation, other data require some change to fit the schema. SWATSL can be commanded from the application side, so each user of the portal with the privileges will be allowed to run it to import the uploaded projects within the system.

Name	Date	Imported	Active	Activate
lakefork_watershed_Mon_Jul_26_13.54.35_CEST_2010.zip	Thu Jul 29 19:27:17 CEST 2010	0	0	Activate
ac1_watershed_Mon_Jul_26_13.56.39_CEST_2010.zip	Thu Jul 29 19:06:05 CEST 2010	0	0	Activate
SAN_SPERATE_watershed_Mon_Jul_26_14.01.38_CEST_2010.zip	Thu Jul 29 19:06:39 CEST 2010	0	0	Activate

Figure 3. In figure it is shown a set of 3 projects imported with SPRITE. The imported projects can be set active just by clicking on the activate button which runs the SWATSL procedure.

In the Data Manager Section of the BASHYT interface, the subsection Watershed management enables to activate the watershed to be analyzed. Many watershed can be imported in the framework. By clicking the activate button, the following situations can occur:
if the watershed is already processed by SWATSL, then the application set the project active by changing the connection to the db file
if the watershed has been uploaded by SPRITE but no db file has been created then, SWATSL is run and the project is set to active
In figure 4, a synthetic overview/report of the active project is shown.



Proj. Name: ac3
Description: DESC
Subbasin number: 19
Version: ArcSwat
Creation Date: Mon Jul 26 13:58:48 CEST 2010

ID	sim_start_time	sim_end_time	sim_desc
1	01-01-1977	01-01-1978	DESC

Figure 4. A synthetic report of the Active watershed viewed on the BASHYT interface.

Conclusion and Future Work

Client/server applications for data and compute resource virtualization are the paradigm introduced in the Internet cyberspace. The diversity and complexity of environmental problems imposes the adoption of a cross-disciplinary approach, only possible through the development of problem solving models based on advanced information technologies, to set up virtual organizations sharing common interests and objectives providing high value-added complex services, accessible from anywhere.

The SPRITE – SWATSL tools improve deeply the usability of the BASHYT web-based environment. The use of such interactive tools is expected to increase data interpretation abilities at present exploited for the SWAT model mainly with desktop technologies.

The BASHYT framework operates on the boundary between production and research. Our work aims at bridging the gap between public water protection agencies, scientific/technical partners, stakeholders and citizens. On this regards we will address the need to build local, national and regional capacity for the Black Sea region also through active interaction between the partners and cooperation to the GEOSS and INSPIRE initiatives.

Acknowledgments

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B4-2

Development of a Field Based Decision Support Tool Integrated with Socio-economical Model for Managing Water Quality and Quantity

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Abstract

Human activity is intricately linked to the quality and quantity of water resources. Although many studies have examined human-water dynamics, the complexity of such coupled systems is not well understood largely because of gaps in our knowledge of water-cycle processes which are heavily influenced by socio-economic drivers. Considerable research has been performed to develop an understanding of the impact of local land use decisions on field and catchment processes at an annual basis. Still less is known about the impact of economic and environmental outcomes on decision-making processes at the local and national level. This study proposes to support a new approach which integrates physical and socioeconomic modeling with computational intelligence.

Often times farms interact with complicated environmental and social-economic factors while making farmland management decisions. To study human decision-making processes under different uncertainty, in our socio-economical model called 'agent-based model' (ABM), we develop alternative scenarios based on three main driving forces of farm-based decision making: climate, federal energy and agricultural policies, and market value of crops and fuels.

Through this study, tools have been developed which integrate the output from ABM model with the SWAT model at farm field level. Based on the ABM simulation results, we further investigate how the water quality responds differently under different scenarios. Current work also includes modification of decision modules to reflect agricultural practices in Iowa and the incorporation of agricultural policies.

Keywords: Human-water dynamics, Socio-economical model (ABM), Water quality model (SWAT), Decision support tool

Introduction

Human activity is intricately linked to the quality and quantity of water resources. Although many studies have examined human-water dynamics, the complexity of such coupled systems is not well understood largely because: (a) gaps exist in our knowledge of water-cycle processes which are heavily influenced by socio-economic drivers; (b) typical analyses utilize a narrow range of disciplinary expertise and are often inward-looking; and (c) appropriate tools and data for multidisciplinary research do not exist (Schnoor et al., 2009). In the absence of a full understanding of the relationship between human and natural system behavior, there is a risk of unintended consequences (e.g., adoption of technologies for bio-based fuel production which adversely impact the environment, the structure of rural communities, and the sustainable production of agricultural food products). Considerable research has been performed to develop an understanding of the impact of local land use decisions on field and catchment processes at an annual basis (Bennett et al., 2009). Less well understood is how these processes scale-up to basin-level outcomes or scale down to short term (e.g., daily) dynamics often relevant to aquatic ecosystems. Still less is known about the impact of economic and environmental outcomes on decision-making processes at the local and national level – these are essential components of an adaptive management strategy. Do decision-makers understand the tradeoffs among economic return and environmental impact given alternative assumptions about the application of nutrients? Does such understanding change the way farmers manage the landscape or regulators set policies? At a time of growing demand for water, the gap between science and practice is widening and calls are made to the scientific communities to produce research that addresses the societal needs related to water dynamics in the environment (Schnoor 2009). New tools are needed to sense and model the water cycle and its interactions with the environment and bounded human activities (Muste, 2009). This work tends to do so in a smaller way.

Study Area and Data Used

The Clear Creek watershed is a 267 km^2 HUC (Hydrologic Unit Code) 10 units located in east-central Iowa It is part of the Lower Iowa HUC 8 unit and discharges into the Iowa River. Approximately 85% of the land cover in the watershed is agricultural or grassland, 8% is forest, 6% is roads or urban, and the remaining area is water or barren (Iowa DNR 2008). The main channel of Clear Creek is approximately 47 km long.

Discharge is measured at two US Geological Survey (USGS) gauging stations located in the middle of the watershed at Oxford, and near the outlet of the watershed at Coralville. There are three (near) real-time sensing stations with high frequency measurements (every 20 minutes) of pH, temperature, stage-discharge, conductivity, dissolved oxygen, and nitrate.

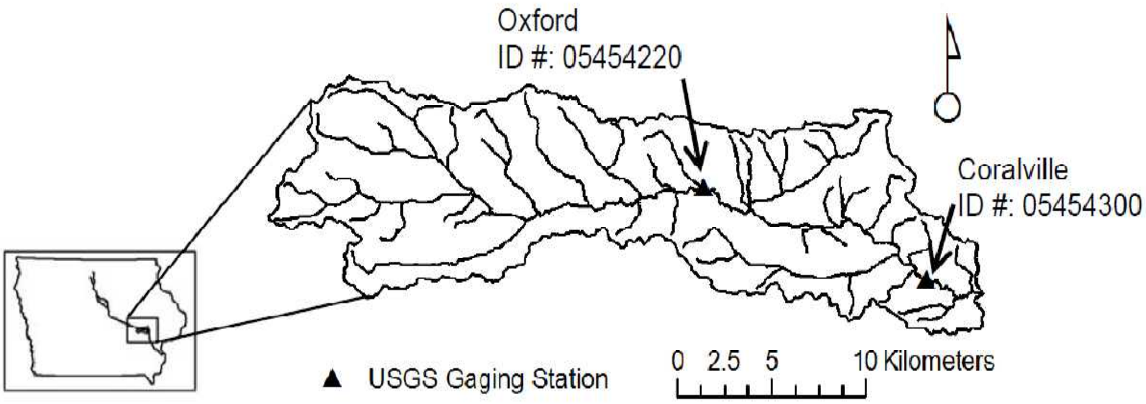


Figure 1. The Clear Creek Watershed located in east-central Iowa. USGS gauging stations are present in the middle of the watershed and at the outlet which drains to the Iowa River.

Table 1. Data used

Data inputs	**scale**	**Data sources**
DEM	One arc second (30m resolution)	http://seamless.usgs.gov/
Landuse, Landcover	15 m	NRGIS (http://www.igsb.uiowa.edu/nrgislibx/)
Soil	1:24,000	SSURGO (http://soildatamart.nrcs.usda.gov/)
Stream flow data	Daily	http://waterdata.usgs.gov/ia/nwis/
Weather data	Daily	http://www.ncdc.noaa.gov/oa/ncdc.html
Water quality	Daily, Sub daily	STORET, local sensors
CLU (common land units)	Farm field	NRGIS (http://www.igsb.uiowa.edu/nrgislibx/)
Farmer's survey	2009-2010	University of Iowa and SIU

Following figures show the raster input data used in the model. Upstream part of the watershed is of higher elevation and partly hilly in nature. Interestingly Land use data has considerable amount of corn and soybean and small amount of Alfa Alfa, Oat and other crops. There is a tremendous variability in soil properties over the entire watershed which certainly has strong implication on hydrologic responses of those land.

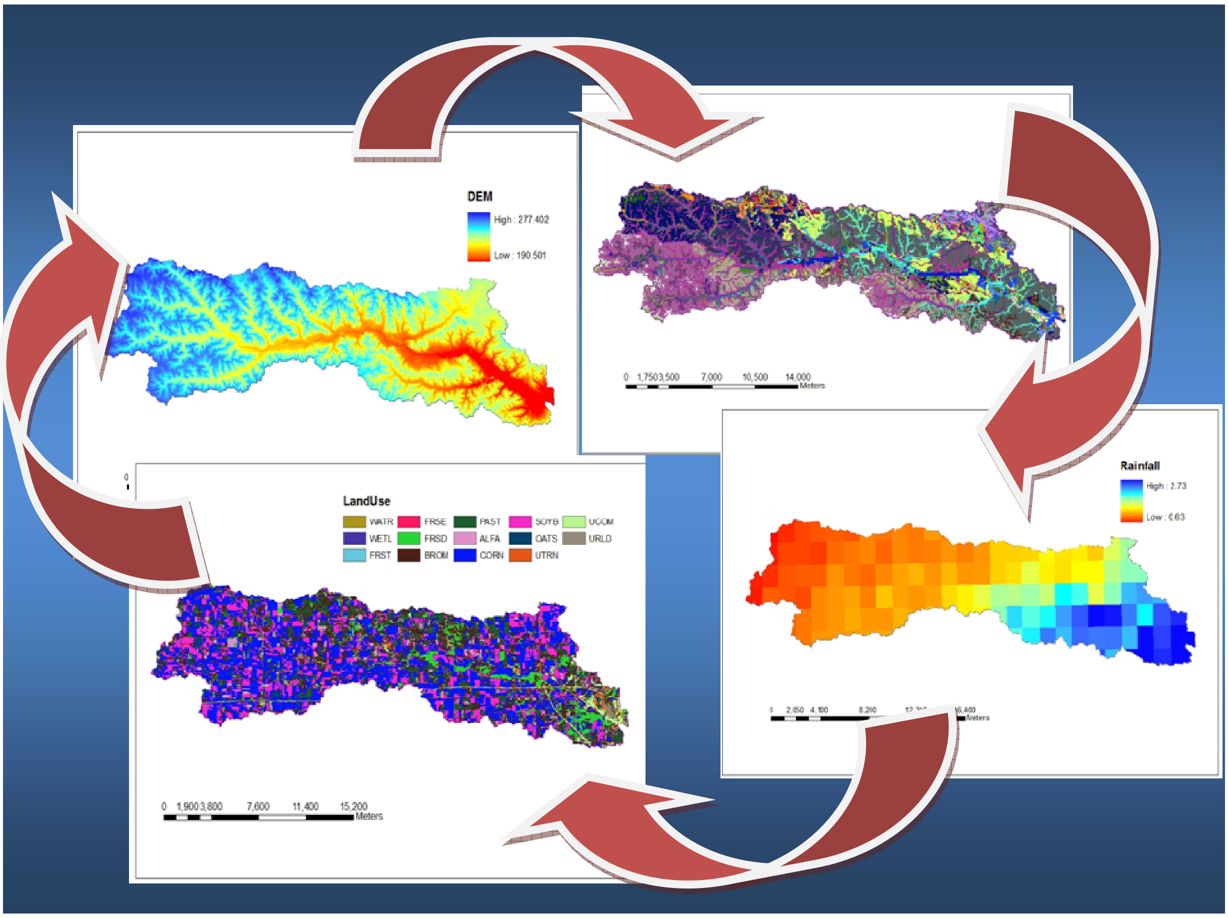


Figure 2. DEM, Landuse and Soil and Rainfall map for Clear Creek.

Building a Coupled SWAT-ABM Modeling Framework

Agent Based Modeling (ABM) and scenario development

Agent-Based Model (ABM) is a cyber-enabled approach of simulating the actions and interactions of heterogeneous autonomous agents in complex adaptive systems (CAS) such as a land-use system (Bennett and McGinnis, 2008). An ABM could contain numerous autonomous agents at different levels corresponding to its capability of representing the system complexities. Agents in the system make decisions and behave based on specific decision-making heuristic, learning and adaption rules. To simplify the system simulated in an ABM, external variables in a non-agent environment are specified and parameterized instead of involving high-level agents in the system. In land use modeling, the ABM could capture and represent 1) the heterogeneous set of driving forces on land-use decisions, 2) the interactions among agents, and between agents and environment, and 3) the complex feedback mechanisms and non-linear dynamics. Thus it is considered as a useful alternative to traditional approaches in this field.

In this paper, one of our main objectives is to simulate the agricultural land use in the Clear Creek Watershed. While making farmland management decisions, farms interact with complicated environmental and social-economic factors. These factors include climate, government policies about energy (e.g. 2007 Energy Bill), government policies about environment and agriculture (e.g., the conservation reserve program), and market prices of crops and fuels, and etc. The complicated interactions and feedbacks compose a farm-based complex adaptive system which could be well simulated by an agent-based model. In this system, the complexity and uncertainty are caused by the heterogeneous characteristics of farmers in their objectives, resources, access to information, and their willingness to assume risk, and the complex interactions of different components of the system. Thus the system may respond differently in various environmental and social-economic scenarios. To study human decision-making processes under different uncertainty, in our agent-based model (ABM), we will develop alternative scenarios based on three main driving forces of farm-based decision making: climate, federal energy and agricultural policies, and market value of crops and fuels. For example, we will investigate how the farmer decision on crop types, such as corn for food, corn for biofuel, and perennial switch grass, are affected by the energy and agricultural policies under the alternative scenarios. Based on the ABM simulation results, we will further investigate how the water quality responds differently under those scenarios.

In this paper, we created three scenarios about corn grain market. As an external input to the agent-based model, in Scenario 1, the time series of yearly cash corn price was the actual data obtained from Iowa Agricultural Statistics. In Scenario 2, the cash corn price during the last 8 years from 2000 to 2008 was increased by 25% comparing to the actual price in Scenario 1. In Scenario 3, the price increase was 50% comparing to the actual price. By running the ABM model with the external inputs at three levels of cash corn price, we obtained the CLU-specific management information respectively for the three scenarios.

Coupling ABM with SWAT

Current work includes modification of decision modules to reflect agricultural practices in Iowa, the incorporation of agricultural policies and economics relevant to biofuel production, and integrating the output of the ABM with the SWAT model.

Land management inputs from ABM simulation is feed into management files of SWAT which is done after reconfiguring HRUs. Since basic unit for SWAT is HRU, we do not alter its hydrologic properties. We only split HRUs (and hence associated management files) into more classes based on CLU map so to make desired land management changes (from ABM) within HRUs through the use of HRU reconfiguration algorithm which is shown in the figure 3 below. Overall data flow for this coupled SWAT-ABM modeling framework is shown in figure 2.

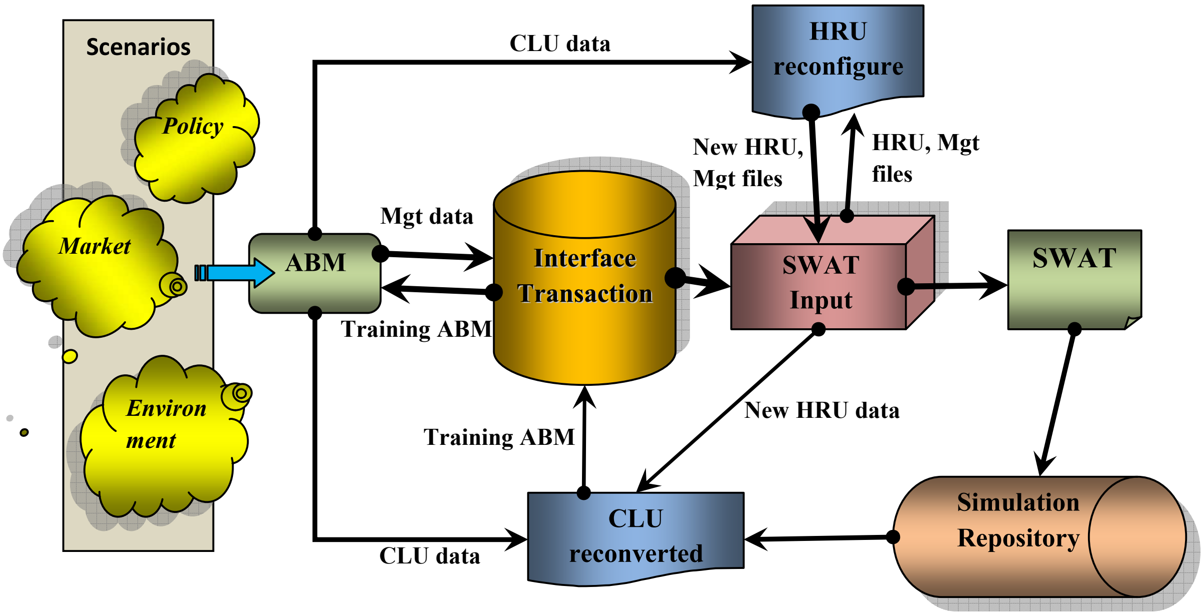
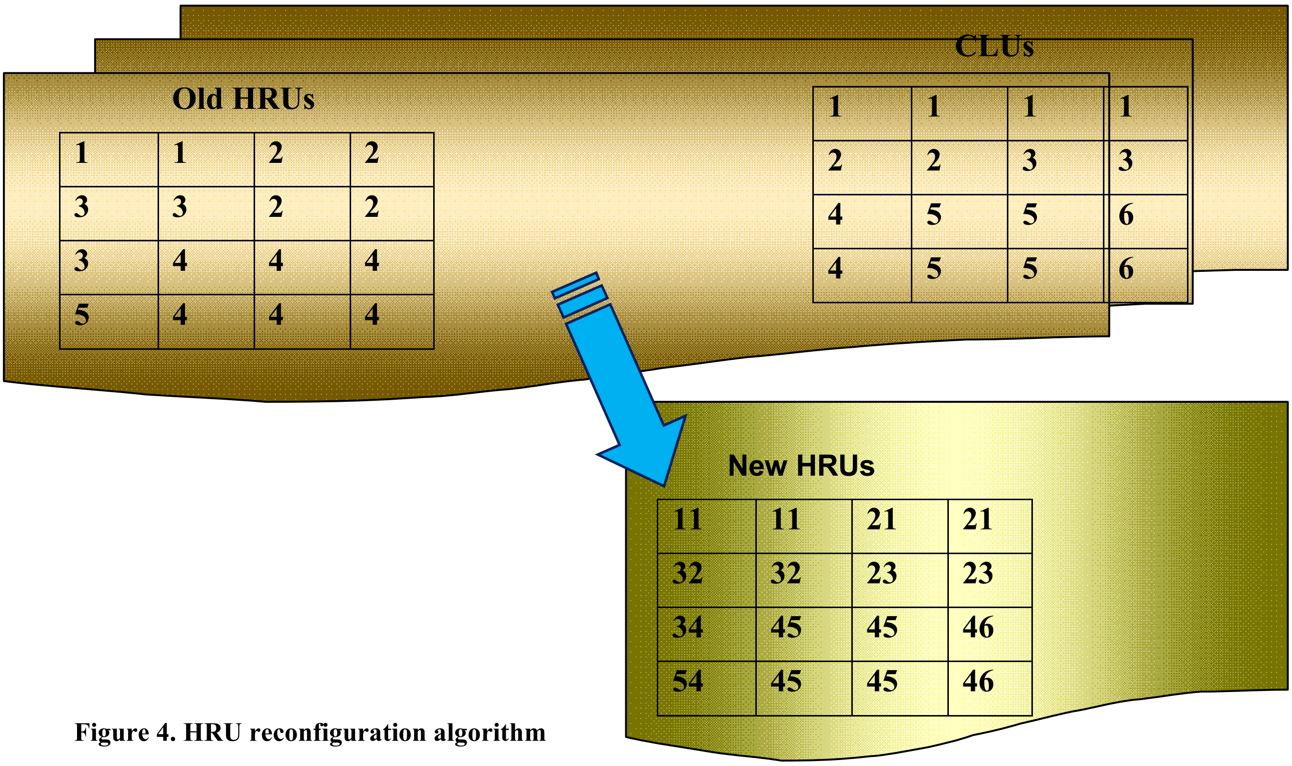


Figure 3. Coupling SWAT-ABM



Old HRUs

1	1	2	2
3	3	2	2
3	4	4	4
5	4	4	4

CLUs

1	1	1	1
2	2	3	3
4	5	5	6
4	5	5	6

New HRUs

11	11	21	21
32	32	23	23
34	45	45	46
54	45	45	46

Figure 4. HRU reconfiguration algorithm

Algorithm: New HRU Index = Old HRU Index * B + CLU Index; where B equals to 10 here

Visualization of stakeholders/farmers

We are making progress on getting data and models into a user-friendly format and representation for visualization such that water quality managers and agricultural experts (including farmers) can use it to understand possible management decisions. We are also building an interface based on what farmers might see and the information that they would like to have to make management decisions about their fields in this year and next.

Initial Implementation

Model parameterization

The model has been auto-calibrated over 8 years (2000-2008) considering yearly corn-soybean rotation over the watershed. Sensitivity analysis has also been done and parameters sensitivity ranks, along with their calibration values obtained, are shown below in the table.

Table 2. Calibration parameters

Parameter	**Description**	**Sensitivity ranking**	**Value**
CN2	Initial SCS CN 2 value	1	4.73
Esco	Soil evaporation compensation factor	2	0.41
SOL_AWC	Available water capacity	3	3
Alfa_Bf	Baseflow alpha factor	4	0.06
Surlag	Surface runoff lag time (days)	5	1.4
Sol_Z	Soil depth (mm)	6	24.5
Ch_K2	channel effective hydraulic conductivity	7	7.45
Blai	Maximum potential leaf area index	8	1
Gwqmn	Threshold water depth in shallow aquifer flow	9	500
Canmx	Maximum canopy storage (mm)	10	0.07

Case study: generating corn market scenarios

In this work, the agents (farmers) make decisions on corn-soybean rotation based on the comparisons of the profitability of the two crops in their land parcel. There are three kinds of agents in the model: 1) farmer; 2) land parcel, 3) farmer net.

With the model, we conducted an experiment about the influence of corn price increase on the land parcel allocations between corn and soybean. The number of farmer nets in the experiments is set to be 300. Figure 5a shows the original prices of the two crops from 1960 to 2008. Figure 5b illustrates that the number of land parcels in which corn or soybean is planted during this period. It shows that there have been more corn parcels than soybean parcels in overall during 1960 and 2008. In Figure 5c, the corn price has been increased by 20% since 2001. Therefore, in Figure 5d, the difference between the numbers of corn parcels and soybean parcels has become bigger since 2001, which indicates a positive influence of corn price on the number of corn parcels.

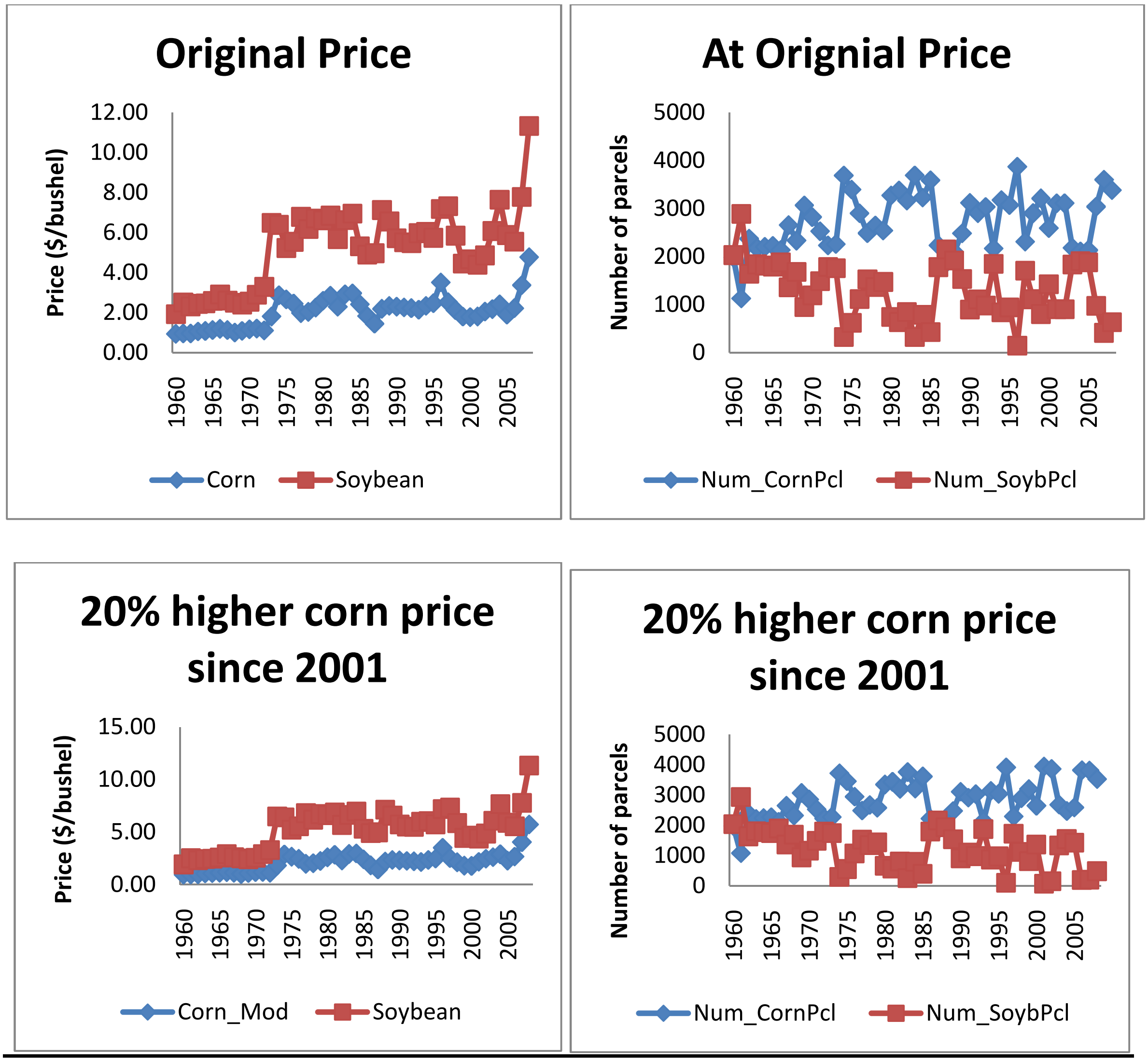


Figure 5a, 5b, 5c and 5d. Corn prices scenarios

Simulating coupled SWAT-ABM model for different scenarios

HRUs are first reconfigured based on CLU map as shown below in table and then management parameters from ABM simulation are written. Then SWAT is run for three different corn price scenarios as defined as:

Scenario1: original corn price

Scenario2: 25% increase on original corn price since 2000

Scenario3: 50% increase on original corn price since 2000

Table 3. HRU reconfiguration statistics

Sub basins number	Old HRUs	New HRUs	Sub basins number	Old HRUs	New HRUs
1	1	1-145	12	15	1311-1356
2	2	146-205	13	16	1357-1385
3	3	206-319	14	17,18,19	1386-1593
4	4	320-409	15	20,21	1594-1601
5	5	410-501	16	22,23	1602-1734
6	6	502-578	17	24	1735-1745
7	7	579-789	18	25	1746-1761
8	8	790-831	19	26	1762-1881
9	9,10	832-1047	20	27	1882-1990
10	11,12	1048-1154	21	28	1991-2027
11	13,14	1154-1310			

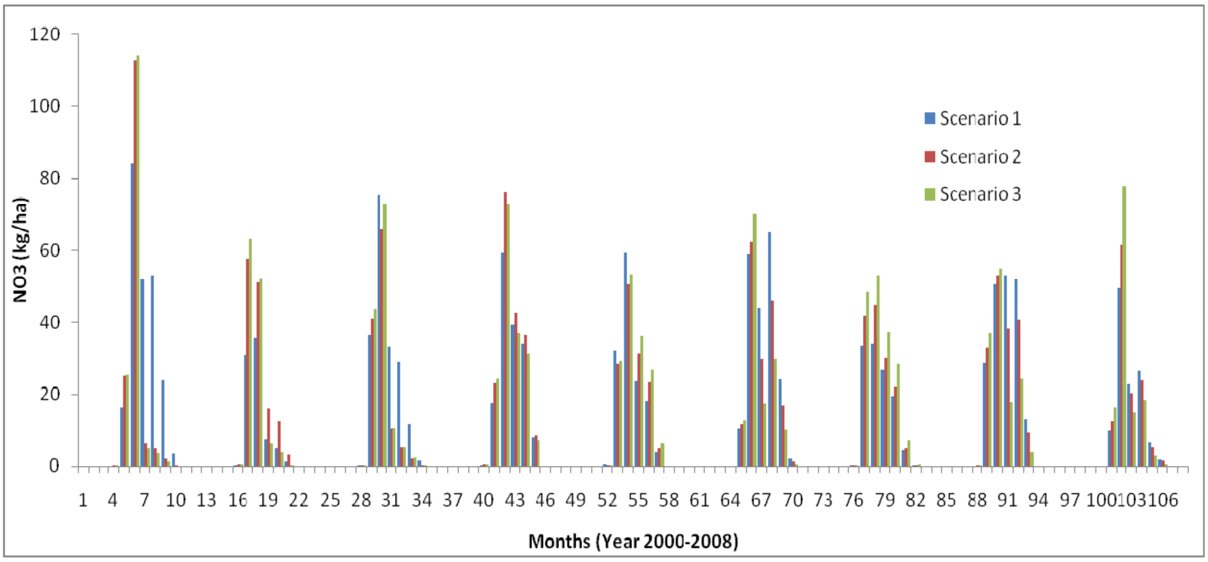


Figure 6a. Nitrate yield at different scenarios.

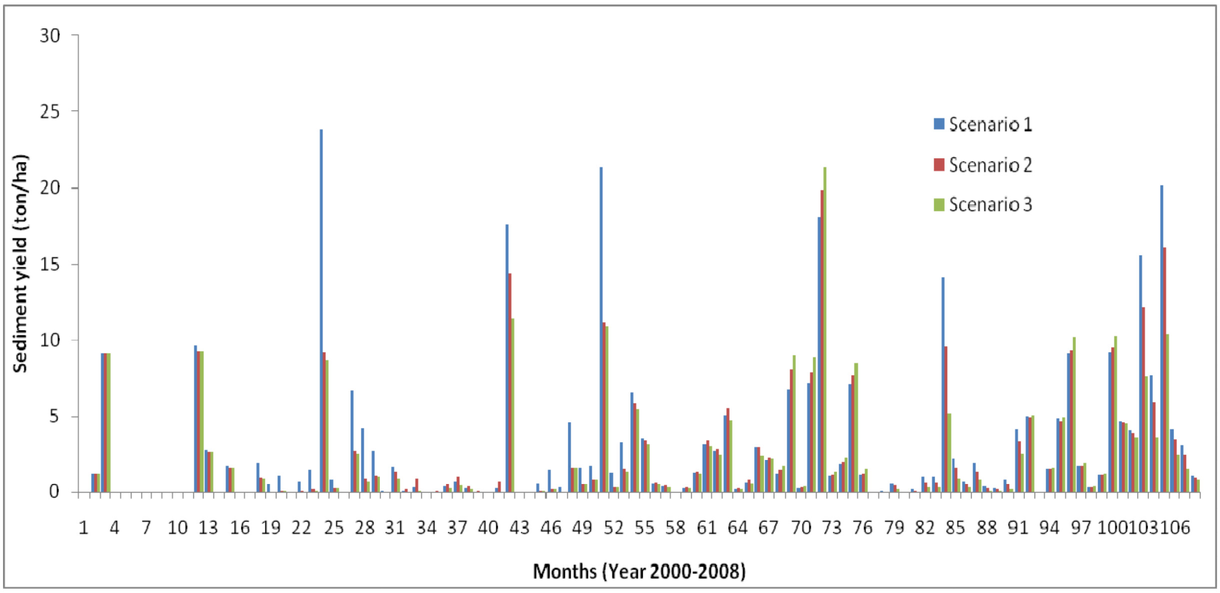


Figure 6b. Sediment yield at different scenarios.

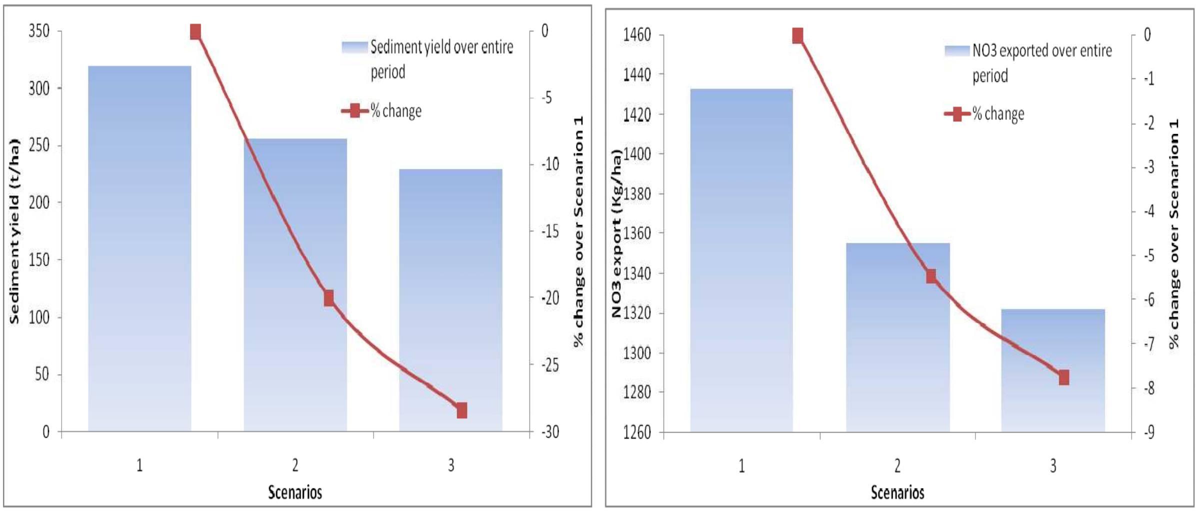


Figure 7a and 7b. Sediment and NO_3 flux change over whole simulation period

Above results show that increase in corn price will result into reduction in NO_3 export from field. This will also reduce sediment yield at watershed outlet. Clearly more refinement in terms of crop rotation need to be done, but the overall trend from this simulation are clear that from water quality point of view scenario 3 like situation is preferable. But the scenario developed might have interaction with other scenarios (e.g. Climate change, rainfall extreme variability over spring and fall and their changing pattern) and that can have considerable impact on the final response. Authors intend to do more robust study by merging simple scenarios (like the one here) and built on complex, interacting scenarios in later part of the study.

Conclusion and Future Direction

Environment, market and policy scenario has considerable impact on natural system which is evident through its responses in terms of water quality and quantity. Through this scenarios studies (as Corn price scenario case study shown in this work) stakeholders can better understand implication of certain policy decision on natural system and thus may help in formulating more eco friendly policies in long term.

This work is a humble effort for modeling coupled Natural-Human system and understand there interactions. The research effort carried out through this work will produce a prototype Intelligent digital watershed (IDW) which is envisioned to be comprehensive, real-time operational in next stage.

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B4-3

Evaluation of Streamflow and Water Quality in an Agricultural Watershed of South Korea using SWAT and KOMPSAT-2 Detailed Land Use Information

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Abstract

This study is to evaluate the SWAT (Soil Water Assessment Tool) streamflow, sediment, T-N (Total-Nitrogen), and T-P (Total-Phosphorous) in case of using a quite detailed land use data, and discuss the discrepancy in model parameters when applying comparatively coarse land use data. Detailed land use information is crucial to establish agricultural BMPs (best management practices) as a watershed scale. The spatial resolution of land use also critically influences the watershed runoff and soil erosion directly linked to the sediment and nutrients transports, and finally affects the stream flow and water quality during the model run such as SWAT. Now, as the high spatial resolution of satellite image such as IKONOS, QuickBird, and KOMPSAT is available, it is possible to use a detailed land use data for model setup. For a 260 km^2 agricultural watershed located in the northwest part of South Korea, the 2 m resolution land use was prepared using KOMPSAT (Korea Multi-Purpose SATellite)-2 satellite image acquired in 17th September 2007. The KOMPSAT land use was classified into 26 categories compatible with USGS (United States Geological Survey) Level-I explaining the type of upland crops. Using the land use data, the SWAT model was calibrated with 2 years (2001-2002) daily streamflow and monthly water quality (sediment, T-N and T-P) data, and validated for another 2 years (2003-2004) data. The average Nash–Sutcliffe model efficiency of streamflow during validation was 0.81, and the coefficient of determination (R^2) of sediment, T-N and T-P were 0.94, 0.62, and 0.46 respectively. To identify the scale effect of land use in the modeling, the SWAT was once more calibrated and validated using 30 m land use of Landsat satellite classified into 8 categories comprising the upland crops as one category. The average Nash–Sutcliffe model efficiency of streamflow during validation was 0.76, and the coefficient of determination (R^2) of sediment, T-N and T-P were 0.87, 0.59, and 0.43 respectively. Even though the two results have modeling errors and there are some problems for one to one comparison between parameters, we found that the watershed CN (curve number) parameter that affects the watershed runoff showed a big difference between 2 land use applications. The KOMPSAT watershed CN was calibrated with 11.4 greater than the Landsat watershed CN. This difference came from the increase of impervious areas viz. paved roads, residential areas, and bare fields that were not classified in Landsat land use.

The increased CN resulted in the increase of surface runoff and streamflow. The increased surface runoff by different occurrence in space and streamflow subsequently influenced the sediment transport and affected the T-N and T-P transports. Further analysis will be done especially for the model parameters between 2 land use applications.

Keywords: SWAT, Land use, KOMPSAT-2, Landsat, Scale effect, Sediment, T-N, T-P

Introduction

Recently, the practical use of high spatial resolution imageries such as IKONOS, QuickBird and KOMPSAT (KOrea Multi-Purpose SATellite) has been accommodated in various land use-related application fields. Researches in agricultural field as well as natural hazard and environmental assessment field are now in an increasing trend (Lee et al., 2009). The data can be used to identify detailed hydrologic cycle, soil erosion process, sediment and pollutant transport mechanism (Kim et al., 2007). The quality of spatial information is presumed to directly affect the simulation results of hydrologic models. In many cases, the nonpoint sources modeling analysis is prohibitively hindered because of insufficient information and unbearable data intensive requirements. In addition, the detailed land use information is crucial to establish agricultural BMPs (best management practices) as a watershed scale.

Recent hydrologic models have structures reflecting high resolution land-cover information to examine such impacts on the heterogeneity of storm water pollution sources. However, large variability in land use categories required by models and provided by land-cover datasets needs extensive understanding of land-cover effects on water quality (NRC, 2008).

This paper investigates the impact of USGS Level-I land use on streamflow, sediment, T-N (Total-Nitrogen), and T-P (Total-Phosphorous) loads using the Soil and Water Assessment Tool (SWAT, Arnold et al., 1998). For a 251.7 km^2 watershed, the land use of 2 m and 26 categories was prepared from the KOMPSAT-2 image acquired in 17th September of 2007. The model results were compared with the case of land use of 30 m and 9 categories to understand how much the land use detail affects the watershed hydrology and stream water quality.

Materials and Methods

SWAT Model description

The SWAT model is a physically based and continuous time model developed to predict, over long periods, the impact of land management practices on water, sediment and chemical yields in watersheds with varying soils, land use and management conditions (Arnold et al., 1998). SWAT model operates on daily time step and based on the concept of hydrologic response units (HRUs) which are portions of a sub-watershed that possess unique land use/management/soil attributes. In its model includes 102 different land use types in the model database. The success of the simulation depends highly on the accurate assignment of land uses (Neitsch et al., 2001). A complete description of SWAT equations can be found in Arnold et al (1998). To predict the runoff generation, SWAT uses a modified version of the SCS-CN (Soil Conservation Service-Curve Number) method (USDA-SCS, 1972) and the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) to predict sediment generation. The hydrologic cycle as simulated by SWAT is based on the water balance equation. In-stream nutrient dynamics have been incorporated into SWAT using kinetic routines from in-stream water quality model. The N processes, soil pools, plant supply, and demand of N can also be simulated by SWAT. The N cycle, with plant biomass, N transported with runoff, lateral flow, and percolation, can have different N formations estimated daily. The SWAT model can also model P circle and formations in similar approach to N. While predicting the amount of soluble P removed in runoff, the labile P concentration in topsoil, runoff volume, and P soil partitioning factor and all considered. Sediment transport of P is simulated with a loading function, as is organic N transport (Santhi et al., 2001).

The study area description

A 251.7 km^2 agricultural watershed located in northwest of South Korea were adopted. The watershed stream is the tributary of Han river basin directly linked to Paldang lake. The lake plays an important role for the municipal water supply for Seoul metropolitan city. Thus the protection of nonpoint source pollution from agricultural cultivation becomes more important because of the recently raised consciousness of water quality problem.

Map data, weather, streamflow, and water quality data

The SWAT model requires elevation, soil, land use, and weather data for assessment of water yield and quality at the desired locations of watershed. Elevation data of 2 m spatial resolution was rasterized from 1:5,000 vector map supplied by the Korea National Geography Institute (Figure 1a). The soil data was rasterized from 1:25,000 vector map supplied by the Korea Rural Development Administration. The soil type and hydrologic soil group are shown in Figure 1b and 1c. The 2m resolution land use data was prepared from the KOMPSAT-2 of 17th September 2007. Details are described in the next section.

For the model setup, the four years (2001-2004) daily weather data from 3 weather stations (Suwon, Icheon, and Yangpyeong) and precipitation data from 6 AWS (automatic weather station) were used. The daily streamflow and monthly water quality (sediment, T-N, T-P) data at the watershed outlet (Gyeongan water level gauging station) provided by the Ministry of Land, Transport and Maritime Affairs and Ministry of Environment were prepared.

Land use from KOMPSAT-2 satellite imagery

The KOMPSAT-2 panchromatic and multi-spectral images of 17th September 2007 were used. The mean spatial resolution of two images was 1 m in panchromatic, and 4 m in multi-spectrum (4 bands in visible) respectively. The images were ortho-rectified and geometrically corrected by using 2 m DEM (Digital Elevation Model) and 30 GCPs (Ground Control Points) acquired from GPS (Global Positioning System) equipment. The land use boundary was digitized and classified into 26 categories (Figure 1d).

To discuss the effect of land use classification level in the SWAT modeling, the 30 m Landsat land use was prepared additionally (Figure 1e). By using the Landsat TM (Thematic Mapper) of 3rd June 2004, the land use was classified into 9 categories (paddy, upland crop, grassland, evergreen, deciduous, urban, bare field, road, water). The overall accuracy through maximum likelihood classification was 95.7 %.

Table 1 shows the classification summary of two land uses. The KOMPSAT urban and bare field area increased 4.4 % and 5.2 % and agricultural area decreased 11.6 % comparing with the Landsat classified results. The urban was detected more and the paddy was classified precisely by the fine resolution.

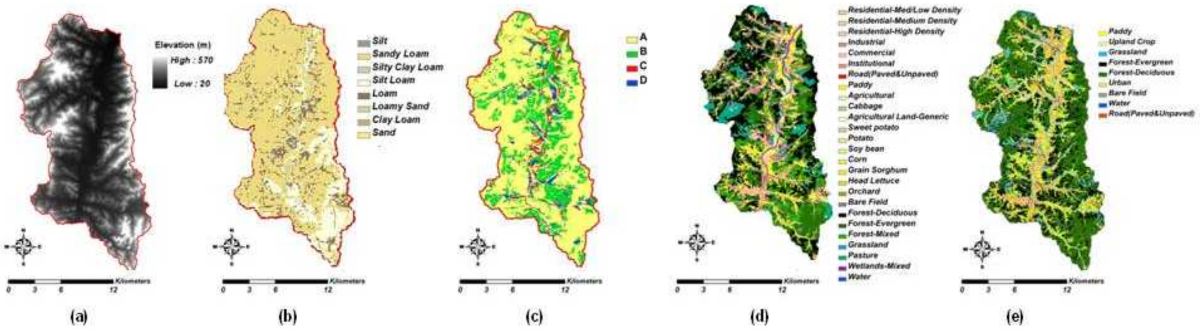

Figure 1. (a) 2 m DEM, (b) 1:25,000 soil type, (c) hydrologic soil group, (d) KOMPSAT (2 m) Land Use, and (e) Landsat (30 m) Land Use.

Table 1. Classification summary of KOMPSAT and Landsat land uses

KOMPSAT (2 m)				Landsat (30 m)			
Class	Area (km$^{2)}$)	[%]	CN	Class	Area (km$^{2)}$)	[%]	CN
Residential-Med/Low Density	16.62	[6.54]	76.1	Urban	21.12	[8.39]	49.8
Residential-Medium Density	0.05	[0.02]	71.0				
Residential-High Density	0.40	[0.16]	75.3				
Industrial	12.01	[4.73]	85.2				
Commercial	5.03	[1.98]	90.5				
Institutional	4.50	[1.77]	43.1				
Road	4.49	[1.77]	89.4	Road	11.00	[4.37]	89.4
Sub Total	**43.10**	**[16.96]**	**75.8**	**Sub Total**	**32.12**	**[12.76]**	**69.8**
Paddy	18.99	[7.47]	78.0	Paddy	46.56	[18.50]	78.0
Agricultural Land-Close-grown	0.04	[0.02]	67.5	Upland Crop	8.41	[3.34]	72.3
Cabbage	0.42	[0.17]	71.0				
Agricultural Land-Generic	4.12	[1.62]	75.5				
Sweet potato	0.23	[0.09]	71.5				
Potato	0.23	[0.09]	71.8				
Soybean	0.16	[0.06]	70.3				
Corn	0.56	[0.22]	69.7				
Grain Sorghum	0.08	[0.03]	67.9				
Head Lettuce	0.02	[0.01]	71.3				
Orchard	0.39	[0.15]	58.6				
Sub Total	**25.23**	**[9.93]**	**70.3**	**Sub Total**	**54.97**	**[21.84]**	**75.2**

Forest-Deciduous	63.61	[25.04]	50.5	Forest-Deciduous	94.33	[37.48]	50.5
Forest-Evergreen	58.81	[23.15]	53.0	Forest-Evergreen	48.10	[19.11]	53.0
Forest-Mixed	21.04	[8.28]	53.3				
Grassland	1.56	[0.62]	40.7	Grassland	18.70	[7.43]	40.7
Pasture	19.16	[7.54]	57.0				
Wetlands-Mixed	2.56	[1.01]	98.0				
Sub Total	**166.75**	**[65.63]**	**58.8**	**Sub Total**	**161.13**	**[64.02]**	**48.5**
Bare Field	16.33	[6.43]	98.0	Bare Field	3.12	[1.24]	98.0
Water	0.27	[0.11]	100.0	Water	0.38	[0.15]	100.0
Total	**251.7**	**[100]**	**63.0**	**Total**	**251.7**	**[100]**	**57.3**

CN: Curve Number

Results and Discussion

SWAT Model Calibration and Validation

Using the KOMPSAT land use, the SWAT model was calibrated with 2 years (2001-2002) daily streamflow and monthly water quality (sediment, T-N and T-P) data, and validated for another 2 years (2003-2004) data. Figure 2 shows the observed versus simulated streamflow and water quality. The average Nash–Sutcliffe model efficiency of streamflow during validation was 0.81, and the coefficient of determination (R^2) of sediment, T-N and T-P were 0.86, 0.62, and 0.46 respectively.

The error of streamflow may come from the withdrawal through the paddy field irrigation and drainage from the middle of May to the early period of September and the uncertainty of saturated subsurface flow and groundwater contribution to streamflow. The errors were propagated to the prediction of water quality. The simulations of T-N and T-P showed somewhat poor fits with the observed values of the simulation period. But their reliability and performance were within expectations, considering the complexity of the watershed and pollutant sources. The SWAT model by the Landsat land use was also calibrated using the same data and KOMPSAT parameters.

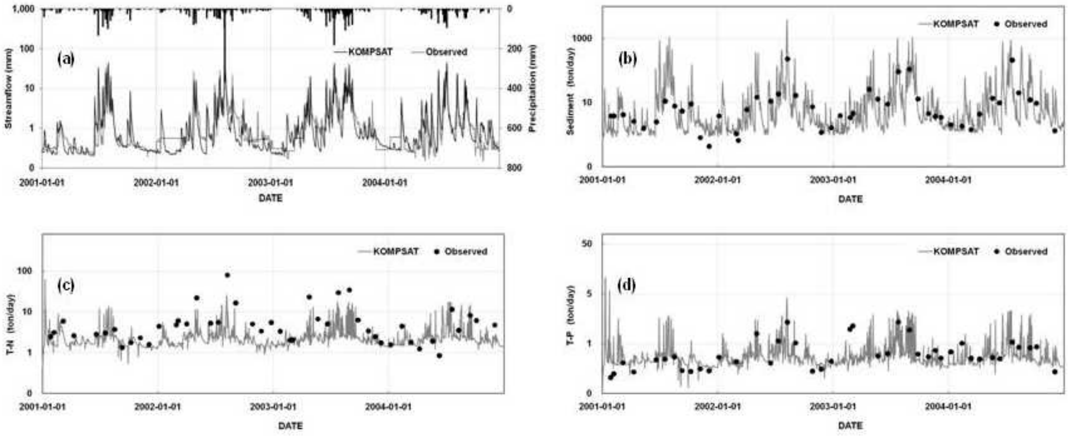

Figure 2. Comparison of observed and simulated daily (a) streamflow, (b) sediment, (c) T-N, and (d) T-P.

The impact of land use classification level on streamflow and water quality

To identify the effect of KOMPSAT detailed land use for SWAT modeling, the KOMPSAT data and results were compared with those of Landsat. SWAT deals with the surface runoff by dividing the land cover into pervious and impervious area. The impervious area of KOMPSAT land use was 4.3 % (10.2 km^2) greater than that of Landsat land use as in Table 1 (urban and road). The increase of impervious areas in KOMPSAT land use came from the minutely classified urban areas that were not classified in Landsat land use of 30 m resolution.

The increased impervious area affected the increase in watershed CN value. The higher CN is the greater surface runoff is. The KOMPSAT watershed average CN was 5.7 greater than the Landsat one as in Table 1. The KOMPSAT watershed runoff was greater than the Landsat one. Even though the results have modeling errors and there are some problems for one to one comparison by the different spatial distribution and resolution of two land uses, we can infer that the CN value basically affected the spatial runoff within the watershed. Table 2 shows the summary of KOMPSAT and Landsat annual watershed runoff for 4 years (2001-2004).

Table 2. Summary of KOMPSAT and Landsat annual streamflows for 4 years (2001-2004)

Year	Precipitation (mm)	Total Runoff (mm)			Runoff Ratio (%)		
		Obs.	K	L	Obs.	K	L
2001	1036.0	469.0	608.2	555.9	45.2	58.7	53.7
2002	1463.5	933.2	860.9	805.9	63.8	65.1	55.1
2003	1597.0	984.9	903.9	911.8	61.7	56.6	57.1
2004	1136.0	573.2	786.8	768.8	50.5	69.2	67.7
Mean	1272.9	740.1	790.0	760.6 [3.72]	55.3	62.4	58.4 [6.41]

Obs.: Observed, K: KOMPSAT, L: Landsat
[ ]: Percent of decrease based on KOMPSAT

Successively, the sediment and nutrient loads, T-N and T-P were simulated using KOMPSAT and Landsat land use data. Table 3 shows the summary of simulated results. For the soil erosion of SWAT, the 2 m KOMPSAT land use affected the slope and slope length computation and sediment yield. The watershed average LS (length and slope) factor in MUSLE was 0.137 in KOMPSAT and 0.118 in Landsat land use. Mengistu (2008) mentioned that the effect is more prevalent in mountainous watersheds compared to flat topography because of relatively more variations in slope and slope length in mountainous watersheds. The increased runoff and soil erosion directly affected the sediment. As the sediment yields increased, the T-N, T-P loads also increased as in Table 4. The sediment, T-N, and T-P of KOMPSAT land use showed 12.3 %, 4.1 % and 33.3 % higher than those of Landsat land use.

Table 3. Summary of annual KOMPSAT and Landsat annual water quality for 4 years (2001-2004)

Year	Sediment (ton/day)			T-N (ton/day)			T-P (ton/day)		
	Obs.	K	L	Obs.	K	L	Obs.	K	L
2001	5.1	3.6	4.4	2.6	2.2	2.1	0.2	0.3	0.2
2002	26.1	41.3	31.2	13.6	2.2	2.5	0.4	0.2	0.2
2003	23.9	28.7	26.1	10.0	3.2	2.6	0.5	0.4	0.3
2004	23.9	8.2	9.9	3.8	2.2	2.2	0.3	0.3	0.2
Mean	19.8	20.4	17.9 [12.25]	7.5	2.4	2.3 [4.16]	0.3	0.3	0.2 [33.3]

Obs.: Observed, K: KOMPSAT, L: Landsat
[ ]: Percent of decrease based on KOMPSAT

Summary and Conclusion

In this study, we tried to evaluate the SWAT streamflow, sediment, T-N, and T-P in case of using a quite detailed land use data of a 260 km^2 agricultural watershed of South Korea. The 2 m land use containing 26 categories was prepared by using KOMPSAT-2 satellite imagery acquired in 17th September 2007. The KOMPSAT land use could explain the type of upland crops.

Using the land use data, the SWAT model was calibrated and validated with 0.81 Nash–Sutcliffe model efficiency of streamflow was 0.81, and 0.86, 0.62, and 0.46 determination coefficient of sediment, T-N and T-P respectively during validation. To understand the classification level and scale effect of land use in the modeling, the SWAT results by KOMPSAT land use were compared with those by 30 m and 9 categories Landsat land use. Even though the two results could not be compared directly, we found that the 2 m KOMPSAT land use detected the impervious areas unrevealed in 30 m Landsat land use, and the increased impervious areas increased the watershed CN and runoff. In addition, the 2 m resolution affected the slope and slope length factors in the computation of soil erosion by using MUSLE. The increase of surface runoff subsequently influenced the sediment transport and affected the T-N and T-P transports.

Acknowledgements

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SESSION A3

Climate Change Applications (1)

A3-1

Multivarite Nonstationary Markov Chain Model and Its Use for SWAT Rainfall-Runoff Model

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Precipitation and runoff are key elements in the hydrologic cycle because of their important roles in water supply, flood prevention, river restoration, and ecosystem management. Global climate change, widely accepted to be happening, is anticipated to have enormous consequences on future hydrologic patterns. Studies on the potential changes in global, regional, and local hydrologic patterns under global climate change scenarios have been an intense area of research in recent years. The present study contributes to this research topic through evaluation of design flood under climate change. The study utilizes a weather state-based, stochastic multivariate model as a conditional probability model for simulating the precipitation field. An important premise of this study is that large-scale climatic patterns serve as a major driver of persistent year-to-year changes in precipitation probabilities. The simulated precipitation through the proposed downscaling model is used to evaluate change in design floods that are calculated by SWAT rainfall-runoff model. A case study is also performed with the Soyang Dam watershed in South Korea as the study basin. Finally, a comprehensive discussion on design flood under climate change is made.

A3-2

Hydrologic Response to Climate and Landuse Change in the Minnesota River Basin

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Predicting the combined effects of climate change and urbanization from empirical data is difficult and has a lot of uncertainty associated with it. However, forecasting the combined hydrological impacts of such anthropogenic changes is important in developing proactive strategies to protect water resources. Therefore, as part of EPA's Global Climate Research Program (GCRP), the implications of future climate prediction derived from four global climate models (GCMs) and future landuse forecasts obtained from Integrated Climate and Land Use Scenarios (ICLUS) datasets were used to evaluate possible future changes in the hydrologic response of the Minnesota River basin. The Soil Water Assessment Tool (SWAT) was used to investigate these complex stressors. This study uses the North American Regional Climate Change Assessment Project (NARCCAP) simulations of climate change over the period of 2040-2070 and the ICLUS demographic model to project population to 2100 for each county in the conterminous U.S. and will provide an initial assessment of separate and combined effects of urbanization and climate change on the hydrology of the Minnesota River Basin in USA. The results from this study will help policymakers and stakeholders to reassess proactive management actions that may enable the society to adapt these changes.

A3-3

Impact of Climate Change on Water and Soil Loss in Daecheong Reservoir Watershed

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The impact of climate change on the water budget and soil losses in the watershed of Daecheong Reservoir(Korea) was assessed using the Soil and Water Assessment Tool (SWAT). Future climate data including precipitation, temperature and humidity generated by introducing a regional climate model (Mesoscale Model Version 5, MM5) to dynamically downscale global circulation model (European Centre Hamburg Model Version 4, ECHAM4) were used to simulate the hydrological responses and soil erosion processes in the future 100 years (2001-2100) assuming the Special Report on Emissions Scenario(SRES) A1B. The results indicated that the climate change may increase the amount of surface runoff and thereby sediment load to the reservoir. Spatially, the impact was relatively more significant in the subbasin Bocheongcheon because of its lower occupation rate of forest land compared to other subbasins. Seasonally, the increase of surface runoff and soil loss was more significant during late summer and fall season when both flood control and turbidity flow control are necessary for reservoir operations. Occurrence of large flood events during these period is more signigicant for turbidity management because the suspended solids that remained water column can be resuspended by vertical mixing during winter turnover period. The study results provide useful information for the development of adaptive management strategy for the reservoir to cope with the expected impact of future climate change.

Assessment of MIROC3.2 hires Climate and CLUE-s Land Use Change Impacts on Watershed Hydrology using SWAT

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Abstract

This study is to evaluate the future potential climate and land use change impacts on hydrologic components for a mountainous dam watershed of South Korea. The MIROC3.2 hires GCM A1B data of 2020s, 2050s and 2080s was prepared through change factor simple statistical downscaling method. The future land uses were predicted by the conservation of land use and its effects model (CLUE-s) using Landsat satellite images from 1975 to 2000. By applying the future predicted climate and land use data to SWAT, the watershed hydrologic components of evapotranspiration, groundwater recharge, and streamflow were evaluated. For the future 2080s temperature increase of + 4.8 ℃, and 6.2 % forest decrease and 4.8 % grass increase conditions, The future evapotranspiration (ET) was mostly affected by the climate change than land use change. The 2080s ET showed + 23.1 % by climate change only while + 28.8 % change by climate plus land use changes scenario. The future groundwater recharge (GW) and streamflow (ST) were more affected by the land change. The future land use change impact on GW and ST were up to + 14.4 % and + 18.6 % respectively. The results notify that the groundwater resources will become more important in the future.

KEYWORDS: Climate change, Land use change, Hydrologic component, CLUE, SWAT

Introduction

The Intergovernmental Panel on Climate Change (IPCC) report reaffirms that the climate is changing in ways that cannot be accounted for by natural variability and that global warming is occurring (IPCC, 2007). The scientific consensus is that future increases of temperature will result in elevated global-mean temperatures with subsequent effects on regional precipitation, evapotranspiration, soil moisture and altered flow regimes in streams and rivers (Arnell, 2003, 2004; Wilby et al., 1994).

Land use change is also becoming important and has attracted a lot of scientific interest due to the close correlation between land use change and flood disaster and water resources management along with climate change (e.g. Fischer and Sun, 2001; Matthews et al., 1997; Verburg and Veldkamp, 2001). Land use changes directly affect evapotranspiration, infiltration and soil water storage which change the dynamics of surface runoff, subsurface runoff and groundwater recharge. The accompanying spatial and temporal distributions of vegetation cover change the parameters of calculating evaporation from soil and transpiration from vegetation (Park et al., 2009).

The aim of this study is to evaluate the climate and land use change impacts on watershed hydrology using SWAT (Soil and Water Assessment Tool) model. For a 6,642.0 km^2 typical mountainous watershed in South Korea, the 2020s, 2050s, and 2080s MIROC3.2 hires A1B future climate data were prepared and the CLUE-s future land use were predicted using the 6 past Landsat satellite images of 1975, 1980, 1985, 1990, 1995, and 2000.

Study Area Description and Data for Model Evaluation

Figure 1 shows the Chungjudam study watershed that has a total area of 6,642.0 km^2 located in northeast of South. The elevation ranges from 115 m to 1559 m with average hillslope of 36.9 % and average elevation of 609 m. The annual average precipitation was 1,359.5 mm, and mean temperature was 9.4 ℃ over the last 30 years. A dam of 97.5 m in height, 447 m in length, 9.7 million m^3 in volume, is located at the watershed outlet. More than 82.3 % is forested, and 12.2 % is cultivation area.

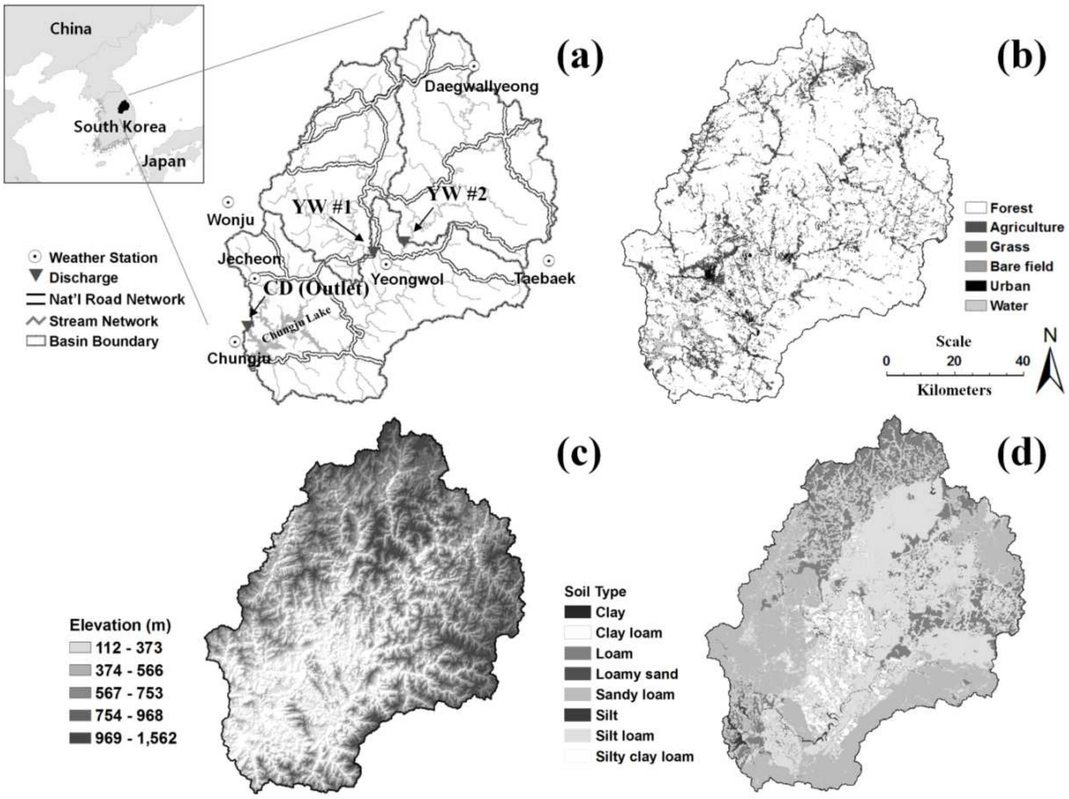

Figure 1. Location of Chungjudam watershed, and weather stations, streamflow (YW #1, YW #2 and CD) gauging stations (a), land use in 2000 (b), elevation (c), and soil type (d).

The watershed spatial data of elevation, land use, and soil were prepared for SWAT and CLUE-s. The 6 Landsat land uses (1975, 1980, 1985, 1990, 1995, and 2000) of 6 classes (forest, agriculture, grass, bare field, urban, and water) were obtained from Water Management Information System. The road and stream networks were also prepared for CLUE-s. The monthly MODIS LAI (Leaf Area Index) was prepared for Penman-Monteith evapotranspiration.

As the climate data, the MIROC3.2 hires A1B monthly data of 1977 to 2100 were adopted, and the 30 years (1977-2006) daily weather data of 6 ground meteorological stations were collected from Korea Meteorological Administration for watershed scale downscaling. The MIROC3.2 hires model, developed at the National Institute for Environmental Studies of Japan, has the spatial resolution of approximately 1.125° x 1.125°. For the SWAT model calibration and validation, the 6 years (1998-2003) daily streamflow data of 3 gauging stations (YW #1, YW #2, and CD in Figure 1) were obtained from Han river flood control office.

SWAT Model Description and Techniques for Future Data

SWAT hydrological model

SWAT is based on the concept of hydrologic response units (HRUs) which are portions of a subbasin that possess unique land use/management/soil attributes. The runoff, sediment, and nutrient loadings from each HRU are calculated separately using input data about weather, soil properties, topography, vegetation, and land management practices, and then summed together to determine the total loadings from the subbasin (Neitsch et al., 2001).

Downscaling technique of GCM climate data

The downscaling was performed by two steps. Firstly, the bias corrections were carried out for each weather station individually by applying Alcamo et al. (1997) and Droogers and Aerts (2006) method. The temperature and precipitation data of MIROC3.2 hires were corrected by fitting the 20C3M data with observed data (1977-2006, baseline period) to have similar statistical properties. This method is generally accepted within the global change research community (IPCC-TGCIA, 1999). Secondly, the MIROC3.2 hires data were downscaled using Change Factor (CF) method (Diaz-nieto and Wilby, 2005; Wilby and Harris, 2006; Park et al., 2009). Monthly mean changes in equivalent variables from the 30 years observed data and the climate data for three future time periods: 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) were calculated for the MIROC3.2 hires grid cell. The percent changes in monthly mean were applied to each day of 2000 weather data (selected as a base year for future assessment) of each weather station.

CLUE-s land use change model

The CLUE-s model comprises two parts: a non-spatial demand module; and, a spatially explicit allocation procedure. In the spatial explicit allocation procedure, non-spatial demands are converted into land use changes at various locations in the study area. The allocation is based on a combination of empirical and spatial analyses and dynamic modeling (Verburg et al., 2002). The empirical analysis of location suitability starts with the collection of relevant data (Lin et al., 2007). Spatial policies (such as the nature reserve area) and decision rules (including a land use transition matrix) are specified for the study watershed. For each type of the land uses, its specific conversion elasticity is specified to account for the typical conversion conditions of the different land uses (Verburg et al., 2002). The model allocates land use change in an iterative procedure using probability maps, the decision rules in combination with the actual land use maps, and the demand for the different land uses (Verburg et al., 2002).

Results and Discussion

SWAT model calibration and validation

The SWAT model was calibrated for 3 years (1998-2000) daily stramflow data at 3 locations (YW#1, YW#2, and CD), and validated with another 3 years (2001-2003) data. Figure 2 shows the comparison of observed and simulated streamflow at 3 locations. The average Nash and Sutcliffe (1970) model efficiency (NSE) during validation was 0.64 at YW#1, 0.52 at YW#2, and 0.72 at CD respectively. This means that the model predicted 64 %, 52 %, and 72 % better than simply using the average streamflow value during that period. The root mean square error (RMSE) during validation was 3.00 mm/day at YW#1, 3.35 mm/day at YW#2, and 2.28 mm/day at CD respectively. As seen in Figure 2, the error of YW#2 streamflow during winter periods showed the biggest RMSE, and the most errors came from the peak runoff difference for storms. We can infer that the YW#2 low flow errors arise from the uncertainties of forest humus layer function, soil and groundwater parameters.

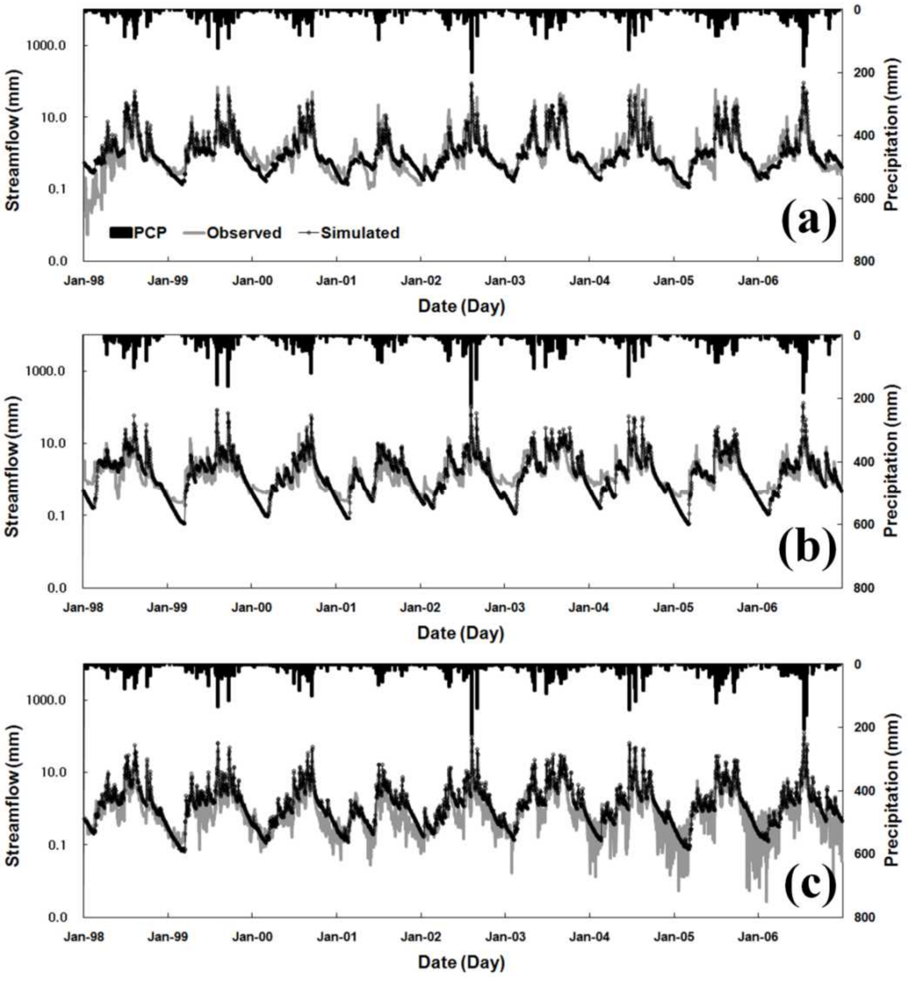

Figure 2. The comparison of observed and simulated streamflow at 3 locations YW #1 (a), YW #2 (b), and CD (c).

The MIROC3.2 hires A1B future climate data

As described above, the bias of MIROC3.2 hires A1B data was firstly corrected using 30 years (1977-2006) ground observed data. Secondly, the bias-corrected data were downscaled by applying CF statistical downscaling method. Figure 3 shows the monthly change of 2020s, 2050s, and 2080s downscaled precipitation and temperature based on 2000. The average bias of MIROC3.2 temperature was + 2.20 ℃. Regarding the relatively high elevation of the watershed within the MIROC3.2 hires grid cell, it seems that the correction was done in an acceptable direction. The future 2080s temperature increased up to 6.1 °C in winter, 5.3 °C in autumn, 4.3 °C, and 3.6 °C in summer. The future precipitation increased except August and September.

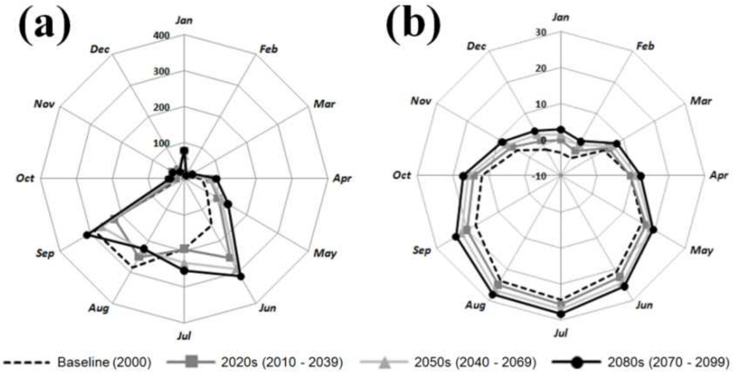

Figure 3. The monthly change of 2020s, 2050s, and 2080s MIROC3.2 A1B precipitation (a) and temperature (b) based on 2000.

The future predicted land use by CLUEs

The probability maps of each land use type were prepared from the logistic regression results. The forward stepwise logistic regression and relative operating characteristic (ROC) analyses between 5 land use types and 11 driving factors as in Table 1 were conducted by using Statistical Package for the Social Sciences (SPSS). The ROC values in the model range from 0.602 to 0.778, indicating a capable correlation for the spatial variation of land use patterns. Looking at the derived coefficients of each land use, the forest was dependent on the 11 driving factors. The urban were fully dependent on the distance factors. The grass and agriculture showed a mixed relation with altitude, distance, and soil driving factors. Bare field was independent on the soil factors.

Table 1. The logistic regression model for the 5 land use types with 11 driving factors

Driving factor	Land use type				
	Urban	Bare field	Grass	Forest	Agriculture
Altitude	–	0.0014	0.0010	0.0019	0.0007
Slope	–	–	–	0.0081	–
Aspect	–	- 0.0024	–	- 0.0006	–
Distance to national road	- 0.0003	- 0.0001	- 0.0001	- 0.0001	- 0.0002
Distance to local road	–	–	–	0.0002	–
Distance to city	- 0.0001	–	- 4.0E-05	0.0001	–
Distance to stream	- 0.0004	–	–	4.0E-05	–
Soil drainage class	–	–	–	- 0.1256	- 0.0960
Soil type	–	–	0.1100	0.0774	–
Soil depth	–	–	–	- 0.0027	–
Land use in the soil	–	–	–	- 0.0346	–
Constant	- 3.5653	- 5.2972	- 4.800	- 1.6195	- 2.2253
ROC	0.7340	0.7480	0.6020	0.7780	0.6460

–: not significant at 0.05 significant level, thus excluded in model

By applying the derived regression models and the prepared land uses, the future land uses of 2020, 2050, and 2080 were predicted. Figure 4 shows the future predicted land change areas.

The most changed areas were occurred around lake of Chungjudam, and near the urban area. The 2080 forest and agriculture decreased 6.2 % and 1.6 % respectively based on 2000. Meanwhile, the urban, bare field, and grass increased 1.7 %, 1.3 %, and 4.8 % respectively in 2080. The big increase of grass was come from the steady construction of pasture during 1970s and 1980s and golf courses in 1990s within the watershed.

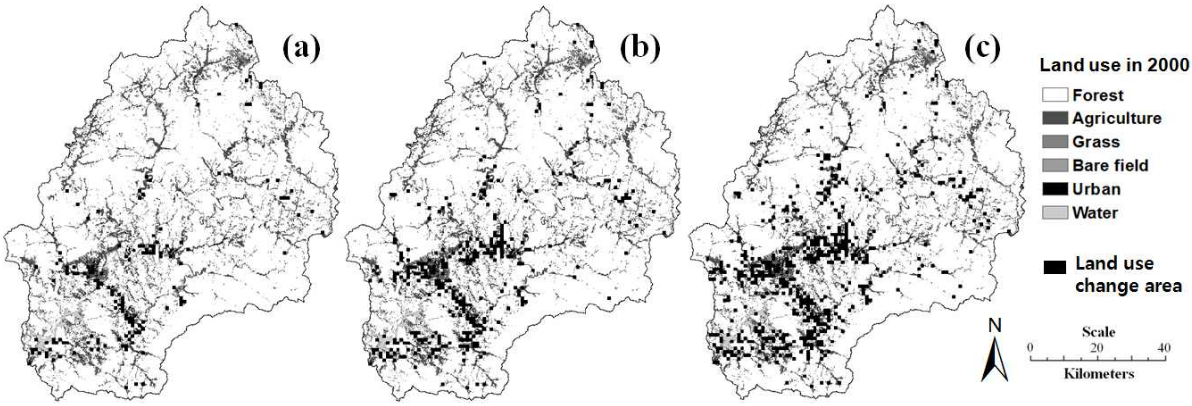

Figure 4. Comparison of land use change areas in 2020 (a), 2050 (b) and 2080 (c) based on 2000 land use.

The future impact on watershed hydrology by climate and land use changes

By applying the future MIROC3.2 downscaled climate and CLUEs land use conditions, the SWAT was run to evaluate the future watershed impact on hydrologic components viz. evapotranspiration (ET), surface runoff (SR), groundwater recharge (GW), and streamflow (ST).

Table 2. Summary of the future predicted annual hydrologic components by climate and land use change scenarios

Scenario		P (mm)	ET (mm)	SR (mm)	GW (mm)	ST (mm)
Baseline	2000	1155.1	408.9	404.4	225.7	678.3
Land use	2020	1155.1	420.9 (2.9)	422.7 (4.5)	233.5 (3.4)	711.8 (4.9)
	2050		428.0 (4.7)	436.0 (7.8)	241.3 (6.9)	742.6 (9.5)
	2080		439.2 (7.4)	451.3 (11.6)	248.0 (9.8)	766.2 (13.0)
Climate	2020s	1304.2 (12.9)	453.9 (11.5)	470.1 (12.1)	262.8 (13.1)	772.6 (11.8)
	2050s	1421.6 (23.1)	479.2 (17.7)	537.8 (28.3)	278.7 (19.9)	861.8 (24.7)
	2080s	1552.1 (34.4)	501.4 (23.1)	619.1 (47.7)	297.8 (28.1)	966.0 (39.8)
Land use with climate change	2020s	1304.2	460.3 (12.6)	474.2 (17.3)	270.3 (19.7)	811.3 (19.6)
	2050s	1421.6	491.2 (20.1)	569.1 (40.7)	293.1 (29.8)	953.0 (40.5)
	2080s	1552.1	526.8 (28.8)	636.8 (57.5)	321.7 (42.5)	1074.3 (58.4)

( ): Percent of increase based on baseline

Table 2 shows the summary of future predicted hydrologic components for land use change only, climate change only, and climate plus land use change scenarios. The future ET and SR were mostly affected by the climate change than land use change. The 2080s ET showed + 23.1 % by climate change only while + 28.8 % change by climate plus land use changes scenario, and the 2080s SR showed + 47.7 % by climate change only while + 57.5 % change by climate plus land use changes scenario. The future land use change impact on ET and SR were maximum + 7.4 % and + 11.6 % respectively. On the other hand, the future GW and ST were more affected by the land change compared to the ET and SR. The 2080s GW showed + 28.1 % by climate change only while + 42.5 % change by climate plus land use changes scenario, and the 2080s ST showed + 39.8 % by climate change only while + 58.4 % change by climate plus land use changes scenario. The future land use change impact on GW and ST were up to + 14.4 % and + 18.6 % respectively. The results notify that the groundwater resources will become more important as time passes, and should be sustained by the proper soil and land cover conservation practice, and the integrated watershed management for stable streamflow security.

Summary and Conclusions

This study was tried to evaluate the future potential climate and land use change impacts on hydrologic components for a 6,642.0 km^2 dam watershed of South Korea. For the future climate condition, the MIROC3.2 hires GCM A1B data of 2020s, 2050s and 2080s was prepared through change factor simple statistical downscaling method.

The future evapotranspiration (ET) was mostly affected by the climate change than land use change. The 2080s ET showed + 23.1 % by climate change only while + 29.4 % change by climate plus land use changes scenario. The future groundwater recharge (GW) and streamflow (ST) were more affected by the land change. The 2080s GW showed + 28.1 % by climate change only while + 59.4 % change by climate plus land use changes scenario, and the 2080s ST showed + 39.8 % by climate change only while + 58.3 % change by climate plus land use changes scenario. As mentioned, the groundwater resources will become more important in the future. Thus, we need efforts to sustain the groundwater resources by the proper soil and land cover conservation practice, and the integrated watershed management to secure stable streamflow. The future monthly dam inflow change gave us the clue for the future adjustment of dam operation rule for both efficient water use and flood control.

Acknowledgements

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SESSION B4

Database and GIS Application and Development (2)

B4-4

Development of Web-GIS Based SWAT Data Generation System

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Watershed topographical data is essential in the management for water resources and watershed management in terms of hydrologic analysis. Collecting watershed topographical and meteorological data is the first step for simulating hydrological models and calculating hydrological components. This study describes a specialized Web-based Geographic Information Systems, Soil Water Assessment Tool model data generation system, which was developed to support SWAT model operation using Web-GIS capability for map browsing, online watershed delineation and topographical and meteorological data extraction. This system tested its operability extracting watershed topographical and meteorological data in real time and the extracted spatial and weather data were seamlessly imported to ArcSWAT system demonstrating its usability. The Web-GIS would be useful to users who are willing to operate SWAT models for the various watershed management purposes in terms of spatial and weather preparing.

Keywords: SWAT, Real Time, Web-GIS

B4-5

Development of an Interface System to Couple SWAT2005 with HyGIS

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SWAT model was developed by USDA ARS(Agricultural Research Service) in early 1990s, and recently SWAT2005 model was developed. SWAT2000 model was generally used by using the interface system with ArcVeiw or HyGIS-SWAT. Recently, ArcSWAT was developed to run SWAT2005 model in connection with ArcGIS. In this study, the interface system coupling SWAT2005 model with HyGIS was developed to run SWAT2005 model in HyGIS system through analyzing input and output module of SWAT2005 model and upgrading previous version of HyGIS-SWAT. This study can contribute providing the environment to run SWAT2005 model by using domestic data proper to the situation of Korea effectively on the basis of GIS and database.

Keywords: SWAT2005, HyGIS, HyGIS-SWAT

Introduction

SWAT model interprets the behaviors of agricultural chemicals, water, and sediment according to soil, land use, and land management conditions. To run the SWAT model, not only does it require spatial information of basin and the time-series data related to precipitation, and meteorological phenomenon but also, any amount of aspatial information. The SWAT model has been operated by using the coupling system with GIS (Geographic Information System) which allows terrain analysis and database management together. AVSWAT (Di Luzio, et al, 2001), an interface system of SWAT is the widely used interface systems coupling the SWAT model with GIS, and in Korea, HyGIS-SWAT, an interface system for HyGIS and SWAT has been developed (Choi and Kim, 2006).

Texas A&M Univ., EPA (Environmental Protection Agency), and NRCS (Natural Resources Conservation Service) in USA are continuing research on the SWAT model, and ArcSWAT (Winchell et al. 2008), an interface system for the SWAT2005 model and ArcGIS has been developed recently including the development of the SWAT2005 model. Likewise, with the increased usability of the SWAT2005 model, the upgraded version of the SWAT2000 model, this study developed the interface system coupling SWAT2005 model with HyGIS, and we attempt to describe the development process and feature of the system including the difference from the existing HyGIS-SWAT which is the interface system coupling SWAT2000 model with HyGIS.

Overview of an Interface System Coupling SWAT2005 Model with HyGIS

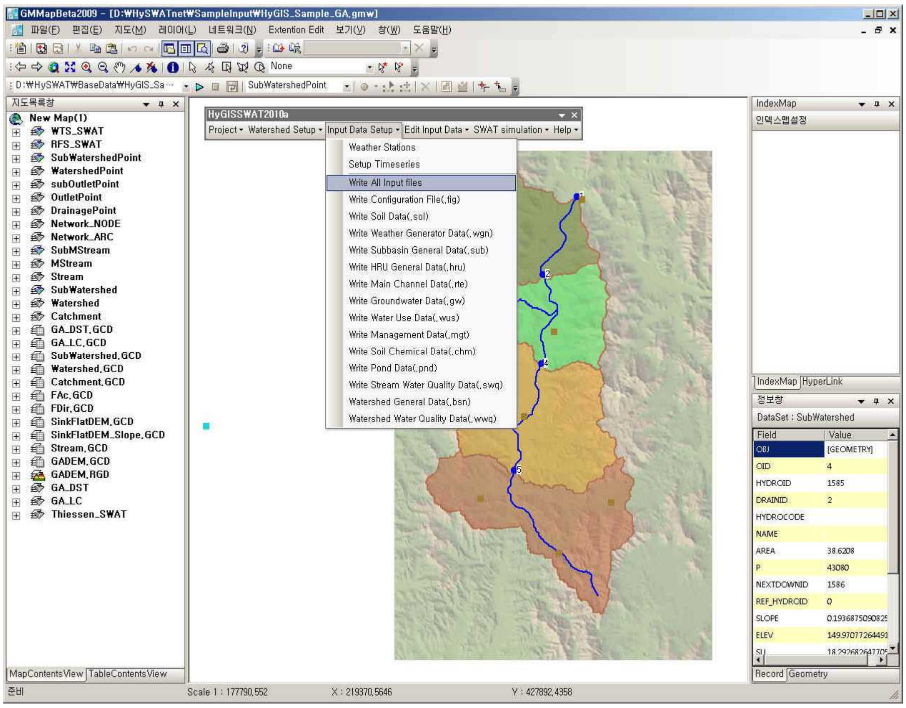
System coupling method

There are three methods to couple two or more individual systems; in general, an interchange method, interface method, and integration method. This study enabled HyGIS and the SWAT2005 model to be coupled through ‘interface method’. Thus, it mainly handles the pre-processing, such as constructing and editing input data, and creating input files of the SWAT2005 model, and the post-processing to process the results of simulation. And the system calls the execution file of the SWAT2005 which is a primitive model, an application program for DOS.

System development environment

HyGIS-Model (The Ministry of Science and Technology, 2007) provides the concept of the system to integrate and operate hydrologic, hydraulic, and water quality model with HyGIS which enables creation and analysis of hydrological geographic information, on the basis of GIS and database. This study aims to develop an interface system based on GIS and database to integrate HyGIS and the SWAT2005 model according to the development environment of the HyGIS-Model.

The system applies the GEOMania GIS which is adopted in HyGIS, and hence uses GSS (GEOMania Storage System) for spatial database. For aspatial database and the time-series database, the study uses mdb which enables convenient searching and editing via the Microsoft Access program. For the system development, we used GDK (GEOMania Development Kit) and Visual Basic .NET, and it can be operated as a pluggable add-on in dll format in the GMMap environment, a general GIS tool of GEOMania. Figure 1 shows the interface system (HyGIS-SWAT) added on GMMap.



DataSet : SubWatershed

Field	Value
OBJ	[GEOMETRY]
OID	4
HYDROID	1585
DRAINID	2
HYDROCODE	
NAME	
AREA	38.6208
P	43080
NEXTDOWNID	1586
REF_HYDROID	0
SLOPE	0.1936875090825
ELEV	149.97077264491
SU	18.2926826477

Scale 1 : 177790.552
X : 219370.5646
Y : 427892.4358

Figure 9. HyGIS-SWAT extension added on GMMap

System Development Methods

The existing HyGIS-SWAT is an interface system to couple the SWAT2000 model with HyGIS. Therefore, through reflective analysis of the differences between the SWAT2000 and SWAT2005 model, this study aims to develop an interface system that couple the SWAT2005 model with HyGIS by improving the system environment including pre and post-processing of existing HyGIS-SWAT.

Analysis of the SWAT2005 model

The SWAT2005 model is a modified and supplemented version of the SWAT2000 model, taking some of the items as primary targets among theoretical background, the types of applicable data, and the type of I/O files and I/O format (Neitsch, 2005). The interface system of HyGIS and the SWAT2005 model emphasizes on I/O file creation and processing to couple HyGIS and the SWAT2005 model rather than analysis process of the hydrological elements and theoretical background of the internal SWAT model; thus, the study concentrated on reviewing the change of I/O files between the SWAT2005 and SWAT2000 model. According to Neitsch (2005), the SWAT2005 model specifies additional of new input files, a parameter change, such as name changing and transferring of parameters, removal of the existing parameters and parameter addition in 16 types of I/O files; Neitsch et al (2005a; 2005b) states changes in input files, namely, a change of format, names of input files and application of rainfall data that is under one hour.

Development of new system through HyGIS-SWAT upgrade

The study aims to converse the existing HyGIS-SWAT that developed via Microsoft Visual Basic 6 to Visual Basic .NET thereby develop an interface system coupling the SWAT2005 model with HyGIS by modifying the interface of the SWAT model. For this, the study used Microsoft Visual Studio 2008 and .NET framework 3.5, and transformed form control, as well as ADO (ActiveX Data Object) that are created via MS COM (Component Object Model) component to .NET framework. We primarily upgraded Visual Basic 6 code to Visual Basic .NET using the code upgrade wizard provided by Visual Studio 2008, and carried out an upgrade process through replacement of reference components and error correction to ensure error-free building.

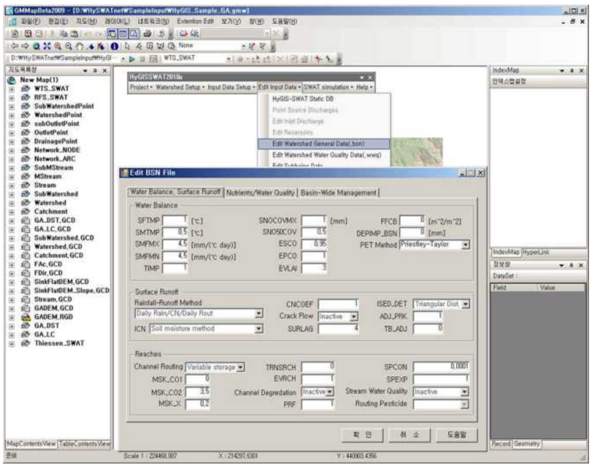
As such, we developed an additional I/O interface required for the SWAT2005 model by making the best use of the existing HyGIS-SWAT codes upgraded to .NET, and a prototype of an interface system for HyGIS and the SWAT2005 model by running the SWAT2005 model using input files created in a newly developed system.

Implementation of the Interface System Coupling SWAT2005 Model with HyGIS

GUI implementation

GUI, a program developed by the study, ensures easy and simple way of using a new program by user who had experienced the existing HyGIS-SWAT by maintaining the GUI of the existing HyGIS-SWAT. In addition, we created infrastructure ensuring the program to be used not only in Korea but also to meet potential demands overseas by adopting the basic language to English.

One of the main differences in the I/O of the SWAT2005 model and SWAT2000 model is that the .cod file used in the SWAT2000 model is no longer used and a change in the setting process of parameters and the parameter of each file, as the parameters included in the .cod file have been transferred to the file.cio and basins.bsn files.
Hence, in the existing HyGIS-SWAT, the creation and modification process of the basins.bsn and basins.wwq files that were involved in the model setup GUI have been added to an individual menu and GUI and the model setup GUI has been changed. Figure 2 – Figure 5 illustrate the main menu and GUIs added to the previous HyGIS-SWAT.



Water Balance

SFTMP 1 [℃]
SMTMP 0.5 [℃]
SMFMX 4.5 [mm/(℃ day)]
SMFMN 4.5 [mm/(℃ day)]
TIMP 1
SNOCOVMX 1 [mm]
SNO50COV 0.5
ESCO 0.95
EPCO 1
EVLAI 3
FFCB 0 [m^2/m^2]
DEPIMP_BSN 0 [mm]
PET Method Priestley-Taylor

Surface Runoff

Rainfall-Runoff Method Daily Rain/CN/Daily Rout
ICN Soil moisture method
CNCOEF 1
Crack Flow Inactive
SURLAG 4
ISED_DET Triangular Dist.
ADJ_PKR 1
TB_ADJ 0

Reaches

Channel Routing Variable storage
MSK_CO1 0
MSK_CO2 3.5
MSK_X 0.2
TRNSRCH 0
EVRCH 1
Channel Degredation Inactive
PRF 1
SPCON 0.0001
SPEXP 1
Stream Water Quality Inactive
Routing Pesticide

Figure 2. Menu for creating .bsn and .wwq files

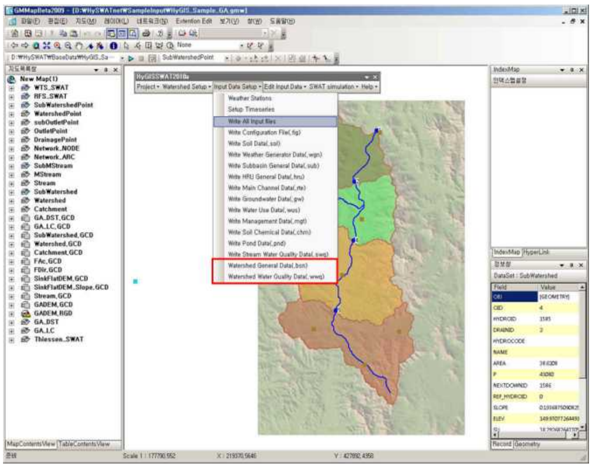
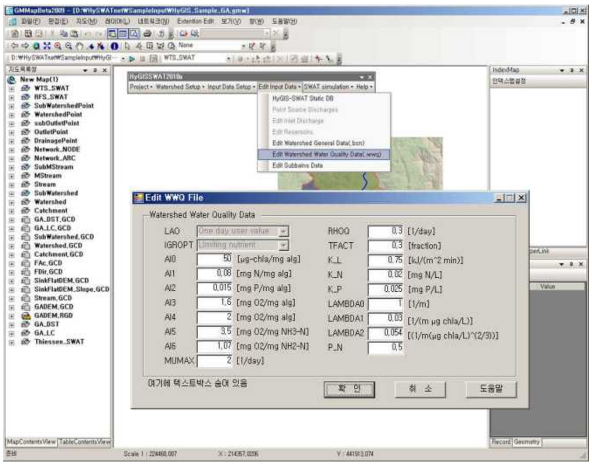


Figure 3. Menu and GUI for editing .bsn file

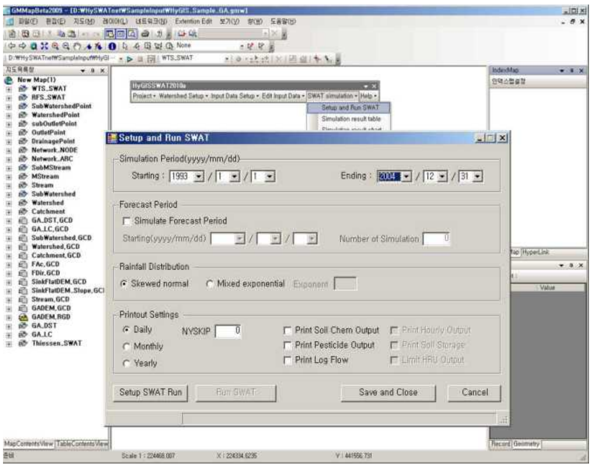


Watershed Water Quality Data

LAO One day user value
IGROPT Limiting nutrient
AI0 50 [µg-chla/mg alg]
AI1 0.08 [mg N/mg alg]
AI2 0.015 [mg P/mg alg]
AI3 1.6 [mg O2/mg alg]
AI4 2 [mg O2/mg alg]
AI5 3.5 [mg O2/mg NH3-N]
AI6 1.07 [mg O2/mg NH2-N]
MUMAX 2 [1/day]
RHOQ 0.3 [1/day]
TFACT 0.3 [fraction]
K_L 0.75 [kJ/(m^2 min)]
K_N 0.02 [mg N/L]
K_P 0.025 [mg P/L]
LAMBDA0 1 [1/m]
LAMBDA1 0.03 [1/(m µg chla/L)]
LAMBDA2 0.054 [(1/m(µg chla/L)^(2/3))]
P_N 0.5

여기에 텍스트박스 숨어 있음

Figure 4. Menu and GUI for editing .wwq file



Simulation Period(yyyy/mm/dd)

Starting : 1993 / 1 / 1
Ending : 2004 / 12 / 31

Forecast Period

☐ Simulate Forecast Period
Starting(yyyy/mm/dd) / /
Number of Simulation 0

Rainfall Distribution

● Skewed normal ○ Mixed exponential Exponent

Printout Settings

● Daily
○ Monthly
○ Yearly
NYSKIP 0
☐ Print Soil Chem Output
☐ Print Pesticide Output
☐ Print Log Flow
☐ Print Hourly Output
☐ Print Soil Storage
☐ Limit HRU Output

Figure 5. Model setup GUI

System process

The interface system coupling SWAT2005 model with HyGIS developed in the study operates through integration with HyGIS in the HyGIS-Model environment. The model, therefore, can be operated based on six conceptual databases (The Ministry of Science and Technology, 2007) which are suggested in the HyGIS-Model, and the static spatial database, as well as the static time-series database of HyGIS can be a direct reference in the same manner to the existing HyGIS-SWAT. Figure 6 demonstrates the relations between the system, the six databases and HyGIS in the HyGIS-Model environment. The HyGIS-SWAT in Figure 6 has its own peculiarity similar to a component that interacts with various factors namely, HyGIS and HydroTools, and database provided by the HyGIS-Model environment and through this, the program ensures independent management of each element.

The existing HyGIS-SWAT has been developed according to the design of the interface system via GIS and database, and the process developed by this study will go through the same process used in the existing HyGIS-SWAT. Figure 7 demonstrates the operation process of the interface system coupling SWAT2005 model with HyGIS.

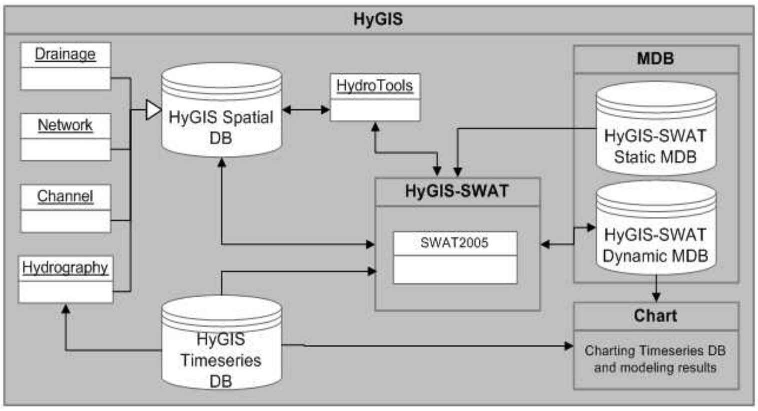


Figure 6. Relationships in HyGIS-Model environment

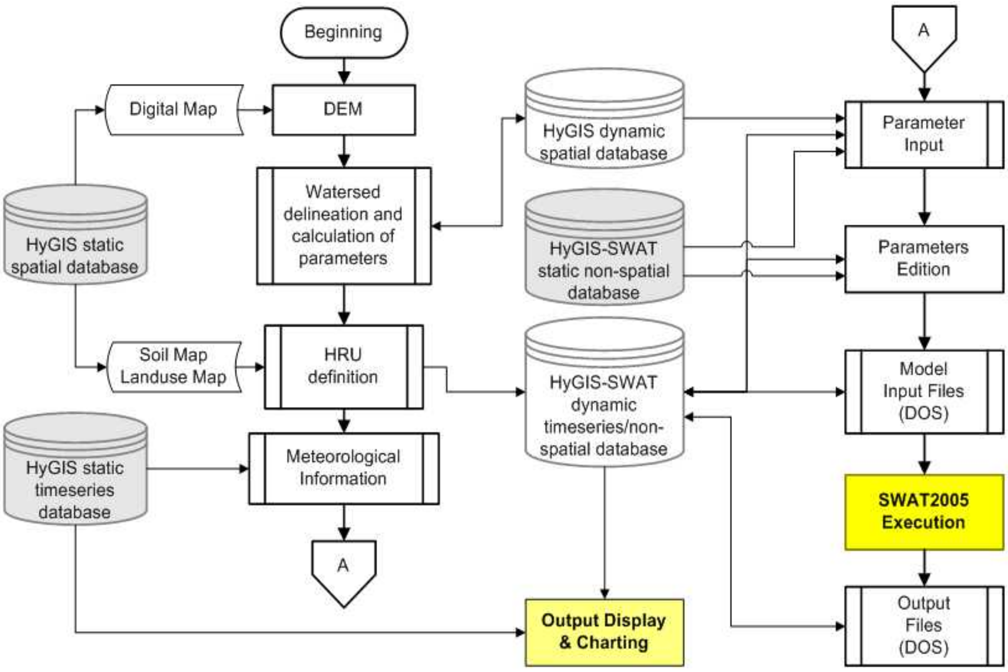


Figure 7. HyGIS-SWAT process

Conclusion

The study developed an interface system coupling HyGIS, the geographic system for water resources with the SWAT2005 model. We upgraded the existing HyGIS-SWAT system based on analysis of differences in I/O interface of the SWAT2000 model and the SWAT2005 model, and developed new HyGIS-SWAT. For the system development, we used GDK and Visual Basic .NET, a latest development tool and we were able to prepare a foundation that allows the continued performance of easy improvement and maintenance of the system henceforth. The application of the SWAT model is increasing gradually these days, and we expect a strong growth and application of the SWAT2005 and SWAT2009 model, the latest release henceforth through the development of an interface system with ArcGIS extreme. Under the circumstances, the study believes that the development of the interface system coupling SWAT2005 model with HyGIS will contribute to broadening the base of the SWAT2005 model in Korea. And also, we will continue to develop an interface system to couple the SWAT2009 model with HyGIS by upgrading the existing HyGIS-SWAT.

Acknowledgements

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B4-6

The Effect of Map Spatial Resolution on Simulation Result of SWAT, Case Study: Chelchay Watershed, Golestan Province in Iran

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Policy maker and watershed managers like to know impacts of the effects of watershed management measures. Complexity of watersheds natural system makes the direct study of management impacts difficult. So some models are developed for these evaluations that one of them is SWAT model (soil and water assessment tool). The aim of this paper is studying of spatial resolutions impact of input maps on runoff and sediment results from SWAT model. To achieve this aim, two series input maps with different spatial resolutions. First simulation was with high resolution maps from detailed study with 1: 50000 scale and second simulation was with global maps of the SWAT. Study area is Chelchay watershed in Golestan province, one of the sub watersheds of Gorgan River, with 25683 ha area and 766 mm mean annual rainfall. After the running of model using these two series of maps, the model results are assessed before calibration. The amounts of R^2 for runoff volume in first and second simulation respectively were 0.29 and 0.26. and for daily sediment concentration were respectively 0.4 and 0.03. The results showed that using maps with higher spatial resolution increased the model ability in estimation of runoff and sediment concentration. The significance of spatial resolutions in estimation of sediment concentration is higher than runoff. Also model can predict the seasonal changes of runoff before calibration.

Keyword: spatial resolution, SWAT model, runoff, sediment concentration, Chelchay, Iran

SESSION A3

Climate Change Applications (2)

A3-5

Estimation of Climate Change Effect on Nonpoint Source Pollution in Juam Lake Watershed

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The potential effect of future climate change on the nonpoint source pollution from the Oenam Cheon watershed, which was a subwatershed of Juam Lake watershed was evaluated with SWAT model. For the analysis of future climate change the GCM(CGCM3.2_T63) data by SRES(Special Report on Emission Scenarios) A2, A1B and B1 scenarios of the IPCC(Intergovermental Panal on Climate Change) were adopted. The future climate data (2010~2100) were corrected using 30 years (1971~2000) weather data of Gwangju station and downscaled by change factor (CF) method.

SWAT model was calibrated using monitored flow and water quality data. Nonpoint source pollution load under climate change scenarios was simulated with calibrated SWAT model parameters and downscaled weather data. Future climate data projected increased rainfall except B1 scenario. Temperature also showed increased trend for all scenarios and the highest increase of 4.1? for maximum and 3.2? for minimum temperature were predicted for A2 scenario.

SWAT model simulated decreased runoff for A1B and B1 scenarios due to increased evapotranspiration by increased temperature. But, SWAT simultion showed increased runoff under B1 scenario. Except B1 scenario, T-N and T-P loads were expected to be increasing under climate change scenario. T-N was expected to increase up to 55.6% compared to baseline and 80.1% increase was predicted for T-P, respectively.

A3-6

The Evaluation of Climate Change Impacts on Water Resources System by Using SWAT Model

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Global climate change has brought significant changes in the hydrological environment temporally and spatially. Those changes also have occurred in the Korean peninsular for the last several decades, increasing the magnitude of damage by droughts and floods.

As an attempt to explore the impact of drought which may be worsened by the climate change, the water balance of the Han-river basin is evaluated. However, enormous uncertainty and various assumptions may be involved in the evaluation of future water balance. Thus, to obtain results as subjective as possible and to minimize the uncertainty in the estimation, we suggest a methodology consisting of three successive sub-procedures: daily rainfall generation for 90 years (2010-2100) by the MM5 RCM with the A1B scenario, daily discharge simulations by SWAT using the generated daily rainfall data, and monthly water scarcity analysis by estimating water balance, relied on the SWAT simulation. In the analysis, the amount of water consumption has influence on water balance in the future critically. To consider the influence, we come up with three water consumption scenarios, namely, “LOW”, “MEDIUM”, and “HIGH”, depending on the expected amount of water consumption.

Firstly, the fifty sets of daily rainfall data for 90 years are generated based on the MM5 RCM with the A1B scenario to produce various daily rainfall events as much as possible. Secondly, each set is used as an input for the SWAT to generate the fifty sets of daily discharges during the drought period of each year of the simulation period (2010-2100). Finally, water scarcity analysis is performed by estimating water balance based on 150 combinations from three water consumption scenarios and the fifty sets of daily discharges.

As results, it is expected that water scarcity in the Han-river basin will increase for each water consumption scenario in the future. Also, the spatial water scarcity analysis shows that water shortage will increase from several sub-basins currently to the entire Han-river basin in the future. The results of this study can be used to establish appropriate plans for minimizing the impact of drought resulted from the climate change in Korean peninsula.

Keywords : Climatic Change, SWAT Model, Water Balance, Water Scarcity

A3-7

Projection of Future Watershed Hydrology by Applying SWAT through the Prediction of Vegetation Community under MIROC3.2 Hires Climate Change Condition

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This study is to evaluate the future watershed hydrology by predicting the forest community under MIROC3.2 A1B climate change scenario. The future data were downscaled by applying Change Factor statistical method through bias-correction using 30 years past weather data. The SWAT model was adopted for the hydrology evaluation, and the Youngsangang watershed (3,455 km^2) watershed located in the southwestern part of South Korea was selected. To predict the future distribution of forest vegetations, here simply classified into 3 categories of deciduous, coniferous, and mixed forest, the present forest distributions were represented by multinomial logit model with environmental variables viz. precipitation (P), temperature (T), elevation, degree of base saturation, and soil organic matter using 30 years (1971-2000) P and T. The future forest community was predicted by applying the MIROC3.2 A1B future climate change scenario. The future change of + 4.1 ℃ temperature and + 20.7 mm (1.5 %) precipitation in 2080s predicted 841.4 % (from 85.0 km^2 to 800.2 km^2) increase, 38.8 % (from 1413.4 km^2 to 865.3 km^2) decrease, and 85.8 % (from 194.8 km^2 to 27.7 km^2) decrease of deciduous, coniferous, and mixed forest areas respectively. Before the future assessment, the SWAT model was calibrated and validated using 5 years (1998–2002) and 6 years (2003-2008) observed dam inflow data with the average Nash-Shutcliffe model efficiency of 0.65 and 0.62 respectively. By applying the climate change and forest community scenario, the future watershed evaportanspiration of 2020s, 2050s and 2080s showed + 15.4 mm/yr, + 63.4 mm/yr, and + 85.7 mm/yr changes respectively based on the present evaportanspiration of 474.35 mm/yr.

Keywords: SWAT, Evaportanspiration, Multinomial logit model, climate change, forest community

Introduction

Among the GCMs (General Circulation Models) and emission scenarios used by the IPCC (Intergovernmental Panel on Climate Change), the temperatures in 2100 are expected to be between minimum 1.1 °C and maximum 6.4 °C higher than temperatures in 1900, accompanied by changes in rainfall intensity and amount (IPCC, 2007).

These changes will likely affect the hydrologic cycle and ecosystem (Ficklin et al., 2009), and the pattern of regional and seasonal climate change is various. Thus the assessment of the effects of climate change on the hydrologic cycle is critical for the proper management of water resources. By the climate change, the forest ecosystem is certainly expected to change and adjusted to the new temperature circumstances. By altering species composition, ecosystem structure, and nutrient availability, vegetation change feeds back to affect climate (Bonan, 2008). The forest community change will firstly affect the evapotranspiration temporally and spatially which occupies the big weight among the hydrologic components. The evapotranspiration change of watershed successively affects other hydrological state variables, soil moisture and groundwater flow, and eventually the streamflow.

Many studies have been done to elucidate the effects that climate change will have on watershed processes. There have been a number of notable studies on the possible effects of climate change on global boreal ecosystems in recent years (Goulden et al., 1997; Sellers, 1997; Myneni et al., 1997). Several empirical models for the prediction of plant species and vegetation type occurrence in relation to hydrological or hydrogeochemical habitat conditions have been developed (Venterink and Wassen, 1997; Ertsen et al., 1998). Although the warming that has occurred during the past 30 years is relatively minor compared to the predictions for the coming 50~100 years, there is already ample evidence that these recent climatic changes have affected a broad range of organisms, including plants, with diverse geographical distributions (Walther et al., 2002; Parmesan and Yohe, 2003; Thomas et al., 2004)

The goal of this study is to assess the potential impact of future climate change on hydrology of a watershed by predicting future forest community. The future forest vegetation information was prepared by applying the multinomial logit model with environmental variables viz. precipitation, temperature, elevation, degree of base saturation, and soil organic matter using 30 years (1977-2006) precipitation and temperature. The SWAT model was applied using the climate change data of MIROC3.2 based on SRES A1B scenario for a 3,455 km^2 watershed located in the southwest of South Korea.

Study Watershed Description

A 3,455 km^2 Youngsangang watershed located in the southwest of South Korea within the latitude-longitude range of 126.3 °E–127.1 °E and 34.4 °N–35.3 °N was adopted. Figure 1 shows the location, weather stations, and streamflow and water rain gauge stations of the watershed. The annual average precipitation of the watershed is 1,338.5 mm and the mean temperature is 13.1 ℃ over the last 30 years (1970-2000). For the land use, 50.6 % is forested, 33.6 % and 7.0 % of rice paddy and urban area respectively.

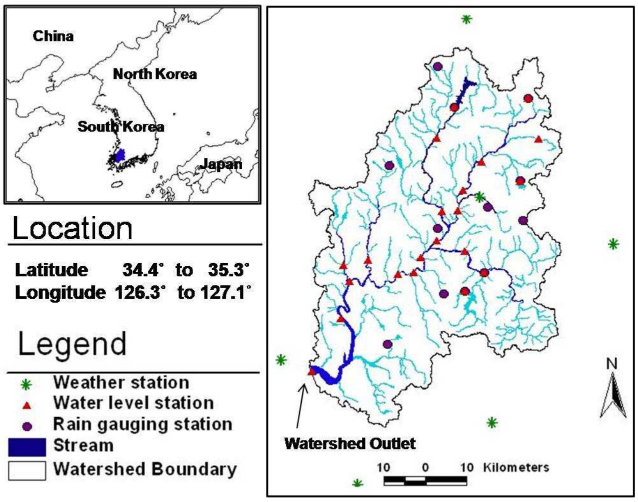

Figure 1. The location, weather stations, and gauge stations of the watershed.

Data Preparation for the Study Watershed

The spatial, weather and streamflow data

The SWAT model basically requires elevation, land use, soil and meteorological data for assessment of water yield at desired locations of watershed. Elevation data was rasterized from 1:5,000 vector map that was supplied by the Korea National Geography Institute (KNGI). Soil data were rasterized from 1:50,000 vector map that were supplied by the Korea Rural Development Administration (KRDA). The 2000 year land use was obtained from Water Resources Management Information System (WAMIS).

The future climate data

As a future climate data, the NIES MIROC3.2 hires data by SRES (Special Report on Emissions Scenarios) climate change scenarios (A1B) of the IPCC (Intergovernmental Panel on Climate Change) were adopted. In this study, a downscaling was performed by two steps. Firstly, the GCM data was corrected to ensure that 30 years observed data (1977-2006, baseline period) and GCM model output of the same period have similar statistical properties by the method used by Alcamo et al. (1997) and Droogers and Aerts (2005) among the various statistical transformations. This method is generally accepted within the global change research community (IPCC-TGCIA, 1999).

Secondly, the data was downscaled using Change factor (CF) method (Diaz-nieto and Wilby, 2005; Wilby and Harris, 2006). The CF method is a relatively straightforward procedure for constructing regional climate change scenarios and has been widely used for rapid assessment of climate change impacts (e.g., Arnell, 2004; Diaz-Nieto and Wilby, 2005). Monthly mean changes in equivalent variables from the 32 years data (1977-2008, baseline period) and the GCM simulations for three time periods: 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) were calculated for the GCM grid cell. The percentage changes in monthly mean were applied to each day of 2005 weather data (base year for future assessment) of each weather station. The procedure was applied for each weather data. The CF method assumes that the spatial pattern of the present climate remains unchanged in the future. However, the key advantages of the monthly CF approach are the direct scaling of the scenario in line with changes suggested by the GCM (Diaz-nieto and Wilby, 2005). The downscaling results showed that there were temperature increase of 1.9 ℃, 3.5 ℃, and 4.8℃ for 2020s, 2050s, and 2080s respectively. The future precipitation change was - 86.8 mm, 13.4 mm, and 20.7 mm for 2020s, 2050s, and 2080s respectively.

The future forest distribution data

For the modeling, the present forest distribution map classified into 4 categories of deciduous, coniferous, mixed (deciduous dominant), and mixed was prepared using 1:25,000 digital map. For the environmental variables, DEM (Digital Elevation Model), soil data (degree of base saturation and soil organic matter) and precipitation (P), temperature (T) (annual, seasonal, coldest and warmest) using 30 years (1971-2000) data were prepared.
The correlation of DEM, degree of base saturation, and soil organic matter to forest community was 0.62, 0.55, and 0.55 respectively. Among the temperature and precipitation variables, the coldest month temperature (-0.69) and summer precipitation (0.38) were selected. Using the 5 environmental variables, the multinominal logit models of each forest type were derived as in Table 3. Forest type is predicted by Table 1 equations, the best for each forest type, using multinomial logit model procedure. The model predicted area of each forest type showed 13.8 %, - 17.0 %, - 8.9 %, and - 4.3 % respectively compared to the present forest area.

Table 1. The derived multinomial logit model of present forest community with environmental variables

Forest type	Multinomial logit model					
Coniferous	- 5.8543	- 0.0032 A	- 0.0088 B	+ 0.0066 C	+ 0.0183 D	- 0.1158 E
Deciduous	- 7.6284	- 0.0069 A	+ 0.0728 B	+ 0.0077 C	+ 0.0181 D	+ 0.5555 E
Mixed (Dominant Deciduous)	- 6.7188	- 0.0076 A	+ 0.2214 B	+ 0.0090 C	+ 0.0096 D	- 0.3283 E
Mixed	- 7.0664	- 0.0106 A	+ 0.1545 B	+ 0.0073 C	+ 0.0194 D	- 0.1894 E

A: Degree of base saturation, B: Soil organic matter, C: DEM, D: Summer precipitation, E: The coldest month temperature

The future forest distribution map was produced by applying the future precipitation and temperature data to multinomial logit model within the present forest region of Landsat land use. Figure 2 shows the prediction results for 2020s, 2050s and 2080s respectively, and Table 2 shows the statistical summary of the future predicted forest cover change. The deciduous forest increased 715.2 km^2, and the coniferous and mixed forests decreased 548.1 km^2 and 167.1 km^2 in 2080s based on the present area.

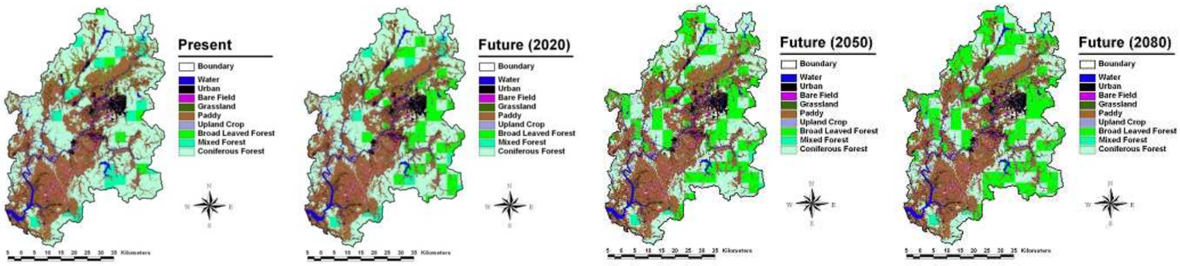

Figure 2. The land uses of the study watershed considering predicted forest community by the multinomial logit model; (a) present, (b) 2020s, (c) 2050s, and (d) 2080s

Table 2. Summary of the future predicted forest community using the multinomial logit model

Forest type	Present (km^2)	2020s (km^2)	2050s (km^2)	2080s (km^2)
Deciduous	85.0	380.2 [+ 295.2]	632.7 [+ 547.7]	800.2 [+ 715.2]
Mixed	194.8	119.6 [- 75.2]	33.0 [- 161.8]	27.7 [- 167.1]
Coniferous	1,413.4	1,193.4 [- 220.0]	1,027.4 [- 386.0]	865.3 [- 548.1]

Results and Discussion

SWAT model calibration and validation

The SWAT model was calibrated using 4 years (1998-2002 excluding 2001) daily streamflow data and validated by 5 years (2003-2008 excluding 2006) data. Table 3 summarizes the results of model calibration and verification. The average coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (ME) (Nash and Sutcliffe, 1970) were 0.71 and 0.64 respectively.

Table 3. Summary of model calibration and verification

Year	P (mm)	Q (mm)		R^2	RMSE (mm/day)	RMAE (mm/day)	ME	Note
		Obs.	Sim.					
1998	1421.1	1278.0	1630.3	0.77	4.42	0.81	0.75	C
1999	1294.4	904.9	1091.9	0.58	3.41	0.66	0.54	C
2000	992.4	1074.8	1141.3	0.64	4.43	1.24	0.61	C
2002	1307.0	1123.5	1243.5	0.71	4.74	0.70	0.71	C
2003	1892.0	1538.7	1664.7	0.80	3.98	0.61	0.78	V
2004	1598.2	1281.6	1429.0	0.75	6.44	0.70	0.74	V
2005	1122.4	714.9	891.7	0.74	2.24	0.55	0.33	V
2007	1550.6	1154.2	1200.0	0.73	5.26	0.80	0.70	V
2008	978.2	627.1	804.8	0.71	1.88	0.43	0.56	V
Mean	1297.1	1075.9	1051.1	0.71	4.09	0.72	0.64	

P:Precipitation, Q:Streamflow, R^2:Coefficient of Determination, RMSE: Root Mean Square Error, RMAE: Root Mean Absolute Error, ME:Nash-Sutcliffe Model Efficiency, C:Calibration, V:Validation

The evaluation of future climate change impact on watershed hydrology considering the change of future forest vegetation cover

The future watershed hydrological behavior was evaluated by applying MIROC3.2 data and future forest vegetation distribution. The prediction was also conducted with the forest cover unchanged in the future to identify the impact of forest vegetation. Table 4 shows the SWAT predicted results of future streamflow, evapotranspiration, and groundwater recharge of the watershed.

By the temperature increase of 1.9 ℃ in 2020s, 3.5 ℃ in 2050s, and 4.8 ℃ in 2080s, the future annual evapotranspiration showed 3 %, 13 %, and 18 % increase respectively based on 474.4 mm in 2005. The future temporal change of precipitation of winter and spring increase, and summer decrease influenced the groundwater recharge and streamflow directly proportional to the change as seen in Table 8. In the evaluation of future climate change impact on hydrology, the impact of forest vegetation cover change was 1 % for the watershed evapotranspiration.

Table 4. Summary of the future predicted annual and seasonal hydrologic components of the watershed

Period	**Temperature (℃)**	**Precipitation (mm)**	**Forest cover unchanged**				**Considering future forest cover change**			
			Q (mm) [V (%)]	QR (%)	ET (mm) [V (%)]	GW (mm)	Q (mm) [V (%)]	QR (%)	ET (mm) [V (%)]	GW (mm)
2005 [Baseline]										
Winter	-3.3	126.3	59.1	46.8	2.3	25.2	59.1	46.8	2.3	25.2
Spring	9.7	211.1	123.4	58.5	126.5	42.3	123.4	58.5	126.5	42.3
Summer	23.0	813.7	523.5	64.3	240.2	141.2	523.5	64.3	240.2	141.2
Fall	11.2	198.1	122.0	61.6	105.4	21.8	122.0	61.6	105.4	21.8
Annual	10.2	1349.2	828.0	61.4	474.4	230.5	828.0	61.4	474.4	230.5
A1B scenario – 2020s										
Winter	-0.3	228.2	147.5[149]	64.6	22.8[891]	68.2	147.1 [149]	64.4	22.8[891]	68.4

Spring	10.6	307.0	196.0 [58]	63.9	125.6 [-1]	65.9	200.2[62]	65.2	125.5[-1]	66.6
Summer	24.4	550.3	301.4[-42]	54.8	229.8 [-4]	87.4	299.3[-43]	54.4	229.0[-5]	87.0
Fall	13.5	176.9	92.3[-24]	52.2	113.2 [7]	15.4	92.1[-25]	52.1	112.4[7]	15.4
Annual	12.1	1262.4	737.2[-11]	58.4	491.4[4]	236.9	738.6[-11]	58.5	489.7[3]	237.5
A1B scenario – 2050s										
Winter	1.6	236.8	155.9[164]	65.8	32.2[1300]	72.0	155.8[164]	65.8	32.1 [1296]	72.5
Spring	12.1	321.3	179.4 [45]	55.8	148.7[18]	55.9	187.6[52]	58.4	148.4[17]	56.0
Summer	26.0	576.9	330.1[-37]	57.2	236.4[-2]	91.5	324.4[-38]	56.2	234.8[-2]	90.7
Fall	15.1	227.6	123.2 [1]	54.1	123.5[17]	22.9	123.5[1]	54.3	122.4[16]	23.3
Annual	13.7	1362.6	788.6 [-5]	57.9	540.8[14]	242.3	791.3[-4]	58.1	537.8[13]	242.5
A1B scenario – 2080s										
Winter	2.8	201.3	114.4 [94]	56.8	36.9[1504]	53.1	114.3[93]	56.8	36.9[1504]	53.6
Spring	13.3	376.1	211.6 [71]	56.3	158.0[25]	62.3	224.9[82]	59.8	157.5[25]	62.2
Summer	27.3	572.7	332.1[-37]	58.0	241.9[1]	90.1	322.6[-38]	56.3	238.6[-1]	88.3
Fall	16.5	219.9	114.3 [-6]	52.0	127.7 [21]	19.2	114.8[-6]	52.2	127.1[21]	19.7
Annual	15.0	1369.9	772.3 [-7]	56.4	564.6[19]	224.7	776.7[-6]	56.7	560.0[18]	223.8

Q: Streamflow, QR: Runoff ratio (Q/P), V: Variation, ET: Evapotranspiration, GW: Groundwater recharge, Winter: December – February, Spring: March – May, Summer: June – August, Fall: September-November

Summary and Conclusion

This study tried to evaluate the future watershed hydrology under MIROC3.2 A1B climate change scenario. In this study, the multinomial logit model was adopted to predict the future vegetation cover. With the 5 selected environmental variables, DEM, degree of base saturation, soil organic matter, the coldest month temperature, and summer precipitation through the correlation analysis with the present forest distribution, the model of each forest cover was derived. The future change of + 4.1 ℃ temperature in 2080s predicted 715.2 km^2 increase of deciduous forest, 548.1 km^2 decrease of coniferous forest respectively.

For the 3,455 km^2 Youngsangang watershed of South Korea, the SWAT model was setup using 9 years (1998-2008) streamflow data for the future assessment. By applying the climate change and forest community scenario, the future watershed evaportanspiration of 2020s, 2050s and 2080s showed + 15.4 mm/yr, + 63.4 mm/yr, and + 85.7 mm/yr changes respectively based on the 2005 evaportanspiration of 474.4 mm/yr. The impact of forest vegetation cover change was 1 % for the watershed evapotranspiration.

In this study, the change of forest vegetation cover was simply predicted by using the future temperature and precipitation data under the soil properties unchanged. In real, if the forest vegetation change is in progress for the century, the litterfall, soil water, soil nutrients are in a succession stage. We can infer that they will influence the infiltration and soil water capacity and successively the evapotranspiration. Thus in addition to the climate-vegetation dynamics, the vegetation-soil dynamics are necessary to understand and some factors to incorporate in the hydrologic model for the climate change study.

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A3-8

Comparison of Watershed Streamflows by Using the Predicted MIROC3.2hires GCM Data and the Observed Weather Data for the Period of 2000-2009 under SWAT Simulation

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The IPCC (Intergovernmental Panel on Climate Change) has offered GCM (General Circulation Model) data both the simulated in 20th century (1900~1999, 20C3M) and the predicted in the future 100 or 200 years (from 2000 to 2099 or 2199). Most water resources impact assessment studies using climate change scenarios have been conducted based on the IPCC GCM data during the past couple of decades. Even the evaluation of climate change impact on watershed hydrology and aqua-environment became a worldwide big issue and important to build a nationwide policy for the future proper adaptation against the abnormal weather, the assessment results have uncertainties such as GCM data in itself, downscaling methods, and model structure and parameters to be resolved. This study traces back the past decade's (2000-2009) GCM climate change data that were predicted in 2000 as of 2010, and compares the GCM data with the ground observed climate data for the same period. After that, we tried to identify the propagation of hydrological discrepancy by applying the two climate data through model run. For the climate change data, the MIROC3.2hires GCM data was selected and the SWAT (Soil & Water Assessment Tool) model was adopted to evaluate the difference of streamflows for the period of 2000 to 2009. For a 6,585.1 km^2 watershed located in the northeastern part of South Korea, the 2000-2009 MIROC3.2hires climate data of the IPCC SRES (Special Report on Emissions Scenarios) A1B and B1 scenarios were prepared through the bias correction and LARS-WG (Long Ashton Research Station – Weather Generator) downscaling using the past 3 decades observed data at 5 meteorological stations. Before the evaluation, the SWAT model was calibrated and validated with the 10 years (2000-2009) observed weather and streamflow data. The average Nash-Shutcliffe model efficiency was 0.66 during the model validation. The discrepancies on MIROC3.2hires GCM data and the corresponding hydrological behavior viz. streamflow, evapotranspiration, soil moisture content, groundwater recharge will be evaluated and discussed in depth.

Keywords: SWAT, climate change, uncertainty, GCM, LARS-WG, past decade, MIROC3.2hires

Introduction

Most water resources impact assessment studies using climate change scenarios have been conducted based on the IPCC (Intergovernmental Panel on Climate Change) GCM (General Circulation Model) data during the past couple of decades. Even the evaluation of climate change impact on watershed hydrology and aqua-environment became a worldwide big issue and important to build a nationwide policy for the future proper adaptation against the abnormal weather, the assessment results have uncertainties such as GCM data in itself, downscaling methods, and model structure and parameters to be resolved.

To aid accurate climate change and hydrologic modeling, quantitative descriptions of the uncertainty in climate outcomes are needed. Several studies have recognized this shortcoming and contributed estimates of the uncertainty in future climate. The uncertainty introduced by choice of driving GCM was assessed by Chen et al. (2006) who used 17 GCMs from CMIP (Coupled Model Intercomparison Project) 2 and a statistical downscaling method to produce regional precipitation scenarios over Sweden. The uncertainty in estimated precipitation change from different GCMs was larger than that for different regions. However, there was seasonal dependence, with estimates for winter showing the highest confidence and estimates for summer the lowest. Similar results were obtained by Wilby *et al*. (2006) who used three GCMs and two emission scenarios to explore uncertainties in an integrated approach to climate impact assessment; linking established models of regional climate, water resources and water quality within a single framework. The magnitude of estimated change differed depending on choice of GCM, for precipitation in particular, and differences were largest in summer months. The uncertainties introduced by downscaling from different GCMs make policy decisions difficult; the A2 run of HadCM3 produced lower river flows and greater water scarcity in summer by the 2080s leading to reduced deployable outputs and nutrient flushing episodes following prolonged droughts, however CGCM2 and CSIRO yielded wetter summers by the 2080s with increased deployable yield. Uncertainties introduced by choice of GCM have also been assessed by Salathé (2005) for a catchment in the north-western U.S. A local scaling method, derived by the ratio between observed and modeled precipitation at each local grid point (Widmann et al., 2003), was applied to data from three GCMs (ECHAM4, HadCM3, and NCAR-PCM) for use in a streamflow model. Variations in model performance were noted, with downscaled output from ECHAM4 able to capture the timing and distribution of precipitation events.

As many of the impacts of climate change will not be detectable in the near future (e.g. Wilby, 2006), there is a need for decision-making tools for planning and management that are robust to future uncertainties. In hydrological impacts research, there is a need for a move away from comparison studies into the provision of such tools based on the selection of robust, possibly impact-specific, downscaling methods. This is essential, together with the examination and understanding of uncertainties within the downscaling and modeling system. This study traces back the past decade's (2000-2009) MIROC3.2hires GCM data that were projected in 2000 as of 2009, and compares the downscaled MIROC3.2hires data by LARS-WG (Long Ashton Research Station – Weather Generator) with the ground observed climate data for the period to examine the degree of uncertainty in data used in impact assessment. After that, we tried to identify the propagation of hydrological disagreement by applying the two climate data through model run.

Materials and Method

Study watershed

The study watershed has a total area of 6,585.1 km^2 located in northeast of South Korea within the latitude-longitude range of 127.9 °E–129.0 °E and 36.8 °N–37.8°N. The elevation ranges from 115 to 1559 m with average hillslope of 36.9 % and average elevation of 609 m. The annual average precipitation was 1,359.5 mm, and mean temperature was 9.4 ℃ over the last 30 years. At the outlet of the watershed, Chungju dam that is 97.5 m in height, 447 m in length and has a volume of 9.7 million m3 is located. More than 83.4 % is forested, 8.8 % and 2.8 % of lowland are upland crop fields and paddy fields.

SWAT(Soil & Water Assessment Tool) model description

SWAT (Arnold et al., 1998) is a well-established, distributed eco-hydrologic model operating on a daily time step. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The smallest spatial subunits resolved by the model are hydrotopes (hydrologic response units), which are assumed to be homogeneous with respect to their hydrologic properties. In each of the hydrotopes, water balance is represented by several storage volumes: canopy storage, snow, soil profile, shallow aquifer and deep aquifer. The soil profile can be subdivided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow and percolation to lower layers. Percolation from the bottom of the soil profile recharges the shallow aquifer. A recession constant is used to lag flow from the aquifer to the stream. Other shallow aquifer components include evaporation, pumping withdrawals and seepage to the deep aquifer (Eckhardt et al., 2005).

The spatial, weather and dam inflow data

The SWAT model requires the data on elevation, land use, soil and weather for assessment of water yield at desired locations of watershed. Elevation data was rasterized from a vector map of 1:5,000 scale that was supplied by the Korea National Geography Institute. Based on the DEM (Digital Elevation Model), the watershed was divided into 18 subbasins. Soil data were rasterized from a vector map of 1:50,000 scale that was supplied by the Korea Rural Development Administration. The 2000 Landsat land use were obtained from Water Management Information System (WAMIS). The monthly MODIS LAI (Leaf Area Index) was prepared for Penman-Monteith evapotranspiration. The dam inflow has been gauged since 1974 by the Korea Water Resources Corporation (K-Water).

The MIROC3.2hires data downscaling

As a GCM data, the NIES (National Institute for Environmental Studies) MIROC3.2hires data by two SRES (Special Report on Emissions Scenarios) climate change scenarios (A1B and B1) of the IPCC were adopted. Here, A1B is ‘middle’ GHG (greenhouse gas) emission scenario and B1 is ‘low’ GHG emission scenario respectively.

The MIROC3.2hires data were downscaled by two steps for the study watershed. Firstly, the bias of GCM data was corrected by using the 30 years (1971-2000) observed climate data to have similar statistical properties. Secondly, the future GCM data of each weather station were downscaled using LARS-WG, a stochastic weather generator which can be used for the simulation of weather data at a single site (Racsko et al., 1991; Semenov et al., 1998) under both current and future climate conditions. The data are in the form of daily time-series for a

suite of climate variables, namely, precipitation (mm), maximum and minimum temperature (°C) and solar radiation (MJ m^{-2} day^{-1}) (Semenov et al., 2002).
Table 1 shows the summary of statistical analysis and Mann-Kendall test for the 2000-2009 MIROC3.2 hires downscaled results and compares with the observed values.

As seen in Table 1, the MIROC3.2 hires projected data showed + 0.4 ℃ and + 0.3 ℃ in temperature, and + 183.0 mm and + 81.0 mm in precipitation for A1B and B1 scenarios respectively compared to the observed average data of 2000-2009.

Table 1. Results of statistical analysis and Mann-Kendall test for the trend in annual and seasonal average for each scenario

Elements/ Scenarios	Temperature (℃)						Precipitation (mm)					
	Min.	Max.	Mean	SD	S.	Z	Min.	Max.	Mean	SD	S.	Z
Observed data (2000-2009)												
Spring	9.7	11.0	10.2	0.41	0.01	0.54	75.2	407.5	218.4	93.0	3.5	0.18
Summer	21.1	23.2	22.2	0.78	- 0.04	-0.09	521.1	1157.1	807.6	197.5	1.7	0.00
Autumn	9.9	12.7	12.0	0.84	0.15	1.62	109.9	292.3	292.3	146.2	- 18.0	- 1.61
Winter	- 5.2	- 0.8	- 2.7	1.35	0.11	0.54	56.4	145.3	84.0	30.7	- 5.6	- 1.43
Annual	10.0	11.1	10.5	0.34	0.05	1.00	953.5	1899.9	1427.0	321.8	- 17.4	- 0.54
MIROC3.2 hires (A1B, 2000-2009)												
Spring	9.3	10.2	11.3	0.63	0.14	1.71*	211.0	402.7	312.5	73.5	- 12.9	- 1.43
Summer	21.4	23.0	22.2	0.48	0.06	1.08	616.1	1049.6	758.4	135.1	- 0.8	- 0.72
Autumn	12.2	13.2	12.5	0.29	0.06	1.55	265.0	630.0	406.4	117.6	3.5	0.36
Winter	- 2.3	0.2	- 1.4	0.77	0.14	1.79*	81.1	198.6	125.9	37.5	- 2.6	- 0.54
Annual	10.4	11.7	10.9	0.47	0.11	2.16**	1180.6	2119.8	1610.0	273.3	- 15.4	- 0.36
MIROC3.2 hires (B1, 2000-2009)												
Spring	9.2	10.5	9.9	0.41	0.02	0.63	132.5	495.7	283.2	95.5	- 14.5	-1.43
Summer	21.4	23.5	22.2	0.66	0.12	1.98**	486.7	992.2	763.4	177.7	- 9.9	- 0.18
Autumn	12.0	13.4	12.8	0.41	- 0.04	-1.00	206.0	532.3	345.6	111.8	- 9.1	- 0.72
Winter	- 3.1	0.45	- 1.8	1.12	0.28	1.79*	56.8	161.4	110.6	35.0	- 6.1	- 0.89
Annual	10.5	11.8	10.8	0.45	0.10	1.35	1036.2	1999.2	1508.0	352.1	- 41.4	- 0.89

Min. – minimum, Max. – maximum, SD – standard deviation, S. – the slope of a trend line (trend line change rate, ℃ or mm / year), Z - Mann-Kendall trend test results (*$p<0.01$, **$p<0.005$).

Results and Discussion

SWAT-K calibration and validation

The daily streamflows of three gauging stations (YW#1, YW#2, and ChungjuDam) were used for model setup. The SWAT model was calibrated for 3 years (1998-2000) daily records and validated for another 3 years (2001-2003). The Nash and Sutcliffe (1970) model efficiency (ME) for streamflow ranged from 0.32 to 0.92. The ME value means that the model predicted from 32 % to 92 % better respectively than simply using the average streamflow value during that period.

The uncertainty analysis of GCM downscaled data for the assessment of watershed hydrological behavior

To identify how much the future projected MIROC3.2 hires downscaled temperature and precipitation produce errors in the evaluation of watershed hydrology, the SWAT model was run with the downscaled data and observed weather data for the past decade (2000~2009). Table 2 summarizes the results of statistical analysis and Mann-Kendall test for the results.

For the dam inflow, the annual inflow of A1B and B1 scenarios showed + 55.6 mm and – 33.7 mm compared to the simulated result by observed weather data. Looking at the seasonal inflow, the big differences occurred in spring and summer with + 70.6 mm, - 65.7 mm for A1B scenario and + 56.8 mm, - 82.0 mm for B1 scenario respectively. The reason was from the over- and under-projected precipitation of spring and summer season respectively as seen in Table 2. For the ET, the annual ET of A1B and B1 scenarios showed + 90.9 mm and + 81.4 mm compared to the simulated result by observed weather data. The reason was from the over-projected temperature for all season except B1 spring temperature.

For the SM, the annual SM of A1B and B1 scenarios showed + 8.9 mm and + 7.5 mm compared to the simulated result by observed weather data. For the GR, the annual GR of A1B and B1 scenarios showed +66.6 mm and +40.0 mm compared to the simulated result by observed weather data. These were mainly from the over-projected precipitation for spring and winter season as seen in Table 2.

Table 2. Results of statistical analysis and Mann-Kendall test for the trend in annual and seasonal average for each scenario

Components/ Scenarios	Groundwater recharge (mm)						Soil moisture contents (mm)					
	Min.	Max.	Mean	SD	S.	Z	Min.	Max.	Mean	SD	S.	Z
Observed data (2000-2009)												
Spring	21.2	101.7	50.8	22.2	- 0.3	- 0.54	110.8	138.4	122.4	7.2	0.3	0.00
Summer	92.2	150.0	122.5	16.4	1.3	0.36	116.8	139.6	127.7	7.3	- 1.6	- 1.97*
Autumn	58.4	134.1	97.1	24.2	-2.2	-0.89	113.1	127.0	120.9	5.3	- 0.1	0.00
Winter	14.1	28.0	19.8	4.1	- 0.5	- 1.07	105.2	125.2	141.6	10.3	- 1.3	- 0.89
Annual	218.0	390.0	283.5	52.3	- 2.5	0.00	102.4	140.0	120.0	11.7	0.2	0.18
MIROC3.2 hires (A1B, 2000-2009)												
Spring	47.9	113.3	83.0	19.3	- 2.0	- 0.36	116.4	136.5	128.5	6.8	- 0.8	- 0.89
Summer	102.7	158.0	123.5	14.8	- 1.1	- 0.72	116.3	128.1	122.6	3.5	- 0.1	0.00
Autumn	86.6	132.5	107.0	14.6	1.5	0.89	124.8	135.4	128.8	3.0	- 0.4	- 0.81
Winter	35.5	46.9	39.6	3.3	- 0.3	- 0.27	121.8	133.5	128.0	3.8	- 0.6	- 1.89*
Annual	279.4	424.0	350.1	36.8	- 2.2	- 0.54	119.2	143.0	128.8	7.5	- 1.6	- 2.15**
MIROC3.2 hires (B1, 2000-2009)												
Spring	44.0	114.1	72.6	20.6	- 4.7	- 2.15	117.8	135.9	126.9	5.8	- 0.7	- 0.63
Summer	95.2	142.6	119.4	17.7	- 0.6	0.00	105.1	126.0	119.3	5.9	0.6	0.72
Autumn	77.5	127.9	103.4	15.4	0.2	- 0.36	121.5	134.5	127.7	4.7	0.3	0.72
Winter	26.5	42.6	34.5	5.5	- 0.5	- 0.72	116.4	134.4	126.8	6.0	- 0.8	- 0.99
Annual	250.3	392.9	323.5	47.4	- 6.3	- 1.25	119.5	136.6	127.4	6.2	-0.1	0.36

Components/ Scenarios	Evapotranspiration (mm)						Dam inflow (mm)					
	Min.	Max.	Mean	SD	S.	Z	Min.	Max.	Mean	SD	S.	Z
Observed data (2000-2009)												
Spring	111.5	151.6	137.1	13.0	2.0	1.07	23.9	247.6	78.5	63.3	- 2.7	-0.18
Summer	175.2	261.7	227.6	25.1	0.5	0.18	196.6	846.3	483.7	233.9	1.7	0.00
Autumn	80.4	110.4	93.5	10.4	- 0.7	-0.54	83.9	483.7	261.7	133.6	- 17.2	-1.25
Winter	19.5	49.0	34.9	8.2	0.4	0.72	14.2	30.7	20.6	4.8	- 0.5	-0.81
Annual	457.1	541.4	507.4	28.3	3.4	0.89	460.7	1305.3	830.8	285.1	- 16.7	-0.54
MIROC3.2 hires (A1B, 2000-2009)												
Spring	136.9	171.0	152.6	10.6	- 0.4	-0.81	65.1	236.7	149.2	51.1	- 9.3	-1.61
Summer	202.7	295.9	263.0	27.9	- 2.2	-0.36	262.3	761.5	418.1	146.1	- 4.5	0.00
Autumn	113.4	129.9	120.2	5.6	- 0.1	0.00	133.5	552.1	284.7	129.8	5.8	0.18
Winter	44.1	55.3	49.6	3.7	0.2	0.00	39.1	53.4	44.9	4.8	- 0.1	-0.27

Annual	548.9	615.7	598.4	19.2	- 1.2	-0.89	501.8	1332.1	886.5	256.8	- 10.9	-0.54
MIROC3.2 hires (B1, 2000-2009)												
Spring	123.4	172.6	145.7	15.1	- 2.9	-2.15	56.9	289.5	135.3	65.9	- 12.3	-1.43
Summer	223.6	292.0	263.3	26.3	- 0.1	0.00	163.8	651.0	401.8	169.8	- 14.5	-1.07
Autumn	106.2	138.6	118.7	10.3	- 1.0	-0.72	94.5	420.7	234.7	114.4	- 10.0	-0.89
Winter	35.3	58.2	45.5	7.0	1.4	1.61	27.7	48.4	38.5	7.4	- 0.9	-0.81
Annual	540.8	631.1	588.8	26.8	-2.2	-0.72	368.9	1228.5	797.2	306.3	- 38.5	-0.89

Min. – minimum, Max. – maximum, SD – standard deviation, S. – the slope of a trend line (trend line change rate, mm / year), Z - Mann-Kendall trend test results (*p<0.01, **p<0.005).

Summary and Conclusions

This study tried to assess the uncertainty of GCM downscaled 2000-2009 data that were predicted in 2000 as of 2009 by comparing the data with the observed weather data of the period, and identified the impact on the hydrological behavior by applying the two climate data through SWAT model run.

For a 6,585.1 km^2 mountainous dam watershed located in the northeast of South Korea, the 2000-2009 MIROC3.2hires climate data of the IPCC SRES (Special Report on Emissions Scenarios) A1B and B1 scenarios were prepared through the bias correction and LARS-WG downscaling using the past 3 decades (1971-2000) observed data at 5 meteorological stations. The SWAT model was prepared with the average Nash-Sutcliffe model efficiency was 0.66.

The 2000-2009 MIROC3.2 hires projected data showed + 0.4 ℃ and + 0.3 ℃ in annual average temperature, and + 183.0 mm and + 81.0 mm in annual precipitation for A1B and B1 scenarios respectively compared to the observed weather data. Even for the annual over-projection, the over-projected spring precipitation and the under-projected summer precipitation showed + 70.6 mm, - 65.7 mm dam inflow for A1B scenario and + 56.8 mm, -82.0 mm dam inflow for B1 scenario respectively compared to the simulated results by using the observed weather data. The annual ET of A1B and B1 scenarios showed + 90.9 mm and + 81.4 mm by the over-projected temperature. The annual soil moisture and groundwater recharge were over-projected by the over-projected precipitation for spring and winter periods.

We confirmed the disagreement of future projected climate data with the observed weather data of the past 10 years, and the mis-projected climate data affected the evaluation of future hydrological behavior of a watershed. Thus, we need efforts to reduce the disagreement, for example, by developing a new bias correction method, weather generation technique, and by augmenting the observed weather data for downscaling process.

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SESSION B5

Biofuel and Plant Growth

B5-1

Hydrologic Effects of Bio-char Applications on Corn Production Fields in Illinois

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SWAT simulations were used to assess the hydrologic impacts of using corn stover as a feedstock for mobile pyrolysis units in the Elkhorn Creek watershed in Illinois. Northern Illinois was chosen as the study area for mobile pyrolysis units that utilize corn stover as a feedstock since Illinois is a major corn production state with several oil refineries that could receive bio-oil from mobile pyrolysis units. It was assumed that mobile pyrolysis units consume corn stover feedstock at a rate of 40 tons/day. Pyrolysis produces bio-char, syn-gas, and bio-oil with 30% of the feedstock ending-up as bio-char. The SWAT model was calibrated and from stream flow and sediment transport for existing conditions. Hydrologic changes due to different residue management scenarios (0 and 100% removal) were simulated. Hydrologic properties such as water holding capacity, porosity, as well as soil erosion, nutrient content, and biomass reduction may be affected by residue management. During calibration, parameters such as the curve number, soil evaporation compensation factor, available soil water capacity and baseflow fraction values were changed. The Nash-Sutcliffe coefficient was used to assess simulation accuracy for monthly stream flow. A Nash-Sutcliffe coefficient of 0.71 was obtained from stream flow indicating good agreement between simulated and observed monthly streaflows. The two residue cover management options had little influence on changes in stream flow and sediment yield in the Elkhorn watershed. However, the amount of residule left did have a large impact on the crop yields in the Elkhorn Creek watershed.

KEYWORDS: SWAT, mobile pyrolysis, corn stover feedstock, residue management, Illinois, hydrologic changes

Introduction

The pyrolysis process converts biomass to bio-oil, syn-gas, and bio-char. Corn stover is a possible feedstock for pyrolysis. However, to minimize feedstock transportation costs to a central plant, mobile pyrolysis units could be deployed to locations with high concentrations of corn stover. The mobile pyrolysis units would convert low density corn stover to high density bio-oil thereby reducing transportation costs.

However, the hydrologic effect of removing corn stover from corn production fields has to be assessed. Specifically, the impacts of corn stover removal on stream flow, sediment transport, and corn production rates needs to be evaluated to ensure that this method of bio oil production is environmentally sustainable. Previous studies using the Soil Water Assessment

Tool (SWAT) have investigated residue management and the resulting environmental impacts. Santhi et al. (2006) studied BMP practices in the West Fork Watershed of the Trinity River Basin in Texas to reduce sheet and rill erosion leaving adequate residue on the ground after harvest and prior to tillage for planting. The BMP scenarios reduced sediment and nutrient loadings to surface water at the farm level.

The SWAT model has been wildly used in the United States (U. S.) as well as many other countries (Arnold and Fohrer, 2005) to simulate non-point source pollution in agricultural watersheds. In this study, the SWAT model was used to predict monthly streamflow, sediment yield and biomass production. The hydrologic impacts of two residue management practices, 0% and 100% residue left on the field were investigated.

Methodology

Study Area

The study area was Elkhorn Creek near Penrose, IL (Figure 1). The Elkhorn Creek watershed is 376.4 km^2 and is located in Ogle, Carroll, and Whiteside counties in Illinois. Corn for grain is the primary agricultural crop grown in these counties. The USGS gauging station number "05444000" is located on Elkhorn Creek (latitude is 41°54'10" / longitude is 89°41'46") in Whiteside County. Annual, monthly, and daily discharge as well as water quality data is available at the National Water Information System from the USGS website for this gauging station. Elkhorn Creek is located in the Hydrologic Unit Code (HUC) number is 0709005. Subsurface drain tiles are used extensively in Illinois, and the Illinois drainage guidelines are available online at http://www.wq.uiuc.edu/dg/subsurface.htm. The subsurface drainage in Illinois is typically installed three feet below the surface.

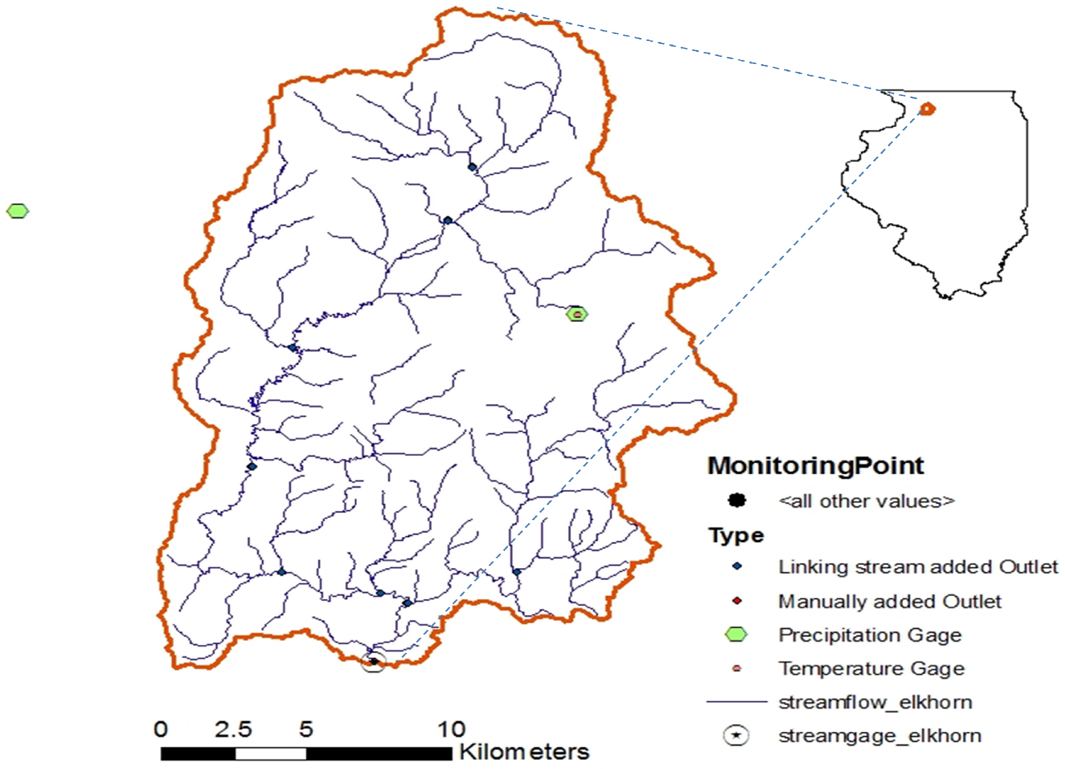

Figure 1. Location of the Elkhorn Creek watershed with the stream network and monitoring points near Penrose, IL.

Databases and Model inputs

The ArcSWAT 2005 (Soil and Water Assessment Tool) 2.3.4 model was selected for this project. SWAT is a basin-scale, continuous-time hydrology model that can produce simulation results on a daily, monthly, or annual basis (Arnold and Fohrer, 2005). The model can simulate water quantity as well as water quality (Saleh et al., 2000). This study will focus on the effects of corn stover removal on streamflow, sediment yield and biomass production in the Elkhorn Creek watershed from June 1995 to April 1997.

Topography

The Digital Elevation Model (DEM) used in this study was obtained from the National Hydrography Dataset (NHD). The average slope of the watershed was 4.0%. In the SWAT model, two different slopes are applied to the study area; 1) 0-4% and 2) 4-99%. The study area was delineated based on the threshold area, of 1,000 ha, and the outlet point for this study was selected to the USGS streamflow gauging station on Elkhorn creek at Penrose, IL. Streamflow data is available at this gauging station from October, 1939 to September, 2009.

Landuse

The locations of actual planted agricultural fields for the state of Illinois are obtained from the 2008 cropland data layer (CDL) database. These were GIS raster files from the spatial analysis research section of National Agricultural Statistics Service (NASS). The CDL program uses imagery from the Resourcesat-1 AWiFS and the Landsat 5 TM satellites and provides digital categorized geo-referenced images exported to Geotiff format for use in the ArcGIS interface. The spatial analysis research section annually provides the CDL with crop specific digital layers in GIS raster formats (USDA-NASS, 2009). Figure 2 shows reclassified landuse map from the SWAT simulation. The corn area is 54.3% of the total study area, which is 20,444 ha. The soybean area and hay area are 18.6% and 11.3% of the total study area. Residential-low density (URLD) and forest-deciduous (FRSD) area are 6.2% and 6.2% of the Elkhorn creek watershed area. The corn, soybean and hay fields are more than 80% landuse of the watershed area in this agricultural watershed.

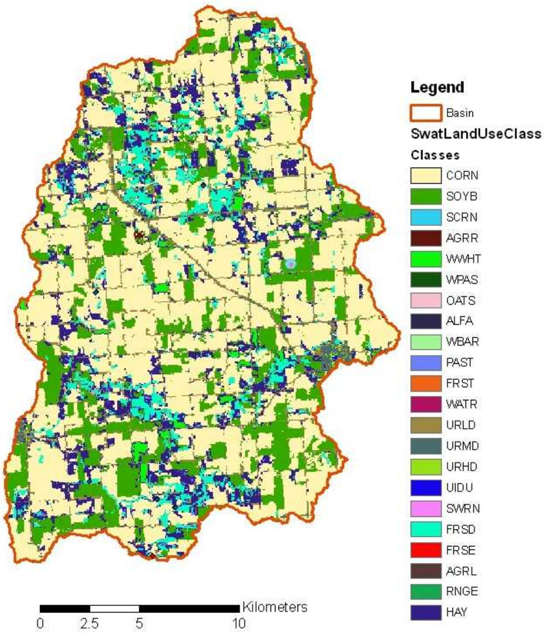

Figure 2. The SWAT land use classification system for the Elkhorn Creek watershed near Penrose, IL.

Soils

The soil properties were mapped based on State Soil Geographic (STATSGO) database by National Resources Conservation Service (NRCS) (USDA-NRCS, 2006). Two major soil types and two minor soil types were used in the Elkhorn Creek watershed simulations. The primary soil series are the Ogle soil (66.9%) and Fayette soil (32.7%) in the study area. The Hydrologic Soil Group (HSG) of this area is classified as a "B" soil type.

Weather

Daily precipitation and air temperatures were obtained from weather stations named Polo 5 NW (-89:36 N, 42:02 W) and Lanark (-89:50 N, 42:05 W) in the Elkhorn Creek watershed. This data was obtained from National Climatic Data Center (NCDC at http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD). Weather data was available from 1995 – 2009 at the Polo 5 NW station and from 2000 – 2009 at the Lanark station. Wind speed, solar radiation, and relative humidity data were generated by the SWAT weather generator during the simulations.

Water quality samples for Illinois

Water quality samples for Illinois were obtained from the USGS National Water Information System at USGS gauging station "05444000" Elkhorn creek near Penrose, IL. There were 155 samples available for sediment (mg/L) from July 1979 to April 1997.

SWAT Simulation Set-up

There were 17 subbasins and 156 Hydrologic Response Units (HRU)s for the study area at Elkhorn Creek during the SWAT simulations. The HRUs was defined 10% land use, 10% soil class and 5% slope class. The SWAT simulation period was from June 1995 to April 1997 and output was assessed on a monthly basis. The simulation period was selected based on data avaiibility from weather stations and USGS gage stations. The Nash-Sutcliffe (1970) coefficient was used to assess simulation performance. The Nash-Sutcliffe Coefficient is defined as, $1 - [\sum (Q_m - Q_p)^2] / [\sum (Q_m - Q_{avg})^2]$ (where Q_m is the measured value, Q_p is the predicted value, and Q_{avg} is the average measured value). The Nash-Sutcliffe coefficient for the uncalibrated simulation was 0.35 when simulated and measured streamflow was compared.

Residue Management

The management practice focused on two options; 1) 0% residue left on the filed, and 2) 100% residue left on the filed. There are two main categories of residue management available in SWAT simulations. Each management option has automatic methods for planting/beginning of the growing season. This automatic method initializes the growth of a specific land cover/plant type in each HRU based on the percentage of accumulated heat units. For this simulation, this was set to 0.15. The following accumulated heat unit fractions were used to time specific operations; 0.15 for planting, 1.0 for harvest/kill for crops with no dry-down, 1.2 for harvest/kill for crops with dry-down and 0.6 for hay cutting operation (Neitsch et al., 2005). Harvest and kill operation harvests the portion of the plant selected as yields, removes the yield from the HRU and converts the remaining plant biomass into residue on the soil surface. The harvest only operation includes no kill after harvest, and harvests only the portion of the plant selected as yield and removes the yield from the HRU, but allows the plant to continue to grow. The harvest and kill operation and the harvest only option in the SWAT simulations had the same heat unit fractions of 0.15 for planting and 1.2 for harvest/kill for crops with dry-down.

The Drain Simulation

Subsurface drainage was simulated in the Elkhorn watershed using the tile drain management parameters in SWAT. The depth to subsurface drain (DDRAIN) was set to 3 ft (914.4 mm) in the Elkhorn wathersehd. Time to drain soil to field capacity (TDRAIN) and drain tile lag time (GDRAIN) were set to 24 hr and 2 hr in the SWAT simulation. Water flows into the outlet by main drains from the subsurface drainge system.

Baseflow Simulation

The separation of the base flow from streamflow determines the contribution from overland flow during a rainfall event in a watershed. Automated methods for estimating baseflow and groundwater recharge (Arnold and Allen, 1999) from streamflow records were downloaded from http://swatmodel.tamu.edu/software/baseflow-filter-program and were used in this study. The observed data was obtained from daily streamflow data at the USGS gage station and used for the input dataset.

The results of the baseflow separation analysis indicated that baseflow ranged from 0.56 and 0.71. In SWAT, the base flow recession variable (ALPHA_BF) is a direct index of groundwater flow response to changes in recharge. This was set to 0.0197 day for the SWAT simulations. The model input varialbe for ground water delay (GW_DELAY) was set to 117 days (the default is 31 day). This represents the water movement lag time from the shallow aquifer the vadose and groundwater zones. The groundwater flows depend on the soil profiles, water depth and the hydraulic properties of the geologic formations.

Sensitivity Analysis

A sensitivity analysis was performed to identify the primary SWAT input parameters that affect model simulations for monthly streamflows. SWAT 2005 uses a combination of Latin Hypercube Sampling and One-At-a-Time sensitiviy analysis (LHS-OAT method). The daily streamflow data from 1939 to 2009 from the USGS gaguing station was used in the sensitivity analysis and a total 26 parameters for flow analysis were used. It took approximately 4 hours to run 270 simulations using a quad core Intel Xeon Processor 2.0GHz workstation. The curve number was the number one parameter for sensivility for this simulation. The surface runoff lag time(days), soil evaporation compensation factor and baseflow alpha factor(days) ranked 2'nd, 3'rd, and 4'th.

Calibration

The SWAT calibration method was used for this project. This method compared simulated streamflows and sediment yields from SWAT to measured values from USGS gauging station. Model calibrations were performed manually by adjusting hydrologic and sediment parameters in SWAT. Table 1 shows the model input parameters used in SWAT calibration process. The calibration process was basically trial-and-error to yield the highest Nash-Sutcliffe coefficient. The primary SWAT variables adjusted during the calibration were curve number (CN), soil evaporation compensation coefficient (ESCO), base flow recession (ALPHA_BF), ground water delay (GW_DELAY), depth to subsurface drain (DDRAIN), time to drain soil to field capacity (TDRAIN), drain tile lag time (GDRAIN), minimum value of USLE C factor for water erosion applicable to the land cover/plant (USLE_C), linear parameter for calculating the maximumamount of sediment that can be reentrained during channel sediment routing (SPCON), and residue decomposition coefficient (RSDCO). The curve number variable had the most influence on changes to the Nash-Sutcliffe coefficient. ALPHA_BF and GW_DELAY values used in the calibration were from the baseflow filter program. The standard depth to subsurface drains was set 3 ft (914.41 mm).

Table 1. Model input parameters adjusted during the SWAT model calibration.

Variable	Description	Calibrated	Default	Unit
CN2	Curve number	+20 %	Data	
ESCO	Soil evaporation compensation coefficient	0.9		
ALPHA_BF	Base flow recession	0.0197	0.048	
GW_DELAY	Ground water delay	117	31	d
DDRAIN	Depth to subsurface drain	914.41		mm
TDRAIN	Time to drain soil to field capacity	24		hr
	Drain tile lag time			
GDRAIN	Minimum value of USLE C factor for water	2		hr
USLE_C	erosion applicable to the land cover/plant	0.50		
	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing			
SPCON	Residue decomposition coefficient	0.0001	0.0001	
RSDCO		0.005	0.005	

Results

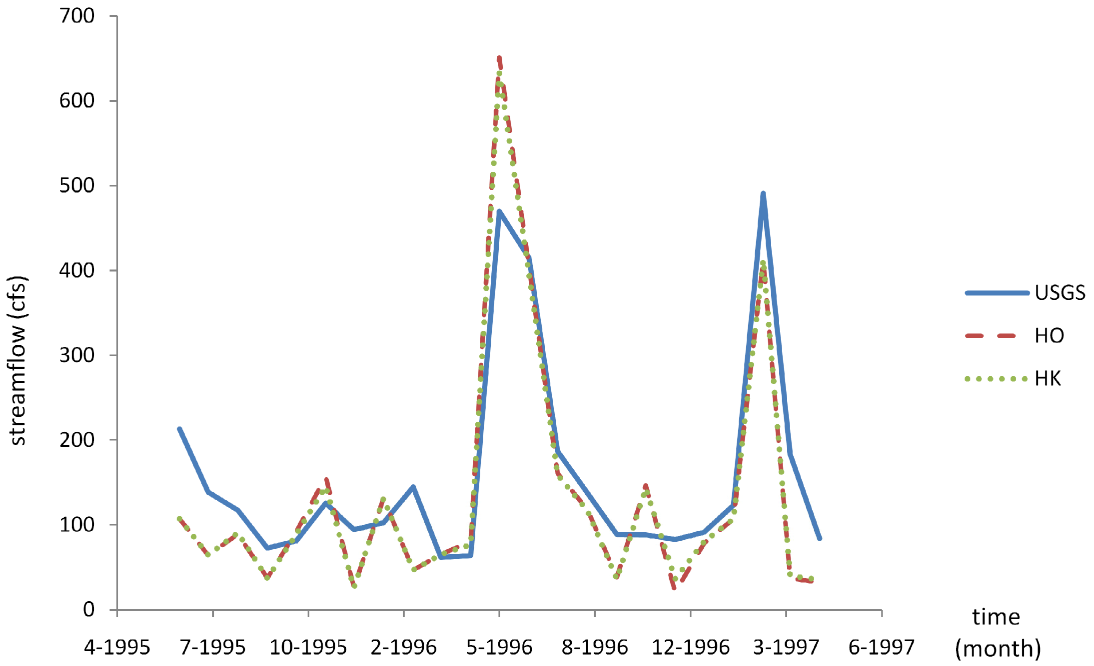

Figure 3. Calibrated simulations compared with observed monthly average of streamflow (cfs) in Elkhorn Creek. The harvest only (HO) operation left 100% crop residue and harvest and kill (HK) operation left 0% crop residue.

Two difference scenarios were simulated based on residue management, 0% residue left in the field and 100% residue left in the field. The Nash-Sutcliffe coefficient was 0.35 from the initial uncalibrated simulation. Figure 3 compares calibrated simulated streamflows with 0%

residue (HK) and 100% residue (HO) operations with observed monthly average of streamflow (cfs). The Nash-Sutcliffe coefficient for the calibrated simulations ranged from 0.68 to 0.71. Based on statistical measures developed by Moriasi et al. (2007), a Nash-Sutcliffe coefficient of 0.68 to 0.71, is between good and very good. As shown in Figure 3, streamflows with 0% residue left were very similar to streamflows with 100% residue left. There were only slight streamflow increases for 0% residue in November 1996.

Figure 4 shows simulated and observed daily average of sediment concentration (mg/L) in Elkhorn Creek. Simulated daily sediment concentration ranged from 0 mg/L to 261 mg/L. Observed daily sediment concentration ranged from 4 mg/L to 352 mg/L. Only one out of 16 observed daily sediment concentrations did not fall within the ranges of simulated sediment concentrations.

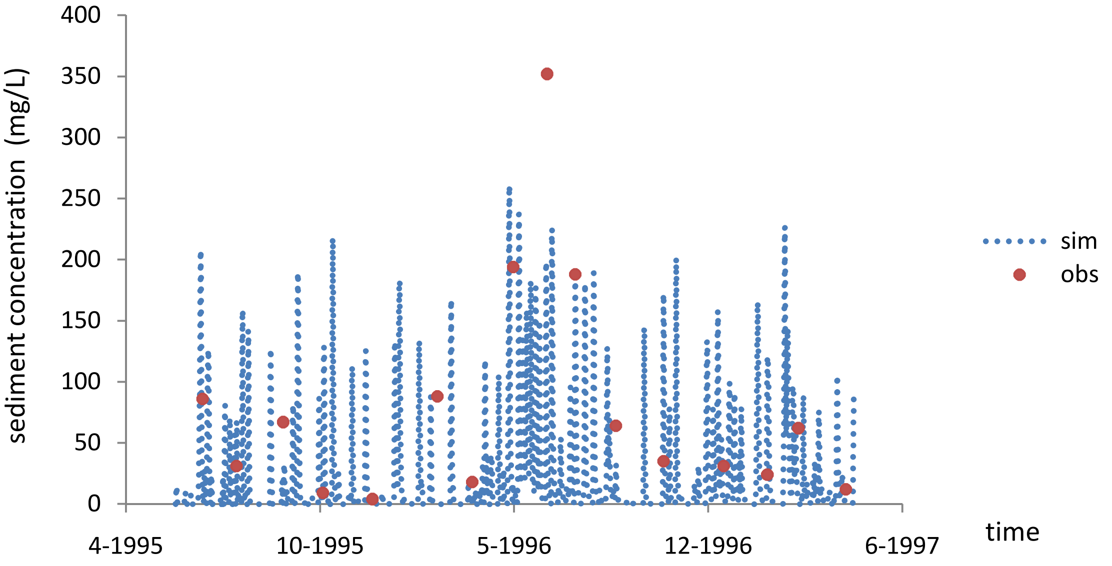

Figure 4. Simulated and observed daily average of sediment concentrations (mg/L) in Elkhorn Creek.

Figure 5 shows simulated monthly average of sediment concentrations (mg/L) 0% residue left on the field (HK) and 100% residue left (HO). The sediment trend with residue 0% cover is similar to the sediment trend with residue 100% cover. However, there is a 26.1 mg/L difference between the two different management operations in November 1996.

Figure 5. Simulated monthly average sediment concentration (mg/l) for 0% residue cover (HK) and 100% residue cover (HO) in Elkhorn Creek.

Corn Yield

The corn yield statistics were obtained from NASS for the counties in the Elkhorn watershed and is summarized in Table 2. The 3 year (1995 – 1997) weighted average corn yield is 7,372 lbs/ac for Carroll county (28.8%), Ogle (64.3%), and Whiteside (6.9%) counties. The average corn yield for the SWAT simulations with 0% residue left was 7,072 lbs/ac and the average corn yield with 100% residue left was 8,671 lbs/ac. The corn yield for the 0% residue management option were less than the average corn yield reported by NASS, and the corn yields for the 100% residue management option were more than the average corn yields. Therefore, the residue management option affects corn production.

Table 2. Average (1995 – 1997) harvested corn production (lbs/ac) statistics for the counties in the Elkhorn watershed (USDA-NASS, 2009).

County	Area (%)	bushel/ac	100% harvested (lbs/ac)
Carroll	14,550 ac (28.8%)	135	7,560
Ogle	32,485ac (64.3%)	130	7,280
Whiteside	3,486 (6.9%)	133	7,448

Conclusion/Discussion

The pre-calibration Nash-Sutcliffe coefficient value for measured versus simulated streamflow was 0.35. After calibration, the Nash-Sutcliffe coefficient increased to 0.68 (100% residue) and 0.71 (0% residue) for the different management operations. The Nash-Sutcliffe coefficient indicated good agreement between simulated and observed monthly streaflows. A total of 10 calibration parameters were adjusted to achieve optimum Nash-Sutcliffe coefficient values. The primary calibration variables adjusted included the curve number, soil evaporation compensation factor, available soil water capacity and baseflow fraction value.

The highest sensitivity parameter was the curve number. The study area consisted of more than 80% agricultural land, such as corn, soybean and hay. Two different management methods were applied; 1) 0% residue and 2) 100% residue left on the filed. Monthly streamflows for both management options were very similar. Monthly sediment concentrations for the two management operations were similar as well except for Nobember 1996. Daily sediment concetrations for observed data from at the USGS gaguing station on Elkhorn Creek were between 4 mg/L and 352 mg/L and the simulated daily sediment concentration ranged from 0 mg/L to 261 mg/L. The actual weighted average corn yield was 7,372 lb/ac for Carroll, Ogle, and Whiteside counties. The average simulated corn yields for 0% residue was 7,072 lbs/ac and 8,671 lbs/ac for 100% residue. The two different management operation had little influence on changes in stream flow and sediment yield in the Elkhorn watershed. However, the amount of residule left did have a large impact on the crop yields in the Elkhorn Creek watershed.

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B5-2

Evaluating the Impact of Biofuel Production on Watershed Hydrology Using SWAT

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Government of Thailand has perceived biofuel as a suitable source of alternative energy to meet the increasing energy demand and reduce imports of fossil fuel. Considerable amount of land is being converted for biofuel production. This land use change can have significant impacts on water resources in terms of both quantity and quality. In this paper Soil and Water Assessment Tool (SWAT) model is used to evaluate the impact of land use change for biofuel production on hydrology of a small watershed, Khlong Phlo in the Rayong province of eastern Thailand. Several land use change scenarios consisting of oil palm, cassava and sugarcane expansion were evaluated. Modeling results indicate that expansion of cassava and sugarcane coverage will decrease annual evapotranspiration and baseflow but increase annual surface runoff and water yield from the watershed which leads to increased sediment, nitrate and total phosphorus extraction into the surface water. Even though land conversion into oil palm plantation showed no significant effect on the water yield, the increased nitrate loss to the surface water is likely to affect the water quality of watershed. This study also reveals that the implication on annual water balance and extent of water quality degradation depends on type of crop chosen to produce biofuel and types of vegetation it replaces. In order to strengthen the study results, a research at a large scale at basin level is recommended.

Keywords: biofuel, land use change, hydrology, Khlong Phlo watershed, SWAT

Introduction

Many countries have perceived biofuel as an opportunity to cut the fossil fuels consumption, to decrease oil import, to reduce the greenhouse gas emission and to reduce poverty of rural communities (Dufey, 2006 and De Fraiture et al., 2008). The production of biofuel has increased because of such factors. Biofuel production which was around 57 billion liters by the end of 2007 has been projected to increase by almost three folds in 2017 (OECD/FAO, 2008).

Production of biofuel, to meet the current and future demands, can have significant implication on the water resources and hydrological process due to land use changes, agricultural intensification and introduction of new plants (Uhlenbrook, 2007). Rising amount of biofuel production is likey to change land-use and large amounts of land will be devoted to biofuel production (UNEP, 2008) for example around 43% to 38% of present cropland in the United States and Europe respectively will be need to substitute just 10% of petrol and diesel fuel (IEA, 2005). Similarly, Bruinsma (2003) estimated 850 million ha of extra land to meet current fuel needs, which is almost 55% of the present total global crop land and nearly same in magnitude of all the crop land in developing countries combined (904 Mha). De Fraiture et al. (2008) estimated that by 2030 globally biofuel will need 30 million additional hectares of cropped area. It is very likely that expansion of biofuel crops (oil palm, sugarcane, soybeans, etc) will replace native rainforests and wetlands. In Asia, countries like Malayasia and Indonesia, oil palm has replaced forest area for biofuel production (Meijerink et al., 2008).

Increase in energy demand and loss of great deal of foreign currency to fossil fuel imports has encouraged Thai Government to initiate policy to explore alternative renewable energy sources such as solar, wind, water and biofuel (Gonsalves, 2006). Ministry of Energy has plans to increase share of renewable energy in total energy consumption from 0.5% in 2002 to 8% (3% from biofuel) by 2011. Government has planned to increase current biofuel demand (2.1 million liters/day) to 13.5 million liters/day by 2022 (Prasertsri and Kunasirirat, 2009). Biofuel, as one of alternative energy, is projected to replace 4,928 million liters of fossil fuel annually by year 2022. In year 2008 Thailand produced 1.22 mLd of biodiesel from oil palm and 0.88 million liters per day (mLd) of bio-ethanol from cassava and sugarcane/molasses (Prasertsri and Kunasirirat, 2009). The crops used for biofuel production are also used for human and animal consumption. For meeting biodiesel demands "Committee on Biofuel Development and Promotion" targets to increase the oil palm coverage by 0.4 million ha within 2012 (APEC 2008) through orchard replacement (Prasertsri and Kunasirirat, 2009). There are also plans of government to expand the oil palm coverage to 1.6 million ha by 2023 (Siriwardhana et al., 2009). At present the remaining feedstock after satisfying the exports and domestic demand goes for biofuel production. With the current diversion of 3 million tons of cassava and 2 million tons of molasses annually the bio-ethanol production potential of Thailand is roughly 3 mLd. The projection of 9 mLd of ethanol by year 2022 signifies that keeping the domestic demands and exports unaffected, Thailand needs to either intensify agriculture or expand the land for feedstock production. This all explains that to meet demands of biofuel there will be considerable land use changes. Biofuel production in Thailand is expected to cause land use changes and add stress on already limited water resources (Hoogeveen, 2009).

Land use change due to crop expansion has considerable impact on the water resources as well as hydrology in terms of water quantity and quality. In order to manage and plan the water resources in either regional or watershed level the impacts induce by land cover changes needs to be assessed. Impact of crop expansion on hydrology has been studied in small as well as large scale basin by many researchers around the world (Mao et al., 2009; Lin and Wei, 2008; Siriwardena et al., 2006; Twine et al., 2004; Costa et al., 2003; Calder 1998) and Thailand (Thanapakpawin et al., 2006; Wilk et al., 2001). But none of above studies emphasized on hydrological implication because of land cover changes due to biofuel crops. Crop type, growing period and spatial extends also has implication on hydrology. Regarding the water quality issues, even though very few studies are done, crop expansion for biofuel production can have significant impact on water quality (Evans and Cohen, 2009; FAO, 2008; Schilling et al., 2008; NRC, 2007; Hill et al., 2006). It is likely that there will be severe impacts of land use changes on hydrological processes and water cycle dynamics due to biofuel production, but they are not well understood (Uhlenbrook, 2007). In fact, worldwide very few studies have focused on this kind of study (Meijerink et al., 2008; WRC, 2007; Stephen et al., 2001). As par literature review, in Thailand such studies are not yet conducted. So there is a need to evaluate the impact of biofuel production on the watershed hydrology and water resources in Thailand.

Hence, this study was conducted to analyze the impact of land use change for biofuel production on annual and seasonal water balance of the Khlong Phlo watershed and to quantify the impact of land use change for biofuel production on water quality in the Khlong Phlo watershed. For the study Soil and Water Assessment Tool (SWAT) model was used because it is physically based and simulates actual process, originated from agricultural models, and degree of support available. Also SWAT has been widely validated in many regions of the world for variety of applications in hydrologic as well as water quality studies (Jha et al., 2007).

Materials and Methodology

SWAT Model Description

SWAT is a river basin or watershed scale hydrologic and water quality model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). It was developed to evaluate the effect of land use management on water, sediment and agricultural chemical yield in large complex watersheds with heterogeneity in land use, soil and management conditions over a long period of time. It is semi-distributed, physically based, computationally efficient and continuous time model. It is also capable of simulating a high level of spatial detail. For modeling purpose, in SWAT, a watershed is partitioned into several sub watersheds or sub basins which are further portioned into hydrological response units (HRUs). HRUs are lumped land area within the sub basins having homogenous land cover, soil and management combinations. SWAT simulates the hydrology of watershed in two major phases: the land phase and the water or routing phase. The land phase of the hydrological cycle controls the amount of water, sediment, nutrient and pesticide yields to the main channel in each sub basin, while the routing phase control the movement of water, sediments, nutrients and pesticides through the channel network of the watershed to the outlet. In land phase SWAT simulates nine primary components: weather, hydrology, crop growth, sediment, nutrients, pesticides, soil temperature, land management and bacteria.

SWAT calculates the hydrological processes in water balance for surface soil and groundwater in each HRU. The model can simulate major hydrologic processes namely evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer, deep aquifer and channel routing. The simulation of process can be done in four subsystems namely: surface soil, intermediate zone, shallow and deep aquifer and open channel. Flow generation, sediment yield, nutrients and pesticides loadings are summed across all HRUs in a sub watershed, and routed through channels, ponds, and/or reservoir to the watershed outlet. The detailed theoretical description of various components can be found in Neitsch et al. (2005).

Description of Study Area

The Khlong Phlo is the sub basin of Khlong Prasae basin located in the Rayong province of Thailand (Figure 1). The study watershed lies within 12°57’-13°10’ N and 101°35’ – 101°45’ E and encompasses a total area of 202.8 km^2 above the stream gauge station Z. 18 of the Royal Irrigation Department (RID). The watershed receives an average annual rainfall of 1,734 mm with the maximum rainfall during May to October.

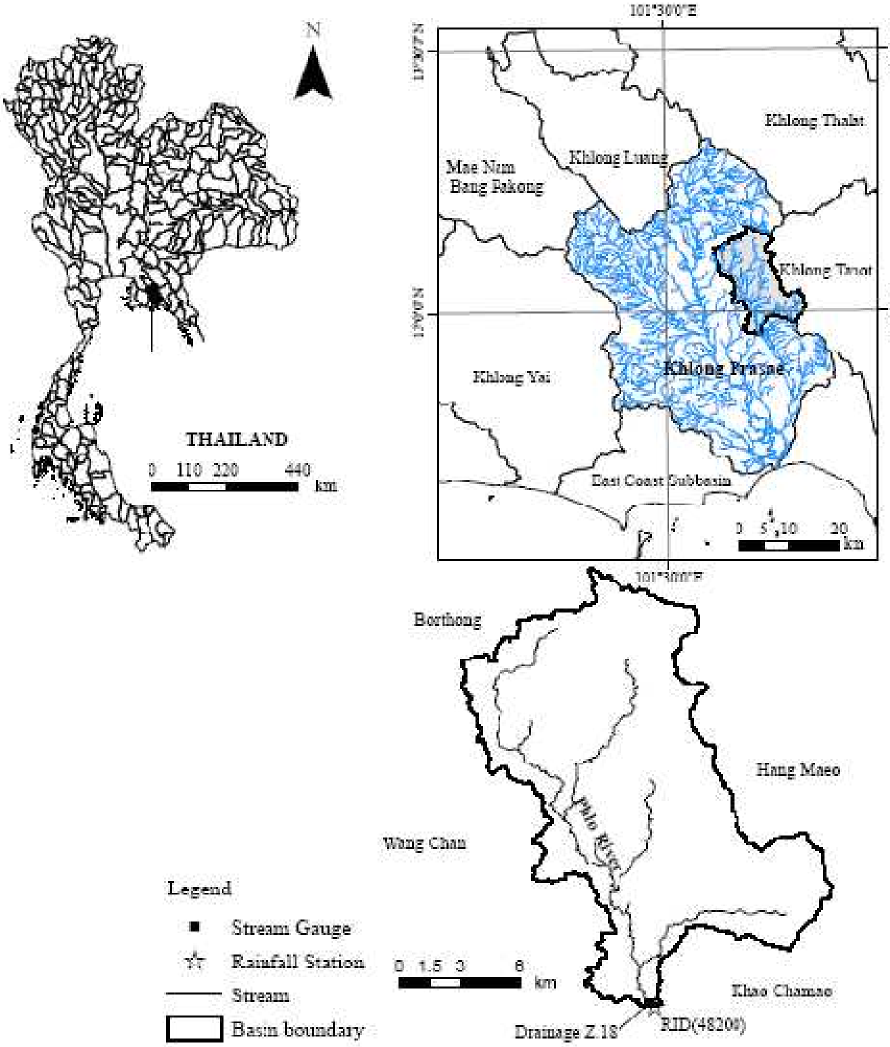


Figure 1. Location of the Khlong Phlo watershed, stream gauge and rainfall station.

The annual mean temperature ranges from 27 to 31°C and the relative humidity ranges from 69 to 83 percent. The elevation of the watershed ranges from 13 m above mean sea level at its lowest point to 723 m at its highest point. Agricultural land is the dominant land cover of the watershed, which comprises nearly 66 percent. Soils in this watershed are predominantly sandy clay loam and sandy loam in texture.

Model inputs

Climatic data on daily temperature, wind speed, humidity and sunshine hours were collected from Thai Meteorological Department (TMD), while daily rainfall data was obtained from both TMD and Royal Irrigation Department (RID). Discharge and sediment yield in the study area were obtained from RID. Drainage map of the Phlo river watershed was acquired from RID. A 30 m resolution Digital Elevation Model of the study watershed was downloaded from http://www.gdem.aster.ersdac.or.jp.

Land use map of year 2006 with the scale of 1:25,000 m for the study watershed was obtained from Land Development Department (LDD). The land cover is comprised of 65.51% agriculture crops predominantly rubber and orchard and 32.75% forest (Table 1).

Table 1. Land use in the Khlong Phlo watershed.

Land use	Area (km^2)	Percent
Agriculture	132.85	65.51
Rubber	85.12	64.07
Orchard	27.96	21.04
Cassava*	9.88	7.44
Cashew nut	4.84	3.64
Sugarcane*	2.11	1.59
Rice	1.82	1.37
Oil palm*	1.12	0.84
Forest	66.41	32.75
Range	1.83	0.90
Urban	0.79	0.39
Water bodies	0.89	0.44
Wetland	0.01	0.01

* crops used for biofuel production (area = 13.1 km^2, roughly 10% of agricultural land)

The crops used for biofuel comprises roughly 10% of total agricultural land. For the HRU definition purpose the land use map from LDD was reclassified based on SWAT land use classification (Table 2).

Table 2. Land use based on SWAT classification.

Code	Land Use	SWAT code	Area (km^2)	Percent
3	Rice	RICE	1.82	0.90
8	Cashew nut	CAJU	4.84	2.39
9	Cassava	CASA	9.88	4.87
21	Evergreen forest	FRSE	66.36	32.73
27	Deciduous forest	FRSD	0.05	0.03
41	Institutional land	UINS	0.51	0.25
43	Water bodies	WATR	0.89	0.44
47	Residential low density	URLD	0.28	0.14
57	Wetland	WETN	0.01	0.01
64	Orchard	ORCD	27.96	13.79
67	Oil palm	OILP	1.12	0.55
70	Rubber	RUBR	85.12	41.98
82	Range	RNGE	1.83	0.90
89	Sugarcane	SUGC	2.11	1.04

The physical properties for cassava and leaf area index of rubber is based on literature. For other land use SWAT default values were used because local values for these parameters were not available.

Soil distribution map (1:100,000 m) and soil physical properties of the Khlong Phlo watershed were obtained from Land Development Department (LDD). Seven major soil types in the study area and their percent distribution are presented in Table 3. LDD has defined the soil types of hilly topography as slope complex (SC). The properties of SC soil were not studied by the LDD. Hence, the properties for SC soil were extracted from Harmonized World Soil Database developed by the Land Use Change and Agriculture Program of IIASA (LUC) and the Food and Agriculture Organization of the United Nations (FAO). This database is obtained from the website http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/. The hydraulic properties of the soil were calculated using Soil-Plant-

Air-Water Model (SPAW model, Saxton & Willey, 2005). The soil database for the watershed was added to the "usersoil" database file and the soil map was reclassified based on the provided usersoil.

Table 3. Soil series and percent distribution in the Khlong Phlo watershed.

Soil Series	Area (km^2)	Percent
Nong Khla	13.00	6.40
Lamphu La	53.20	26.30
Khlong Teng	3.40	1.70
Tha Sae	16.50	8.10
Huai Pong	9.20	4.50
Phanga-nga	19.90	9.80
Slope complex (SC)	87.60	43.20

Fertilizer application rate was provided by Department of Agriculture and obtained from www.fao.org/ag/agl/fertistat/fst.fubc.en.asap. Agricultural practice was constructed based on farmer interview, literature and assumptions to provide appropriate input to the model. For fertilizer application the elemental nitrogen and elemental phosphorus options in SWAT was used. For other management data SWAT deafult values were used.

Evaluation of Model Prediction

A goodness-of-fit measure was evaluated to test the model accuracy. These measures include percent differences in mean and standard deviations over the simulation period, coefficient of determinant (R^2) and the Nash-Sutcliffe measure (Nash and Sutcliffe, 1970). R^2 value indicates the strength of relationship between the observed and simulated value. NS value indicates how well the plot of observed versus simulated value fits the 1:1 line. If R and NS approach zero, the model performance is unacceptable or poor. If R and NS close to 1 then the model performance is acceptable or better.

Model Calibration and Validation

The Khlong Phlo watershed SWAT model was simulated for 22 years (1984-2006) to test the accuracy of model for baseline conditions. Year 1984 and 1985 was used as a warm up period for model to equilibrate itself between various water storages in the hydrological cycle (Guo et al., 2008). First the model was calibrated and validated for the streamflow and then for sediment load by comparing with observed data. The model was not calibrated for nitrogen and phosphorus because there was no measured data. The calibration period for streamflow was 1986-1995 (10years) and validation for 5 years (1996-2000). The sediment yield was calibrated for 3 years (1997-1999) and validated for year 2000. Prior to calibration process, baseflow was separated from surface flow for observed streamflow using an automated baseflow method developed by Arnold and Allen (1999). The baseflow was estimated about 66% of the total average annual streamflow.

The calibration process was performed following the procedure as stated by Santhi et al. (2001) and SWAT user manual 2000 to achieve good fit between simulated and observed values. The calibration of flow and sediment was performed manually adjusting key hydrologic and sediment related parameters (Table 4). The parameters adjusted were selected based on suggestions by Santhi et al. (2001), Jha et al. (2007) and Schilling et al. (2008).

Table 4. Adjusted parameters for SWAT calibration and their final value for the Khlong Phlo watershed.

Model processes	Parameters	Description*	Model range	Final value/ change used
Flow	CN2	Curve number	± 8	-8
Flow	ESCO	Soil evaporation compensation factor	0.01 - 1.0	0.5
Flow	SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)	± 0.04	+ 0.04
Flow	RCHRG_DP	Deep aquifer percolation fraction	0.0-1.0	0.20
Flow	GW_REVAP	Groundwater "revap" coefficient	0.02-0.20	0.20
Flow	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)		50
Sediment	SPCON	Linear parameter for calculating the maximum amount of sediment	0.0001-0.01	0.0001
Sediment	SPXEP	Exponential parameter for calculating the maximum amount of sediment	1-2	1.6
Sediment	USLE_P	USLE support practice factor	0.1-1	0.8

*detail description available in SWAT user manual 2005 and SWAT input/output file documentation 2005

Curve number (CN2) was adjusted within range of $\underline{+}$ 8 and available water capacity of the soil layers (SOL_AWC) was adjusted to match annual surface runoff, while soil evaporation compensation factor (ESCO), deep aquifer percolation fraction (RCHRG_DP), groundwater revap coefficient (GW_REVAP) and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) was changed to match baseflow (Table 4). ESCO controls the depth distribution used to meet the soil evaporative demand. As the value for ESCO is reduced, the model is able to extract more of the evaporative demand from lower levels or simply evapotranspiration amount will increase hence reducing total water yield. RCHRG_DP controls fraction of percolation from the root zone which recharges the deep aquifer. GW_REVAP represents water that moves from the shallow aquifer into the overlaying unsaturated zone/root zones and plant uptake from deep root (Arnold et al, 1993). Sediment yield was calibrated after the completion of the flow calibration process. In order to match modeled sediment yield with observed yield, the linear (SPCON) and exponential (SPEXP) parameters for calculating the sediment transported in the channel sediment routing were adjusted (Table 4). The support practice factor or P factor of universal soil loss equation (USLE) was also adjusted to better represent the farming practice (contouring).

Land use change scenarios

Several land use change scenarios were evaluated to estimate the impact of biofuel crop expansion on water balance components, sediment yield, nitrogen and phosphorus loss. Land use change scenarios are grouped into three, namely oil palm, cassava and sugarcane expansion. There are four scenarios under each group and they are presented in Table 5.

The present land use (year 2006) comprises of 41.98% rubber, 32.73% forest, 16.18% orchard, 4.87% cassava, 1.04% sugarcane and 0.55% oil palm. Scenario A1, which is increase in the oil plam area from less than 1 percent to nearly 17 percent, was evaluated because Committee on Biofuel Development and Promotion (CBDP), jointly formed by the Ministry of Agriculture and Cooperatives and the Ministry of Energy, plans to expand palm production through orchard replacement and in response to palm promotion, palm ranchers have begun growing palm in new areas including the North, Northeast, East and South regions of Thailand by replacing old orchards (Prasertsri and Kunasirirat, 2009). Scenario A2 was evaluated on the basis that economically oil palm is better alternative than rubber in areas where the two crops can be grown, because the internal rate of return for oil palm is a lot higher due to early harvesting as compared to rubber (Chirpanda et al., 2008) and implication on water quantity and quality needs to be evaluated if oil palm replaces rubber. Remaining scenarios are hypothesized.

Table 5. Details of the land use change scenarios in the Khlong Phlo watershed.

Scenarios	Land use												Conversion
	Rubber		Forest		Orchard		Cassava		Sugarcane		Oil palm		
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	
Baseline	85.12	41.98	66.36	32.73	32.80	16.18	9.88	4.87	2.11	1.04	1.12	0.55	
A. Oil palm expansion scenarios													
Scenario A1	85.12	41.98	66.36	32.73	-	-	9.88	4.87	2.11	1.04	**33.92**	**16.73**	Orchard to oil palm
Scenario A2	-	-	66.36	32.73	32.80	16.18	9.88	4.87	2.11	1.04	**86.24**	**42.53**	Rubber to oil palm
Scenario A3	-	-	66.36	32.73	-	-	9.88	4.87	2.11	1.04	**119.04**	**58.71**	Orchard and Rubber to oil palm
Scenario A4	85.12	41.98	-	-	32.80	16.18	9.88	4.87	2.11	1.04	**67.48**	**33.28**	Forest to oil palm
B. Cassava expansion scenarios													
Scenario B1	85.12	41.98	66.36	32.73	-	-	**42.68**	**21.05**	2.11	1.04	1.12	0.55	Orchard to cassava
Scenario B2	-	-	66.36	32.73	32.80	16.18	**95.00**	**46.85**	2.11	1.04	1.12	0.55	Rubber to cassava
Scenario B3	-	-	66.36	32.73	-	-	**127.80**	**63.03**	2.11	1.04	1.12	0.55	Orchard and Rubber to cassava
Scenario B4	85.12	41.98	-	-	32.80	16.18	**76.24**	**37.60**	2.11	1.04	1.12	0.55	Forest to cassava
C. Sugarcane expansion													
Scenario C1	85.12	41.98	66.36	32.73	-	-	9.88	4.87	**34.91**	**17.22**	1.12	0.55	Orchard to sugarcane
Scenario C2	-	-	66.36	32.73	32.80	16.18	9.88	4.87	**87.23**	**43.02**	1.12	0.55	Rubber to sugarcane
Scenario C3	-	-	66.36	32.73	-	-	9.88	4.87	**120.03**	**59.20**	1.12	0.55	Orchard and Rubber to sugarcane
Scenario C4	85.12	41.98			32.80	16.18	9.88	4.87	**68.47**	**33.77**	1.12	0.55	Forest to sugarcane

Results and Discussion

Model Calibration and Validation

Streamflow

The annual average water yield of the watershed was predicted to be 596.51 mm, which consists of 206.69 mm of surface runoff, 390.85 mm baseflow (groundwater flow plus lateral subsurface flow), and 1.03 mm of transmission loss. The model was able to predict the total water yield and its components very well. The total water yield and baseflow was modeled with difference of less than 4% and surface runoff nearly 6% with respect to observed (Table 6).

Table 6. Observed and simulated annual average water balance of the Khlong Phlo watershed.

	Total water yield	Surface runoff	Baseflow
Observed flow (mm)	573.66	195.04	378.61
Simulated flow (mm)	596.51	206.69	390.85
Diff (%)	3.98	5.97	3.23

The modeled baseflow proportion was 65% of the average annual flow which was almost same as observed baseflow proportion (66%). The average annual water balance components of the watershed suggest that water yield (streamflow) comprises nearly 34% of annual rainfall while evapotranspiration comprises almost 50%.

Figure 2 and 3 shows the comparison of monthly simulated and observed streamflow at Z.18.

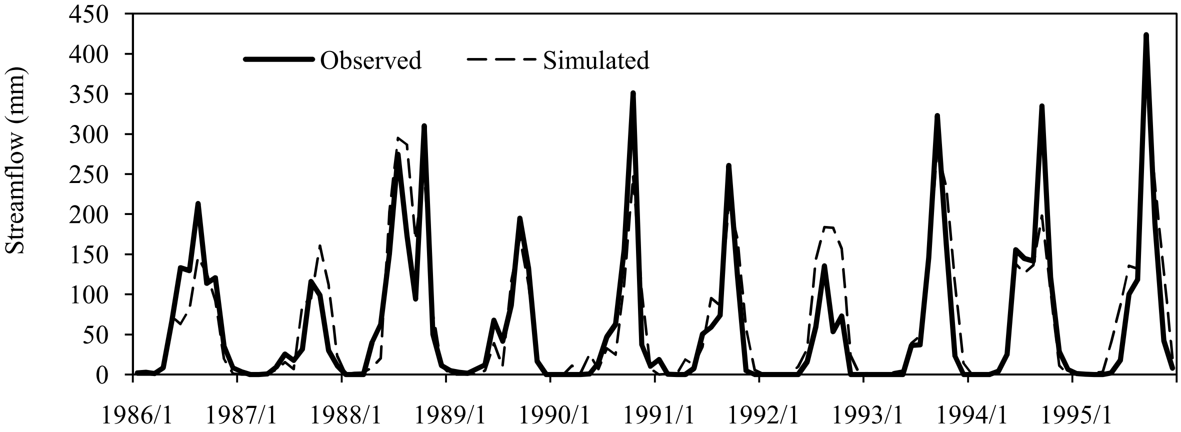


Figure 2. Monthly streamflow calibration for the Khlong Phlo watershed.

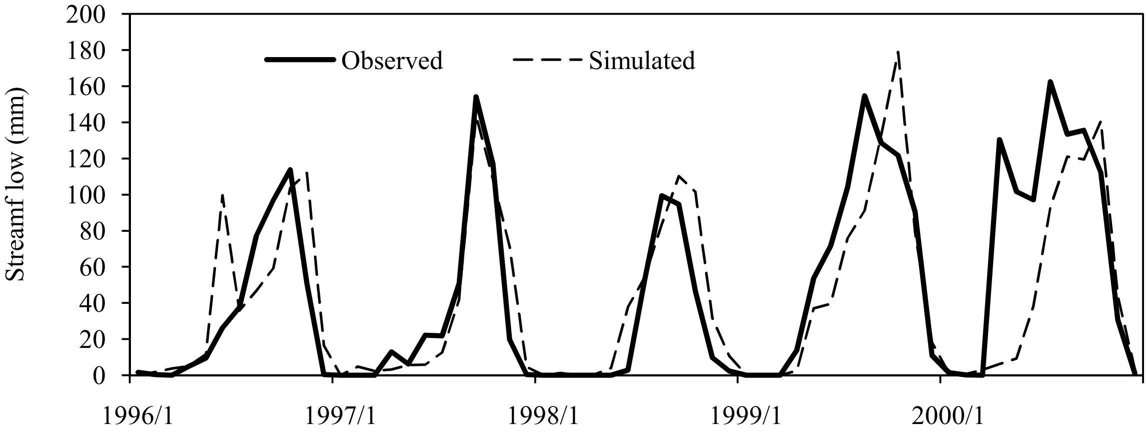


Figure 3. Monthly streamflow validation for the Khlong Phlo watershed.

The graphical representations show that SWAT tracked monthly flow trends of both calibration (1986-1995) and validation (1996-2000) periods well. Nevertheless, streamflow was under predicted in 1986, 1990, 1994 and 2000 and over predicted in 1987 and 1992. The time to peak for 1996, 1998, 1999 and 2000 did not match well. Means and standard deviations (SD) of the observed and simulated flow for both calibration and validation were within a difference of 10% (Table 7).

Table 7. Monthly streamflow calibration and validation results.

	Calibration (1986-1995)			Validation (1996-2000)		
	Mean (mm)	SD (mm)	NS	Mean (mm)	SD (mm)	NS
Observed	59.39	86.94		46.48	52.79	
Simulated	64.4	83.26	0.8	42.88	48.57	0.61
Difference (%)	8.43	-4.23		-7.76	-7.99	

Further the agreement between modeled and observed flow of the Khlong Phlo watershed was confirmed by Nash-Sutcliffe simulation efficiency (NS) greater than 0.5 (Table 7) and coefficient of determinant (R^2) greater than 0.6 for both calibration and validation (Figure 4). The standard for NS and R^2 used here is proposed by Santhi et al. (2001).

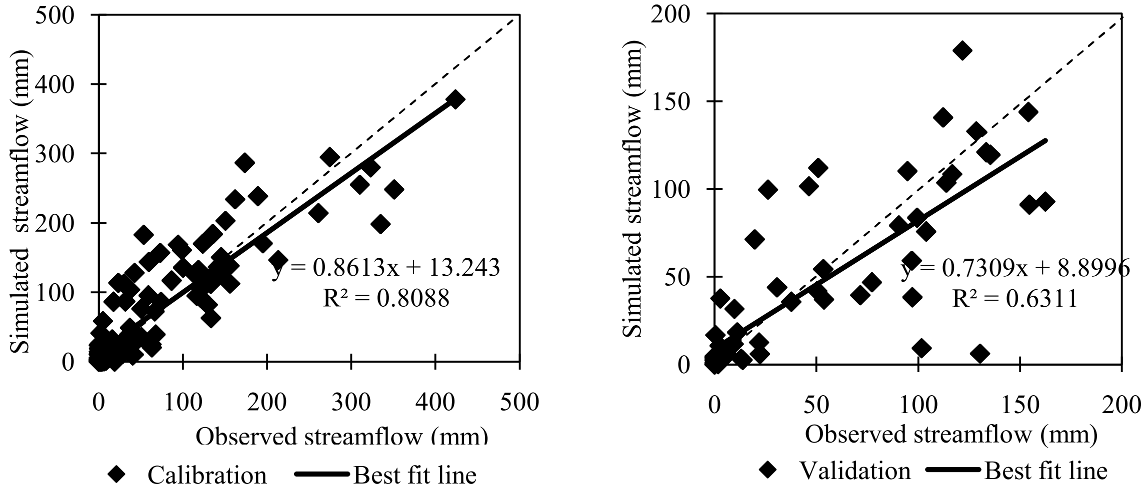


Figure 4. Observed and model predicted streamflow.

Figure 4 shows that R^2 for calibration period was 0.81 while for validation period it was 0.63. The figure clearly implies that for calibration period model predicted well than for validation period. The statistics for validation period is less satisfactory as compared to calibration because the model predicted poorly for year 1996 and 2000 as indicated in the graphical comparison. For these two years NS was less than 0.5 and R^2 less than 0.6. Overall, the model was able to simulate streamflow with reasonable accuracy and annual water yield very well. These results indicate that the model can be extended to study the effect on water balance and streamflow under various land use change scenarios.

Sediment

The model predicted the annual average sediment yield very well. The total 1997-2005 annual average sediment yield of the watershed was predicted to be 0.60 t/ha with the error of 5.13% relative to observed (0.57 t/ha). The graphical representation (Figure 5) shows that SWAT model tracked 1997 well, 1998 fairly however, 1999 and 2000 sediment yield was poorly tracked. The sediment yield was under predicted in 1998 and 2000, over predicted in 1999. The sediment yield was under predicted in 1998 and 2000, over predicted in 1999. The difference in mean and standard deviation of sediment for the calibration was less than 10%, while for the validation standard deviation was within 10% but mean difference was more than 10%.There was relatively satisfactory agreement between monthly observed and modeled sediment yield for calibration, which is confirmed by NS greater than 0.5 (Table 8) and R^2 greater than 0.6 (Figure 6). But for validation period both NS and R^2 were less than the standard.

Figure 6 shows that SWAT model under predicted the sediment load. The under prediction can be due to uncertainty in soil erosion model used by SWAT. SWAT simulates erosion using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) which uses USLE parameters that cannot be measured from the field but based on the qualitative information such as soil type and land cover, also the topographic factor (LS) derived from DEM is highly uncertain.

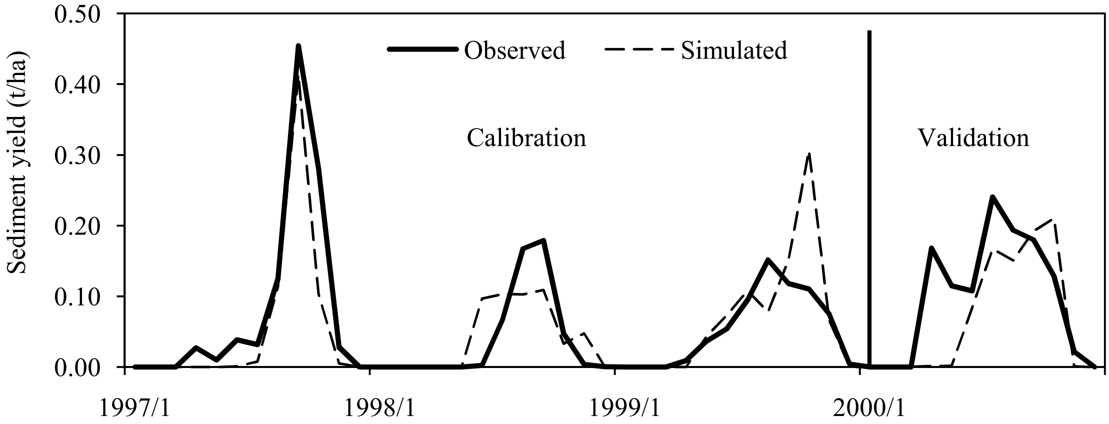


Figure 5. Monthly sediment yield calibration and validation for the Khlong Phlo watershed.

Table 8. Monthly sediment calibration and validation results.

	Calibration Period (1997-1999)			Validation Period (2000)		
	Mean (t/ha)	SD (t/ha)	NS	Mean (t/ha)	SD (t/ha)	NS
Observed	0.059	0.095		0.096	0.089	
Simulated	0.055	0.089	0.67	0.067	0.088	0.36
Difference (%)	-6.98	-5.77		-30.01	-1.32	

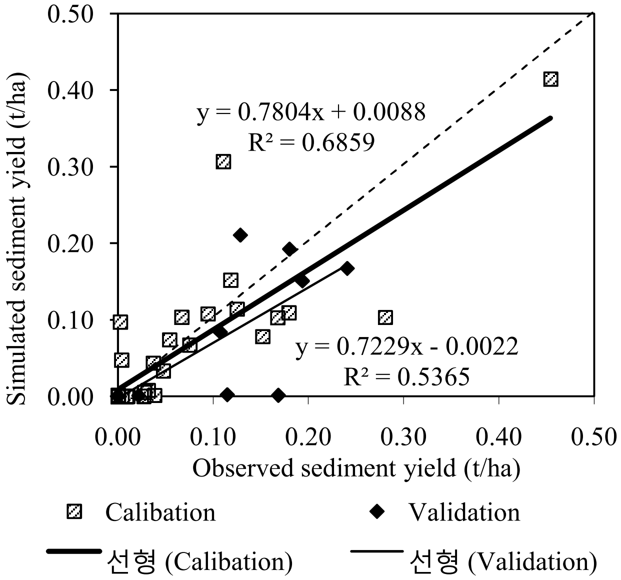
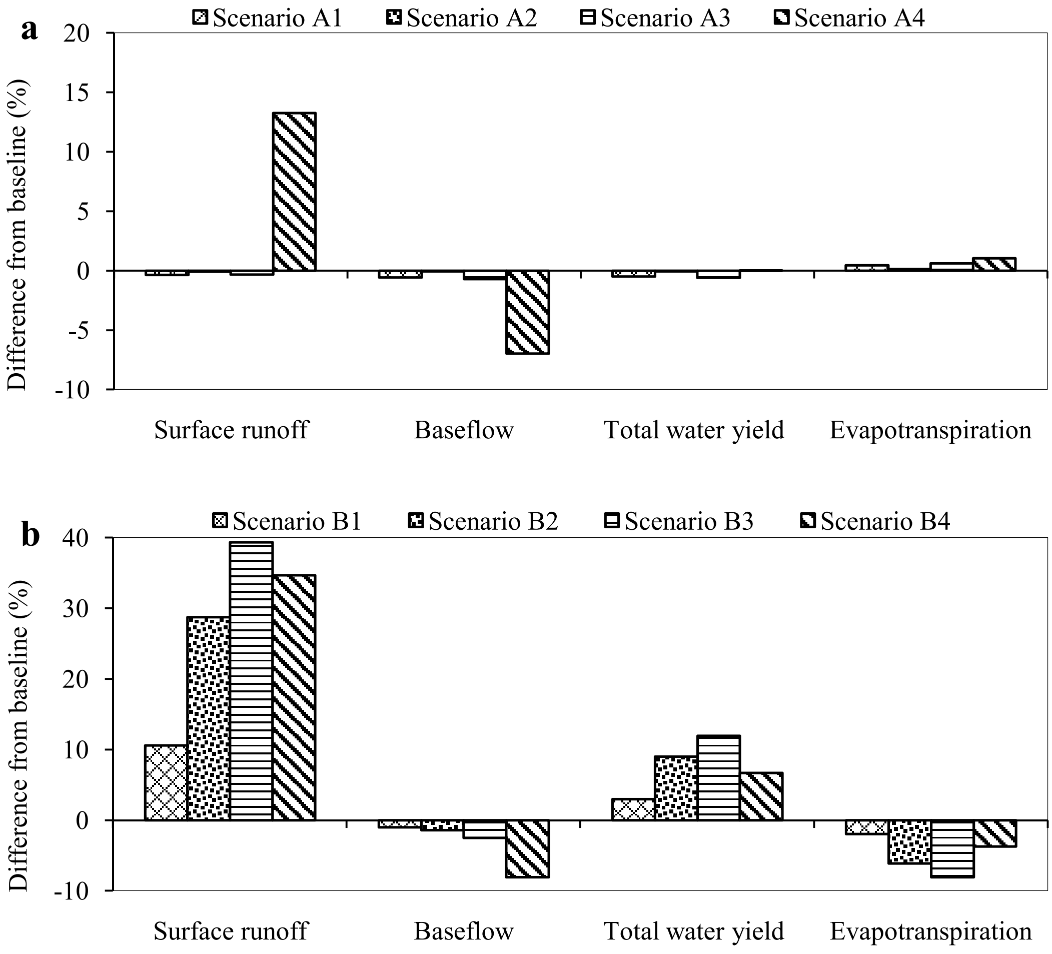


Figure 6. Observed and model predicted sediment yield.

Overall, SWAT was fairly able to replicate the monthly time-series of observed sediment yields of the Khlong Phlo watershed nevertheless, the annual average sediment yield was replicated accurately. The result clearly implies that for this watershed the model can be extended to study the impact on annual sediment yield under various land use change scenarios.

Effect of land use change on the water balance

Under palm oil expansion scenarios, conversion of orchard area and rubber to oil palm plantation (Scenario A1, A2 respectively) decreased surface runoff by less than 1 mm for both cases and baseflow by 2.21 mm and less than 1 mm respectively. Under maximum area conversion scenario (Scenario A3) both the surface runoff and baseflow decreased by less than 1% (Figure 7a). In contrast forest area replacement (Scenario A4) increased surface runoff but decrease baseflow by nearly 27 mm.



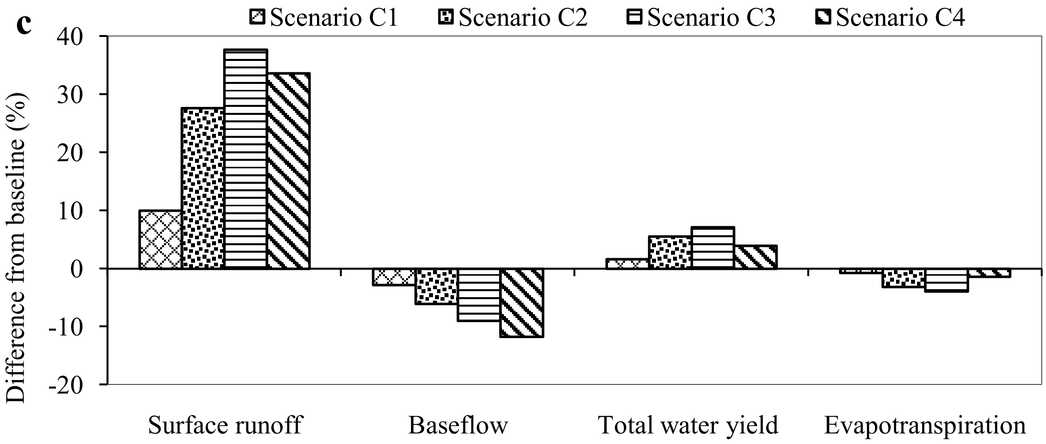


Figure 7. Differences in water balance from land use change scenarios to baseline, a. Oil palm expansion; b. Cassava expansion; c. Sugarcane expansion.

In all the cases the effect on total average annual water yield was negligible (less than 1%) (Figure 7a). This is due to the fact that there was no considerable change in evapotranspiration.

For both the cassava and sugarcane expansion scenarios there was increase in surface runoff and total water yield but decrease in baseflow (Figure 7b and 7c) and the evapotranspiration decrease with increasing hectare coverage. Under orchard replacement scenarios (Scenario B1, C1), conversion of orchards to cassava and sugarcane increased surface flow by nearly 22 and 21 mm respectively, in contrast decreased baseflow by 1% and 3% respectively (Figure 7b and 7c). Rubber replaced by cassava (Scenario B2) increased surface runoff and total water yield from 206.69 to 266.06 mm and 596.51 to 650.13 mm respectively, while baseflow decreased by 1.42% (Figure 7b). Similar trend was also observed for rubber replacement by sugarcane (Scenario C2) where surface runoff and total water yield increased by nearly 28 and 6% respectively, however baseflow declined by roughly 6% (Figure 7c).

Under maximum land use change scenarios (Scenario B3 and C3), where more than half of the total land is converted, conversion to cassava and sugarcane rise surface runoff nearly 39 and 38% respectively and reduced baseflow by 12 and 7% respectively (Figure 7b and 7c). Water yield increased by 71 and 43 mm respectively and the fraction Q/P also increased to 39 and 37% respectively. In contrast, fraction of precipitation loss to evapotranspiration decreased by 8 and 4% respectively. In forest replacement case, cassava increased surface runoff and total water yield by 72 and 40 mm respectively, while baseflow decreased by 32 mm, similarly sugarcane expansion increased surface runoff and water yield by about 34 and 4% respectively and reduced baseflow by nearly 12%. The fraction of precipitation loss to streamflow increased to 38 and 37% respectively for the forest conversion to cassava and sugarcane.

In all cases amount of surface runoff increase was high for cassava expansion scenarios while baseflow decline was high for sugarcane expansion scenarios. Increase in surface runoff will cause significant rise in sediment as well as nutrient loss and increase flooding in lower lying downstream regions. Further there will be reduction in infiltration amount and consequently decline in baseflow. The change in water yield can be attributed to change in curve number and evapotranspiration amount due to changes in canopy structure and surface roughness, which was also concluded by several studies (Monteith, 1965; Lahmer et al., 2001 and Hu et al., 2004). Evapotranspiration can influence the effective rainfall which can have significant implications on the surface runoff and groundwater recharge (Stephens et al., 2001 and Calder, 1993).

On a monthly basis, for maximum land cover change scenarios (Scenario A3, B3 and C3) relative to current land use conditions suggest that conversion to oil palm would yield more water during November and December, January to November for cassava and January to October for sugarcane. In contrast, less water yield would occur during January to October for oil palm, December for cassava and November-December for sugarcane (Figure 8a). Expanding cassava and sugarcane by replacing forest area in watershed would produce more water yield almost all months except for November and December. For oil palm expansion there will be more water yield from watershed during seven months only (January, March to July and September) (Figure 8b).

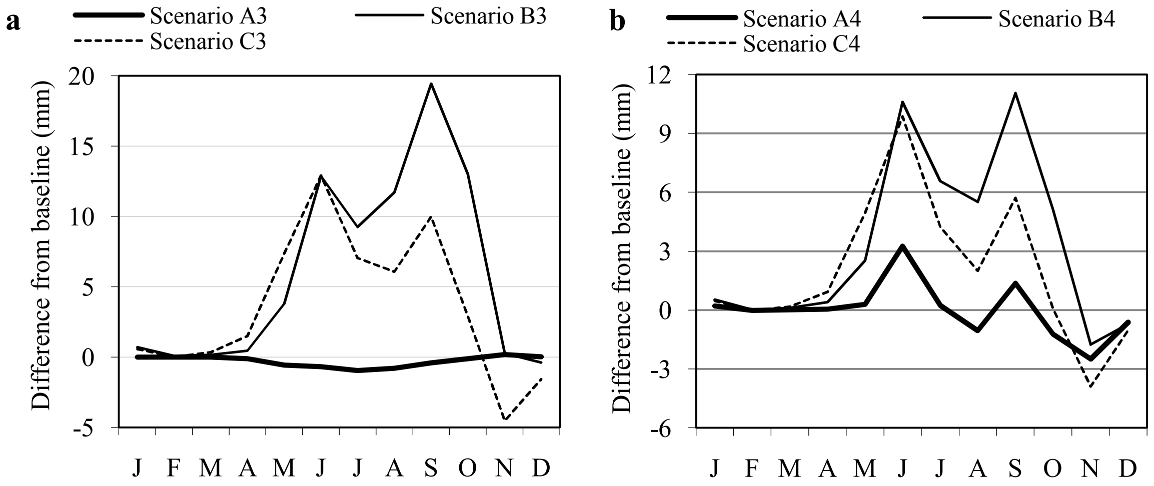


Figure 8. Differences in average monthly water yield from land use change scenarios to baseline, a. Maximum land use change; b. Forest area conversion.

These results implies that the impact of land use change for biodiesel production on water balance seems insignificant except for the forest conversion case where surface runoff increased and baseflow decreased. On the other hand land use change for bio-ethanol production will affect the water balance of the Khlong Phlo watershed due to increased surface runoff and water yield, and decreased baseflow and evapotranspiration.

Effect of land use change on the water quality

Under maximum oil palm coverage scenario while nitrate export from the watershed increased by nearly 21%, total phosphorus and sediment loss declined by almost 4 and 1% respectively (Figure 9a). Nitrate, phosphorus as well as sediment loss was high for forest conversion to oil palm scenario. Replacing forest increased sediment loss from 0.60 to 0.68 t/ha. It also increased annual nitrate and phosphorus loss by nearly 28 and 29% respectively (Figure 9a). Conversion of orchard area to oil palm increased annual nitrate and phosphorus loss by roughly less than 2% and decreased sediment loss by less than 1% (Figure 9a).

Annual nitrate export and phosphorus increased by 22.35 and 78.22% for maximum cassava coverage in the watershed (Figure 9b). Annual sediment loss also increased to 0.89 t/ha with increasing cassava area. Annual nitrate as well as phosphorus export was more pronounced when forest area converted to cassava.

Annual nitrate export increased by 10.21% for maximum sugarcane coverage in the watershed (Figure 9c). Annual phosphorus and sediment loss also rise by 56.16 and 39.51% respectively due to increased sugarcane area. Annual nitrate as well as phosphorus export was high when forest area converted to sugarcane. In contrast, the annual nitrate loss reduced nearly 4.5% when orchard lands converted to sugarcane.

The replacement of forest by all three crops increases pollutant in surface water because runoff from agricultural land contains higher nutrient contents (Nitrogen, Phosphorous and Potassium) than from forest because of higher fertilization rates and intensity of management (Calder, 1998).

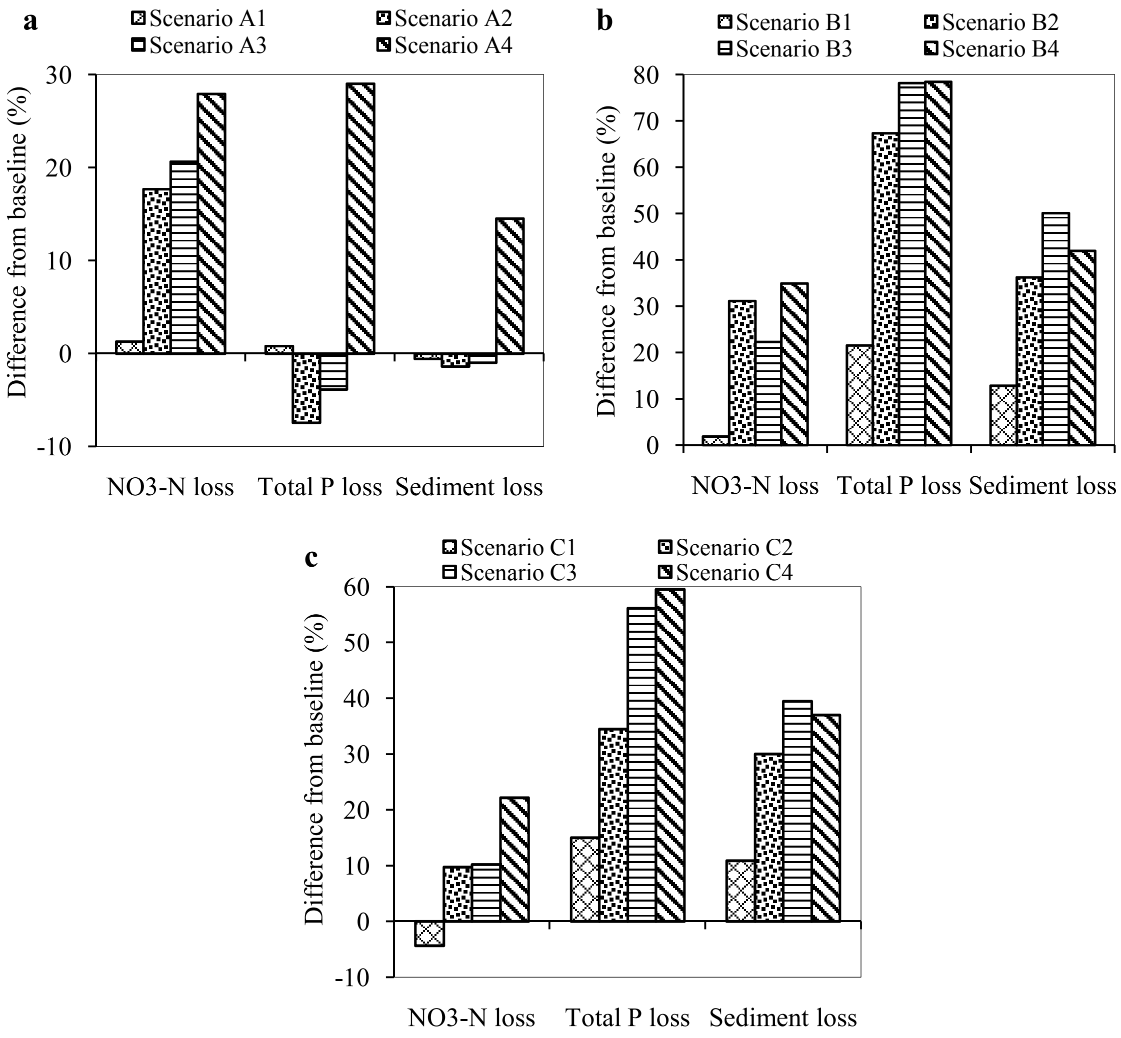


Figure 9. Differences in nonpoint source pollutants due to land use change scenarios to baseline, a. Oil palm expansion; b. Cassava expansion; c. Sugarcane expansion.

Higher loss was evident for nitrate and phosphorus with cassava replacing forest (about 35 and 79% respectively), while for sediment it was evident with maximum cassava coverage in watershed (almost 40%). All land use change scenario except orchard area conversion to sugarcane increased annual nitrate export from the watershed. Nitrate and phosphorus loss is high for cassava because of higher fertilizer application rate and higher erosion loss. The eroded sediments may absorb and carry agricultural pollutants (NRC, 2007; Martinelli and Filoso, 2008; Ella, 2005). Cassava has high soil losses because of its structure which favors large drops (Moench, 1991) and its low soil coverage (approximately 50%) even at peak growth (Nguyen et al., 2008). Increase in sediment and pollutants loss poses serious health threats to people residing downstream and also will make downstream water unusable for activities like drinking, aquaculture and even agriculture.

Overall, the results clearly indicate that the increased nitrate loading into surface water due to land use change for biodiesel production will affect the water quality in the study watershed. However, conversion of orchard for biodiesel production will have less impact on the water quality. Similarly the land use change for bio-ethanol production is also likely to affect the water quality of the Khlong Phlo watershed due to increased sediment and nutrients loads into the water.

Conclusions

In Thailand considerable amount of land is being converted for biofuel production to meet the increasing energy demand and reduce imports of fossil fuel. This land use change can have significant impacts on water resources in terms of quantity and quality. Hence, this study attempts to assess the impact of land use change for biofuel production on the water balance and water quality in a small watershed, Khlong Phlo in the Rayong province of Thailand. SWAT model was used to evaluate several land use change scenarios consisting of oil palm, cassava and sugarcane expansion.

The model was simulated for 22 years to test the accuracy of model for baseline conditions of the Khlong Phlo watershed. The model was calibrated and validated for monthly streamflow and sediment yield. The model was not calibrated for nitrate and total phosphorus loss because of unavailability of measured data. The model was able to track monthly streamflow with reasonable accuracy and annual water yield very well. SWAT was able to simulate the annual average sediment yield accurately nevertheless, it was fairly able to replicate the monthly time-series of observed sediment yields of the Khlong Phlo watershed.

The finding indicates that land use change for biodiesel production using oil palm will not affect the water balance. Forest conversion for biodiesel production however, will affect the water balance of the study area due to increased surface runoff and decreased baseflow. On the contrary, land use change for bio-ethanol production utilizing cassava and sugarcane will affect the water balance of the watershed due to increased surface runoff and water yield and decreased baseflow and evapotranspiration. Expansion of oil palm area for biodiesel production will have impact on the water quality in the Khlong Phlo watershed due to increased nitrate extraction into surface water except for conversion of orchard into oil palm which will not affect the water quality. Likewise, expansion of cassava and sugarcane coverage for bio-ethanol production reveals that there will be impact on water quality in the watershed due to rise in sediment, nitrate and total phosphorus load in surface water. This indicates that biofuel production will have negative impact on the environment of the Khlong Phlo watershed. The study was conducted in small watershed scale. In order to strengthen the study results, a research at a large scale at basin level is recommended.

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SESSION B6

Landscape Processes and Landscape / River Continuum

B6-1

An Efficient Delineation Structure in SWAT to Simulate the Landscape/ River Continuum

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Modeling the cumulative discharge, sediment and solute load of large watersheds (>1000sq. km) requires a balance between data availability, computer processing, and model structure. Large model runs for continental scale assessment are common and assist in evaluating the nation's water quality, the viability and cost benefit of best management practices in the farm bill, amd climate change impacts on water resources. The model runs allow for broad scale evaluation of changes in management, climate, and the impact of legislation on the nations watersheds. In order for a model to be representative of the abiotic and biotic systems, it must represent linkages between the various landscape units at a scale that allows reasonable output. The challenge is to be able to realistically code the functions derived from studies at the hillslope and small catchment scale into models that operate at the meso (.100-1000km^2) and large (>1000km^2) scales. The purpose of this paper is twofold: (1) demonstrate a new way to aggregate detailed watershed processes within subwatersheds which meet the lower limits of dissagregation based on gage density and (2) to allow user defined routing strategies within these basins so that small headwater processes can be assimilated into the large watershed model while at the same time minimizing computer processing. We propose and demonstrate a flexible, computationally efficient stream network model which will integrate soil, landscape elements into a spatially explicit network of stream reaches.

SESSION A4

Pesticides, Bacteria, Metals and Pharmaceuticals

A4-1

Manipulation of the SWAT Code to Model Veterinary Antibiotics in the Environment

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Veterinary antibiotics (VAs) are widely used to treat diseases and protect the health of animals. They are also incorporated into animal feed to improve growth rate and feed efficiency. As VAs are poorly adsorbed in animal intestines, the majority is excreted unchanged in feces and urine. Given that land application of animal waste as a supplement to fertilizers is often a common practice in many countries, there is a growing international concern about the potential impact of antibiotic residues in the environment. Unlike other conventional industrial chemical pollutants, VAs possess several characteristics that make them different while assessing and modeling their fate and transport in the environment. Some of these attributes include: Solubility, pH (both soil and aqueous), organic carbon content, molecular structure, ionization, dissociation constant, octanol water distribution coefficient and sludge sorption/desorption. During this study, the SWAT code was modified to include few major parameters mentioned above to model VAs as well as other veterinary medicines in agricultural dominated watersheds. The watershed used for model testing was the Shell Creek Watershed, which is located in Northeastern Nebraska and drains an area of 1214 square km in parts of Boone, Colfax, Madison, and Platte Counties. Cattles and swine feedlot operations within the Shell Creek drainage constitute the major contributor to VAs loadings. Other major water quality issues include erosion, sedimentation, nitrogen, and phosphorus as well as degradation from other non-point sources and loss of aquatic and wildlife habitat.

A4-2

Potential Soil Transport of 17β-estradiol in a Beneficial Reuse System Land-applying Class B Municipal Biosolids for Forage Production in Central Texas

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The impact of anthropogenic chemicals on water quality, wildlife, and human health has received increasing attention in recent years. One potential source of anthropogenic compounds is land-based recycling programs which apply municipal wastes (biosolids) to large tracts of agricultural land in lieu of chemical fertilizers. Fertilizing with biosolids may increase the risk of soil and water pollution by excess nutrients, metals, endocrine disrupting chemicals (EDCs), and other organic contaminants. It is also unclear how these compounds move through soils to enter natural waters and how different land-based recycling management strategies could be used to minimize chemical movement and transport. We used the USDA-ARS's Soil and Water Assessment Tool (SWAT) pesticide submodel to simulate potential movement of 17β-estradiol through soils at a municipally-operated beneficial reuse site in central Texas that surface applies biosolids to agricultural land for commercial forage production. Specifically, we were interested in the effects of cropping system affects EDC movement, as well as the effects of uncommon, large rainfall events that could potentially flush EDCs from biosolids-applied areas. Two simulations were run (1980-2006, 1980-2007) in which one simulation included a historically high 2007 rainfall year. SWAT simulations showed that the perennial biofuel crop switchgrass reduced leaching of 17β-estradiol through surface soils (A horizon) by 21-23% compared to the current coastal Bermudagrass forage crop. No leaching of 17β-estradiol was simulated to occur through the bottom of the soil profile (1.5 m), but leaching through surface soils (A horizon) increased by 90% with the inclusion of the 2007 rainfall year. Our results suggest that anomalous rainfall events may trigger flushes of EDCs through the soil. The results from this study will be used to aid the development of an emerging contaminants sub-model in SWAT for predicting transport and fate of EDCs and other biosolids-derived organic pollutants. Ultimately, our research findings will assist the development of more sustainable, economically and ecologically sound land-based biosolids recycling management plans.

A4-3

Modeling Approach on Resuspension of *E. coli* from Streambed using Soil and Water Assessment Tool (SWAT)

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Streambed sediment has been attracting attention as a reservoir for bacteria, including pathogenic strains. Soil and Water Assessment Tool (SWAT) has been augmented with a bacteria transport module in SWAT2005 where the die-off of bacteria is the only in-stream process. The purpose of this study was to evaluate the prospective significance of streambed *E. coli* release and deposition within the SWAT microbial water quality simulations. The modified SWAT was applied to the Komacwon Creek (KMC) watershed, South Korea. Sensitivity analyses and calibrations were separately performed on both hydrologic and bacteria-associated parameters. Hydrometric validation results display a very good linear relationship between observed and predicted data (Nash-Sutcliffe efficiency E = 0.82 and 0.85 for calibration and validation steps) and indicate satisfactory simulation of hydrologic processes within the catchment. Based on recommended values for the quantification of catchment modeling accuracy, predictions for *E. coli* can be described as unsatisfactory; this may attribute to the lack of data on wildlife. Although the uncertainty of *E. coli* concentrations in streambed sediments and from wildlife probably affected the performance of the modified SWAT model, this study qualitatively confirmed the significance of EC release from streambed and deposition for the SWAT microbial water quality simulations.

SESSION B7

Environmental Applications

B7-1

Modification of Stream Water Temperature Calculation Equation of SWAT for the Han River Korea using Regression Analysis

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Abstract

In the SWAT model, stream temperature is calculated from the average air temperature using an equation developed by Stefan and Preud'homme which was derived from stream/air temperature relationship of 11 rivers in the USA. Purpose of this study was to derive stream water estimation equation in the Han River, Korea then compare the results to the equation in the SWAT model. Among the 48 water quality measuring points in the Han River water temperature records of 33 points excluding dams and urban areas were used. Linear regression using 8 day interval water temperature records of 33 measuring points and air temperature records of 14 weather stations was carried out. The prediction performance of air/stream water temperature regression equation in this study was higher than original equation of the SWAT model.

KEYWORDS: SWAT, stream/air temperature, linear regression

Introduction

Stream water temperature is one of the important factors affecting ecosystems and water quality of rivers (Benyahya et al., 2007). However, water temperature records are not easily available therefore air temperature is usually used to estimate water temperature in many studies (Mackey and Berrie, 1991; Stefan and Preud'homme, 1993; Mohseni and Stefan, 1999; Sahoo et al., 2009). In the SWAT model, stream/air temperature relation equation developed by Stefan and Preud'homme in 1993 is used to estimate water temperature from air temperature. This equation was derived from linear regression of air and water temperature in 11 rivers in the USA. Motivation of this study was that is this equation adequate to explain stream/air temperature relationship in Korea. To answer this question stream/air temperature relationship in the Han River basin which is one of the four major river basins in Korea was analyzed through linear regression of air and stream temperature.

Data Collecting

There are 14 weather stations and 48 water quality measuring points in the Han River basin operated by Korea Meteorological Administration and Ministry of Environment respectively. To understand the relationship of air and stream temperature, daily air temperature records from weather stations and 8 days interval stream temperature records from water quality measuring points were collected. Thiessen network was used to categorize water quality measuring points with close distance from each weather station as depicted in Figure 1.

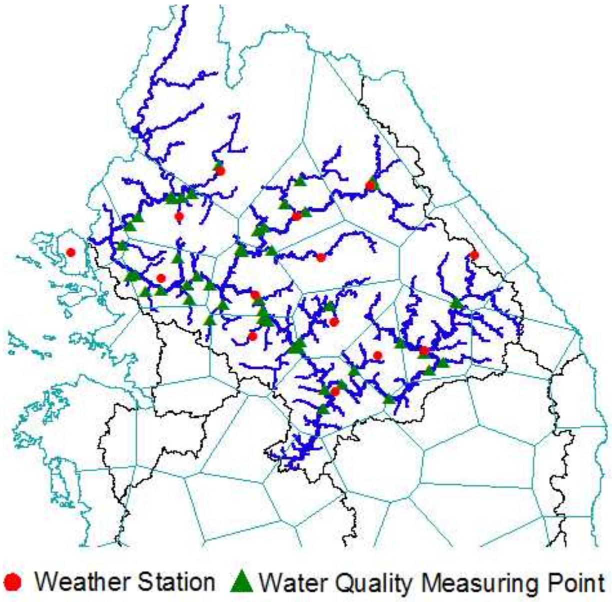
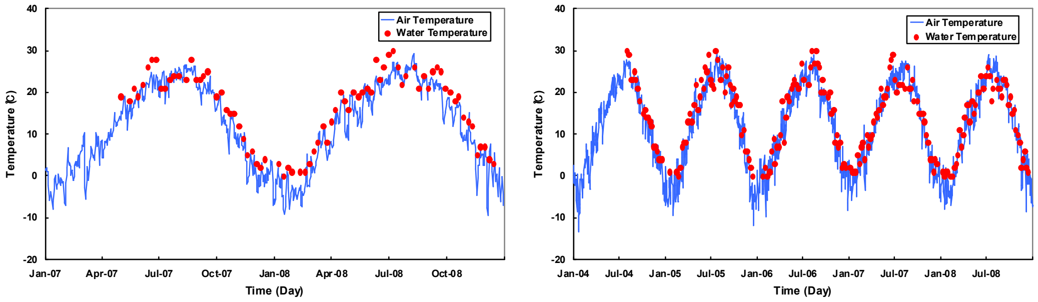
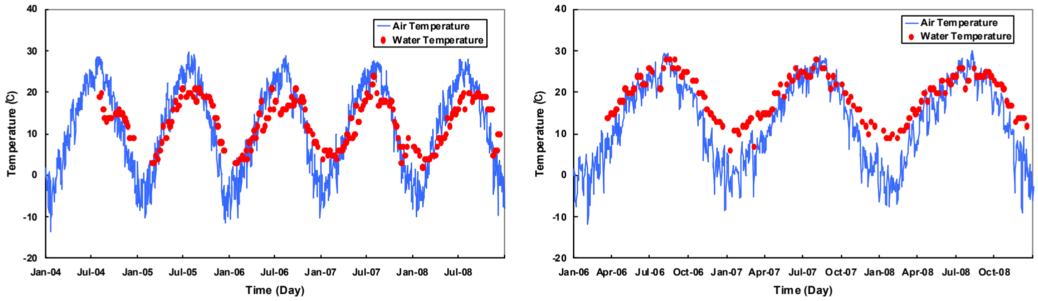


Figure 1. Air and stream temperature data collection points

Among 48 water quality measuring points, 7 points are located at dams and 8 points are within the urban areas. Air and stream temperature relationships in urban areas and dams were different from relationships in other natural streams. As shown in Figure 2, water temperatures of a dam (Figure 2 (c)) are delayed from air temperature distribution and stream temperatures in urban area are higher than air temperatures during winter periods (Figure 2 (d)), while stream temperatures of natural condition are proportional to air temperatures (Figure 2 (a), (b)).



(a) Natural Condition (Hantan B) **(b) Natural Condition (Jojong A)**



(c) Dam (Bukhan A) **(d) Urban Area (Tancheon A)**

Figure 2. Air-stream temperature distributions of natural streams, dam and urban area

In this study, to exclude anthropogenic effects on stream temperature, stream temperature records of 33 water quality measuring points were used in regression analysis except 15 points of dams and urban areas among total 48 points.

Linear Regression

Linear regressions of air and stream temperature for 33 points were carried out to estimate coefficient A and B of linear regression equation (Eq. 1).

$$Tw = A + B\,Ta \qquad (1)$$

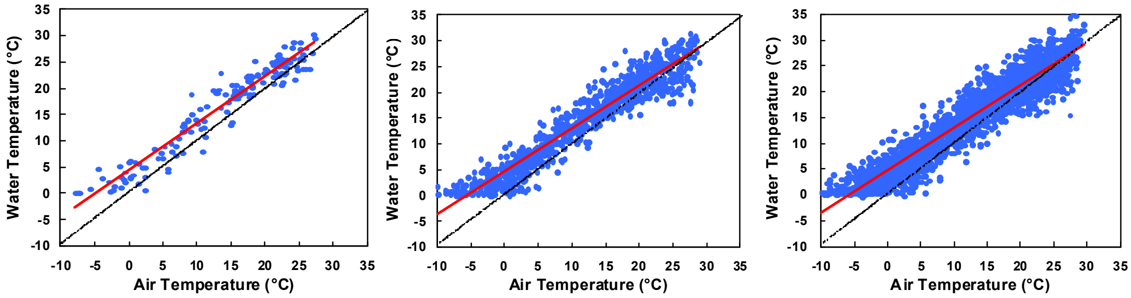
where, Tw is water temperature and Ta is air temperature.

Coefficient A and B for each measuring point and statistical results of linear regression are shown in Table 1. To better understand time lag of stream temperature, air temperature of the day when stream temperature measured (D), air temperature of 1, 2 and 3 days before (D-1, D-2, D-3, respectively) were analyzed with stream temperature. Correlation Coefficient, R of "D" were highest at 21 measuring points while at 10 points, R of "D-1" were highest and R of "D-2" and "D-3" were highest at 1 point. Results of Nash-Sutcliffe Model Efficiency, ME of "D" were highest at 24 points, and "D-1", "D-2" and "D-3" were highest at 7, 1 and 1 points respectively. Statistical results of air and stream temperature neglecting time lag ("D"), R were ranged from 0.903 to 0.982 and Nash-Sutcliffe Model Efficiency, ME were ranged from 0.816 to 0.965. Coefficient A of Eq. 1 for each measuring point decreased as the stream order increased while coefficient B increased as the stream order decreased as shown in Figure 3.

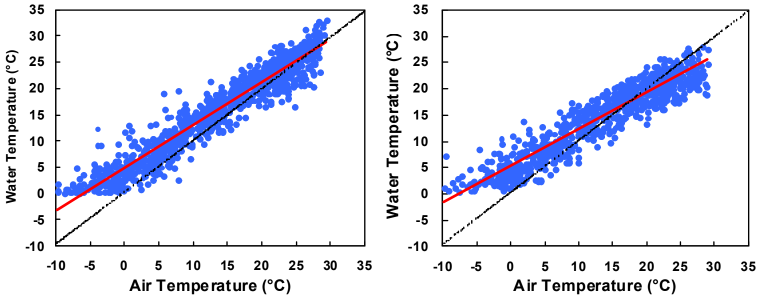
Table 1. Results of linear regression.

Measuring Point	Stream Order	Coefficient		R (Correlation Coefficient)				ME (Nash-Sutcliffe model efficiency)			
		A	B	D	D-1	D-2	D-3	D	D-1	D-2	D-3
Hantan B	3	5.180	0.836	0.967	0.964	0.959	0.942	0.833	0.832	0.820	0.790
Munsan A	4	4.194	0.908	0.965	0.957	0.961	0.949	0.832	0.783	0.798	0.777
Gapyeong A	5	4.334	0.824	0.960	0.959	0.941	0.926	0.864	0.854	0.827	0.813
Gyeongan A	5	5.058	0.825	0.967	0.967	0.959	0.953	0.837	0.824	0.814	0.814
Gokleung A	5	5.014	0.896	0.971	0.972	0.962	0.950	0.783	0.763	0.758	0.740
Odae A	5	5.837	0.815	0.941	0.933	0.922	0.917	0.663	0.642	0.618	0.606
Jojong A	5	3.213	0.874	0.968	0.969	0.955	0.935	0.905	0.904	0.883	0.853
Golji A	6	6.737	0.820	0.954	0.953	0.934	0.929	0.583	0.564	0.521	0.512
Bokha A	6	7.917	0.798	0.961	0.938	0.913	0.898	0.599	0.564	0.531	0.490
Seomgang A	6	4.161	0.827	0.971	0.966	0.951	0.940	0.891	0.878	0.862	0.841
Soyang A	6	2.670	0.841	0.959	0.961	0.954	0.938	0.906	0.911	0.900	0.870
Sincheon A	6	5.986	0.830	0.961	0.951	0.936	0.927	0.765	0.750	0.704	0.674
Yangwha A	6	5.183	0.879	0.982	0.971	0.947	0.934	0.813	0.789	0.747	0.711
Yeongpyeong A	6	4.537	0.837	0.952	0.951	0.936	0.928	0.862	0.859	0.822	0.800
Okdong A	6	5.935	0.638	0.961	0.956	0.944	0.927	0.811	0.799	0.774	0.753
Inbuk A	6	3.589	0.839	0.960	0.953	0.941	0.919	0.881	0.869	0.851	0.812
Imjin A	6	3.703	0.875	0.965	0.964	0.964	0.946	0.883	0.883	0.880	0.849
Jecheon A	6	4.468	0.849	0.970	0.969	0.959	0.937	0.855	0.857	0.833	0.810
Jucheon A	6	4.613	0.838	0.962	0.963	0.944	0.927	0.840	0.837	0.799	0.779
Cheongmi A	6	5.207	0.892	0.971	0.960	0.942	0.926	0.783	0.755	0.732	0.700

Hantan A	6	4.464	0.796	0.969	0.982	0.976	0.963	0.884	0.902	0.880	0.866
Hongcheon A	6	3.840	0.863	0.959	0.972	0.962	0.959	0.871	0.891	0.878	0.880
Heukcheon A	6	3.614	0.849	0.960	0.959	0.945	0.933	0.886	0.882	0.861	0.836
Gyeongan B	7	4.694	0.790	0.967	0.976	0.966	0.956	0.869	0.879	0.862	0.853
Dalcheon A	7	5.238	0.841	0.968	0.967	0.954	0.934	0.823	0.804	0.788	0.772
Dalcheon B	7	7.926	0.678	0.932	0.923	0.912	0.897	0.683	0.655	0.633	0.634
Seomgang B	7	4.406	0.865	0.969	0.965	0.955	0.944	0.860	0.844	0.837	0.810
Imjin B	7	3.722	0.872	0.964	0.965	0.966	0.965	0.883	0.881	0.887	0.876
Pyeongchang A	7	3.656	0.841	0.962	0.966	0.957	0.942	0.886	0.889	0.865	0.851
Hangang A	8	4.340	0.779	0.965	0.966	0.963	0.951	0.877	0.879	0.870	0.845
Hangang D	8	6.974	0.561	0.903	0.899	0.897	0.907	0.722	0.712	0.712	0.723
Hangang E	8	5.249	0.722	0.959	0.960	0.948	0.945	0.847	0.846	0.837	0.832
Hangang F	8	4.754	0.723	0.945	0.943	0.941	0.944	0.846	0.836	0.831	0.839



(a) Stream Order 3, 4 **(b) Stream Order 5** **(c) Stream Order 6**



(d) Stream Order 7 **(e) Stream Order 8**

Figure 3. Air-stream temperature relationship variation with stream order

With 33 equations for 33 water quality measuring points, one generalized equation representing the Han River basin, Eq. 2 was derived by averaging coefficients A and B of Eq. 1. Compared with stream temperature equation in SWAT, $Tw = 5.0 + 0.75\ Ta$, coefficient A decreased 0.139 and B increased 0.066.

$$Tw = 4.861 + 0.816\ Ta \quad (2)$$

To compare the difference of two equations, both equations were applied to 33 stream temperature measuring points. Calculated stream temperature values using Eq. (1) and (2) were compared with observed stream temperature during 2009. ME of the results of Eq. (1) ranged from 0.594 to 0.924 and ME of Eq. (2) ranged from 0.687 to 0.940. ME of the results of both equations for 33 measuring points during 2009 were drawn in Figure 4.

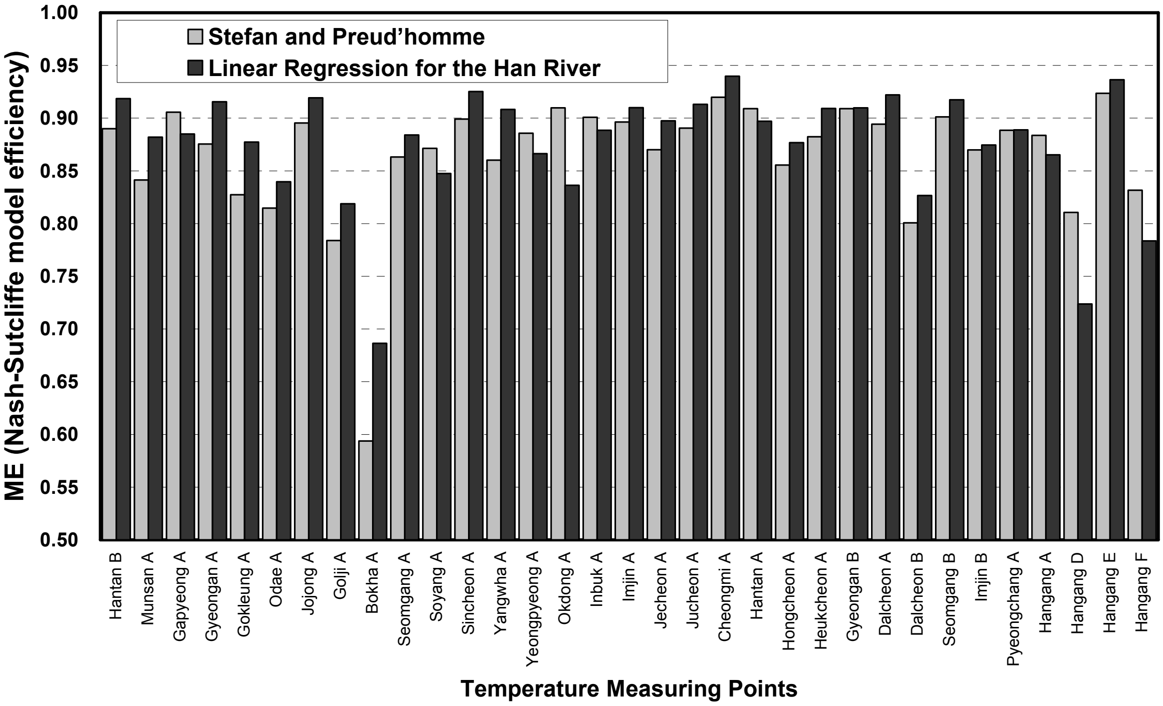


Figure 4. Nash-Sutcliffe model efficiency of equation in SWAT and developed equation in this study

Conclusions

Stream/air temperature relationship in the Han River, Korea was analyzed through linear regression to derive an equation for more accurate stream temperature calculation. An equation derived in this study was proved that can calculate stream temperature with higher correlation with observed values than an equation in the SWAT model. Therefore, when an equation derived in this study is applied in the SWAT model, it is expected that one can get more precise results of environmental simulation in the Han River basin.

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B7-2

Simulating Water Quantity and Quality and Sediment Transport under Varying Land Use and Climatic Conditions in a Monsoonal Driven Watershed

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Integrated modeling of water and solute fluxes throughout a small catchment is under investigation with the spatially-distributed SWAT2005. Field-based meteorological conditions, hydrology, biology, solute and sediment transport, and social and land use pattern data collected in the Haean-myun Basin are used to parameterize and calibrate the model. Key processes that regulate both water quantity and quality are examined to simulate sediment, nitrogen, phosphorous, and dissolved organic carbon outputs.

Several integrated experimental strategies such as monitoring of soil water dynamics and sediment transport measured within run-off plots during extreme event periods are being used to calibrate the soil water and erosion module in SWAT. Topographically variable, spatio-temporal surface water and groundwater elevation and concentration datasets are being collected.

The modeling framework described is used to perform scenario simulations examining temporal changes in land use practices and climatic effects on water quantity and quality in complex terrain. An important part of this work is examining the social relationship between land management practices and the value of sustainable resources. A link between the small catchment population structure and these management practices to the resultant ecosystem services provided is being pursued. The water quality and sediment results from this catchment in conjunction with stochastic estimates from the remainder of the watershed impact the Lake Soyang reservoir, a drinking water supply to Seoul. Future work includes extrapolation of several catchment results with differing land use patterns to quantify potential nutrient loading within the Lake Soyang reservoir.

B7-3

Modelling the Impact of Land Use Change on the Water Balance in the Xiangxi Catchment (Three Gorges Region, China) using SWAT

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The Three Gorges Region in China is currently facing a large scale land use change. Due to the impoundment of the Three Gorges Reservoir, agricultural areas had to shift uphill from the fertile valley bottoms to steep, formerly wooded slopes. Also, many villages and towns had to be relocated including the construction of new infrastructure.

The impacts of the ongoing land use change are currently assessed by the Sino-German project „YANGTZE: Land use change – Erosion – Mass Movements“. Five project partners from Germany are currently working in the Xiangxi Catchment, the chosen investigation area, focussing on different aspects of this topic. The sub-project „Diffuse Inputs“ tries to link the results of the other four sub-projects „Land Use Change“, „Remote Sensing“, „Erosion“ and „Mass Movements“ to the water quantity and quality of Xiangxi River and aims to fill the gap between the terrestrial and the aquatic part of the catchment.

The main tool used in this study is the SWAT model (Arnold et al. 1998). The input data is provided by the German project partners and Chinese cooperation partners and authorities. The database is completed by results of own fieldwork and literature data. The SWAT model is used to simulate the water balance as well as the sediment and phosphorus transport in the catchment. In order to assess the impact of the recent land use change caused by the construction of the Three Gorges Dam and to develop sustainable land use options from an eco-hydrological point of view, simulations will be run with different land use maps and possible future land use scenarios.

A particular challenge to the model application is posed by two factors of human activity in the catchment. Firstly, there is a large number of small hydropower stations along the rivers and secondly, extensive sediment dredging takes place in the riverbeds. Both of these factors significantly affect the water, sediment, and phosphorus transport in the rivers and thus have to be accounted for in the model.

SESSION A5

Sediment, Nutrients and Carbon

A5-1

Comparison of the SWAT Model versus the DAISY-MIKE-SHE Model for Simulating the Flow and Nitrogen Processes

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As diffuse pollution from agriculture is a major concern, catchment scale modelling is a useful tool in estimating pollution loads from the agricutural activities in the river basin. In the Odense river basin, farmland accounts for 68% of the basin area and is the most important source of pollution. The paper discusses (1) the set-up of the SWAT model for the Odense river basin for simulating hydrology and nitrogen transport and transformation (2) evaluate the performance of SWAT in modelling water quantity and nitrogen dynamics by comparison to observations and previousDAISY-MIKE SHE model simulations.

SWAT is a semi-distributed catchment model which simulates water quantity and pollutant loadings based on hydraulic respond units (HRUs). The effect of biological or chemical reactions on nitrate transformation in groundwater is specified in SWAT by the half-life nitrate parameter which is uniform for the whole shallow aquifer. The DAISY MIKE-SHE approach consists of coupling a physically-based root zone model DAISY and a physically-based and fully distributed catchment model MIKE-SHE which are running sequentially. DAISY simulates the crop growth, root development and calculates daily mass of nitrate leaching which are then used as input for MIKE SHE to simulate groundwater and surface water. The MIKE SHE model simulates denitrification in groundwater by considering both oxidized and reduced layers which are seperated by the redoxcline. It is assumed in MIKE SHE that nitrate reaching the redoxcline is removed instantaneously.

The input data is kept the same for the two models. Moreover, parameters in DAISY-MIKE SHE and SWAT that are compatible with each other should have the same value. A sensitivity analysis and calibration are then implemented for flow and nitrogen simulation in SWAT. The performance of SWAT and DAISY-MIKE SHE are compared in terms of the conceptual approach which affects the acurracy of flow and nitrogen simulation. According to premilinary results for Odense river basin, SWAT has problem in simulating low flow in the dry period.

Keywords: SWAT, DAISY-MIKE SHE, nitrogen, denitrification

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Introduction

The EU Water Framework Directive (WFD) has introduced a new approach in water resources protection in which there is a change from focusing on the control of point sources of pollution (emission-based regulations) to integrated pollution prevention at river basin level and setting water quality objectives for the receiving water (immission-based regulations). This new policy requires the integration of all water quality issues, related to both point and diffuse pollution sources, at river basin scale. Due to the past and present efforts in waste water treatment for industries and households, diffuse pollution such as agriculture or groundwater recharge is becoming a major concern, being often the main cause of nitrification and eutrophication of water bodies. Catchment modelling is a useful tool to estimate the pollutant loads from diffuse sources in the catchment to the river.

SWAT and MIKE-SHE are two catchment models with different approaches. SWAT is semi-distributed model in which all processes are lumped at hydrological response unit (HRU) level. MIKE-SHE is a fully distributed physically based hydrological catchment model which simulates all processes at grid level. MIKE-SHE is coupled with the crop model DAISY to simulate the crop yield and nitrogen cycle in the catchment. The DAISY-MIKE SHE model is already set up and simulation results available for Odense river basin in Denmark which is chosen as the case study of this paper.

The paper discusses (1) the set-up of the SWAT model for the Odense river basin for simulating hydrology and nitrogen transport and transformation (2) evaluation of the performance of SWAT in modelling water quantity and nitrogen dynamics by comparison to observations and previous DAISY-MIKE SHE model simulations.

Study Area: Odense River Basin, Denmark

The study area is the Odense river basin that is located on the island of Funen in Denmark. The basin comprises an area of approximately 622 km^2. The river discharges into the Odense Fjord. The Odense floodplain was formed by a meltwater river during the last glacial period. The clay soil types are slightly dominant and encompass approximately 51% of the basin, while the sandy soil types cover about 49% (Fyns county, 2003). The glacial sediment soils of Funen are particularly well suited to the cultivation of agricultural crops. Therefore, the land use in Odense River Basin is dominated by agricultural exploitation just as elsewhere in Denmark. Farmland thus accounts for 68% of the basin, approximately 16% is accounted for by urban areas, 10% by woodland, and 6% by natural/ semi-natural areas (meadows, mires, dry grasslands, lakes and wetlands). Cereals are the dominating crops (approximately 60% of the agriculture area). The rest of the agricultural area is defined as permanent grass (pasture) or fallow fields.

The average monthly precipitation in Odense River Basin varies between approximately 40 mm (April) and 90 mm (December/January). The average air temperature in Funen is 8.2°C (1961—1990). The wind usually blows from the west.

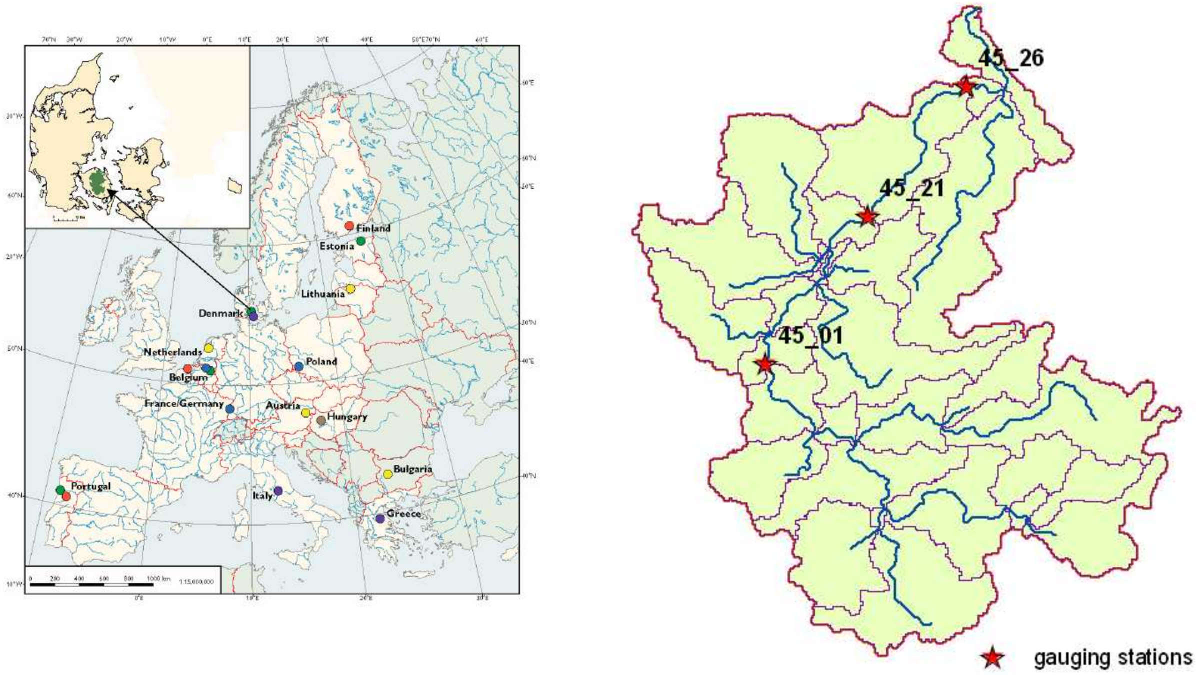

Figure 1. Study area: Odense river basin, Denmark

SWAT Model

The soil and water assessment tool (SWAT) is a physically based, time continuous model, developed by the USDA Agricultural Research Service (ARS) in order to simulate the impact of land management activities on water, sediment, pesticides and nutrient yields in large complex watersheds over long time period. In SWAT, a watershed is divided into multiple sub-watersheds or sub-basins. They are then subdivided into hydrological response units (HRUs) each of which has unique land cover, soil characteristic and management combination. All processes modelled in SWAT are lumped at HRU level (Neitsch et al., 2002).

Flow simulation

In daily time step, SWAT simulates surface runoff using the SCS curve number method (Soil Conservation Service, 1972) in which canopy storage is taken into account in the surface runoff calculation. SWAT assigns the SCS curve number based on land use, hydrologic soil group and hydrologic condition. The amount of infiltration to the soil profile is the difference between the amount of rainfall and surface runoff. The percolation component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Percolation occurs when the field capacity of a soil layer is exceeded and the layer below is not saturated. The flow rate is governed by the saturated conductivity of the soil layer. Lateral subsurface flow in the soil profile is calculated simultaneously with redistribution using a kinematic storage model. The model computes evapotranspiration separately for soil and plants. Potential soil water evaporation is estimated as a function of potential evapotranspiration and leaf area index. Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant transpiration is simulated as a linear function of potential evapotranspiration and leaf area index. For groundwater, SWAT partitions groundwater into two aquifers: a shallow, unconfined aquifer which contributes with return flow to streams within the watershed and a deep, confined aquifer which contributes with return flow to streams outside the watershed. Water percolating past the bottom of the rootzone is partitioned into two fractions each of which becomes recharge for one of the aquifers. Moreover, water in shallow aquifer can be directly removed by plants or move to overlying unsaturated layer when water stored in shallow aquifer exceed a threshold value. Water in shallow or deep aquifer can be removed by pumping (Neitsch et al., 2002).

Nitrogen balance in catchment

Nitrogen is modelled by SWAT in the soil profile and in shallow aquifer. SWAT monitors five different pools of nitrogen in the soil. Two inorganic forms of nitrogen are NH_4^+ and NO_3^- and 3 organic forms of nitrogen are fresh organic N which is associated with crop residue and microbial biomass, active and stale organic N associated with the soil humus. Nitrogen processes in the soil include: mineralization, residue decomposition, immobilization, nitrification, ammonia volatilization and denitrification. Ammonium is assumed is to be easily adsorbed by soil particles, thus, it is not considered in the nutrient transport. Nitrate which is very susceptible to leaching can be lost through surface runoff, lateral flow and percolate out of the soil profile and enter the shallow aquifer. Nitrate in the shallow aquifer may remain in the aquifer, move with the recharge to the deep aquifer, move with groundwater flow into the stream or be transported out of the shallow aquifer with water moving into the soil zone in response to water deficiencies. Nitrate in the shallow aquifer may also be lost due to uptake by the presence of bacteria, by chemical transformation driven by the change in redox potential of the aquifer and other processes. These processes are lumped together to represent the loss of nitrate in the aquifer by the nitrate half-life parameter.

The transformation of nitrate loss to the main stream is modelled using QUAL2E concept in SWAT. However, in this paper, in-stream water quality processes will not be considered.

SWAT Input Data and Description of Model Set-up

Watershed delineation

The ArcSWAT interface delineated the watershed into 30 subbasins based on the available DEM grid map with a spatial resolution of 100 meters. Three out of 30 outlets of subbasins were manually added at the location of three gauging stations 45_01, 45_21 and 45_26 which are then used for model calibration (figure 1). Nine point sources which represented discharges from sewerage systems in the basin were added in nine subbasins.

HRU definition

Soil. The soil profile in Odense river basin is divided into 3 horizons: A (0-30cm), B (30-70cm and C (70-100cm). The soil in each horizon was classified into different soil classes based on the percentage of clay, silt and sand according to the Danish soil classification. In order to decrease the number of soil profiles in the model and number of HRUs created, it is assumed that the distribution of soil types in horizon B and C is the same as in horizon A. Soil characteristics and hydraulic parameters of each soil type in each horizon were estimated by averaging all the value of the same soil type in the same horizon. As a result, there were 7 soil types distributed in the SWAT model in which the dominating soil type are JB3 coarse clayey sand (31.6%), JB4 fine clayey sand (20.5%), JB5 coarse sandy clay (26.6%) and JB6 fine sandy clay (19.4%)

Landuse. Landuse map was taken from the existing DAISY-MIKE SHE model which divided the area into 6 types of landuse: Cattle farms, plant production, pig farms, grass, coniferous forest and dedicious forest. In each agricultural group, one crop rotation was applied (table 1). The cropping schemes related to cattle farms, plant production and pig farms were permutated to ensure that each crop was equally represented for each climate year.

Table 1. Types of landuse and their crop rotations in Odense river basin

No.	Type of landuse	% of the catchment	Crop rotation
1	Cattle farms	11.5	Spring Barley (year 1), Grass (year 2), Winter wheat (year 3), Maize (year 4)
2	Plant production	25.2	Spring Barley (year 1), Grass (year 2), Winter wheat (year 3 + year 4)
3	Pig farms	19.8	Spring Barley (year 1), Grass (year 2), Winter wheat (year 3), Winter barley (year 4)
4	Grass	32.0	Grass (year 1-4)
5	Coniferous forest	3	
6	Dedicious forest	8.5	

Slope. The area is divided in 2 slope classes: 0 – 0.3% and > 0.3%.
HRUs were created by overlaying soil, landuse and slope maps. As a result, there were 654 HRUs in 30 subbasins in Odense river basin.

Climate

Daily precipitation in the area of Odense river basin is available in the forms of 11 interpolated 10km x 10km precipitation grids from Danish Meteorological Institute. The data were then included in the SWAT model by using 11 stations each of which locates at the centroid of each precipitation grid. The temperature was based on 20km x 20km grid values which were applied in the model by 4 temperature stations. Solar radiation, relative humidity and wind speed was taken from a single weather station for the whole area. Potential evapotranspiration was calculated by Penman – Monteith method in SWAT.

Pollution sources

Due to the objective of modelling nitrogen, only data related to nitrogen compounds were introduced into the model. Nitrogen derives from point sources and fertilizer application. Nine point sources which represented discharges from sewage systems were applied in the model. There are 2 types of fertilizer applied: mineral fertilizer N50S which composes of 50.4% NH_4^+ and NO_3^- as remainder and cattle slurry Cslurry13 which include 40% of NH_4^+ and 60% of organic N.

Tile drainage

There were two versions of the SWAT model of the Odense river basin built with and without tile drainage. The model was built first without tile drainage. Because tile drainage is very important in the study area which helps to remove excess water from soil subsurface, tile drains were added to the model.
Drainage was handled using the tile drainage option in the management files in SWAT. The depth from soil surface to tile drainages (DDRAIN) was set at 0.5 m in every HRU. The depth to impervious layer DEP_IMP was set at 3000 mm for the whole basin to allow the rising of perched water table which generates tile flow. If the groundwater table height exceeds the height of tile drains above the impervious zone, tile drainage will occur.

SWAT running, calibration and validation.

The SWAT model was run with daily time step in the 14 year period of 1990 to 2003. The first 3 years was only used as warming-up period. Calibration was done for the period of 1993-1998 while 1999-2000 was the validation period. Sensitivity analysis was implemented using sensitivity analysis tool LH-OAT in SWAT. The calibration and validation was done manually or by auto-calibration tool for both flow and nitrogen at the location of the gauging station 45_26 which corresponded to the outlet of subbasin 3 in the SWAT model (figure 1).

To evaluate SWAT performance for the simulated discharge and nitrogen flux, the following criteria were used:

$R^2_{Q,\text{ daily or annual}}$: the model efficiency calculated on the basis of observed and simulated daily or annual discharge values (Nash and Sutcliffe, 1970).

$R^2_{N,\text{ daily or annual}}$: the model efficiency calculated on the basis of observed and simulated daily or annual total nitrogen flux (Nash and Sutcliffe, 1970).

$r_{Q,\text{ daily or annual}}$: the correlation coefficients between simulated and observed daily or annual discharge.

$r_{N,\text{ daily or annual}}$: the correlation coefficients between simulated and observed daily or annual total nitrogen flux.

DAISY-MIKE SHE Model

DAISY MIKE-SHE (Styczen and Storm, 1993) approach is a coupled model of a physically-based root zone model DAISY (Abrahamsen and Hansen, 2000; Hansen et al., 1991) and a physically-based and fully distributed catchment model MIKE-SHE (Refsgaard and Storm, 1995). The coupling approach includes the entire land-based hydrological and nitrogen cycle from field to river outlet. (Hansen et al., 2009). The DAISY-MIKE SHE model built for Odense Fjord catchment which covers Odense river catchment was carried out by Hansen et al. (2009)

DAISY model

DAISY is a one-dimensional crop model that simulates crop production and crop yield, and describes soil water dynamics, soil temperature, the carbon and nitrogen cycle of the root zone (Abrahamsen and Hansen, 2000; Hansen et al., 1991). Flow and leaching via three possible pathways: matrix, macropores and drain pipe is simulated for a set of computational nodes in a soil column. There were three different lower boundary condition applied in the exiting DAISY model: a constant groundwater level, a gravitational gradient and a time-varying groundwater using a drain pipe option in DAISY. In the model of Odense river basin, the lower boundary conditions were assigned based on the simulated water table from the National Water Resource Model. The drain pipe option was applied at a depth of 1m in all DAISY columns where the simulated mean water table depth is shallow. Where the average water table is deeper than 3 m, the lower boundary condition was set to the deep groundwater level option.

The solute balance model simulates transport, sorption, transformation processes and plant uptake by solving the convection-dispersion equation. DAISY considered three type of nitrogen: ammonium, nitrate and organic nitrogen. Nitrogen processes simulated in the nitrogen balance model include: mineralization, immobilization, nitrification, denitrification, plant uptake of ammonium and nitrate, and leaching of ammonium and nitrate.

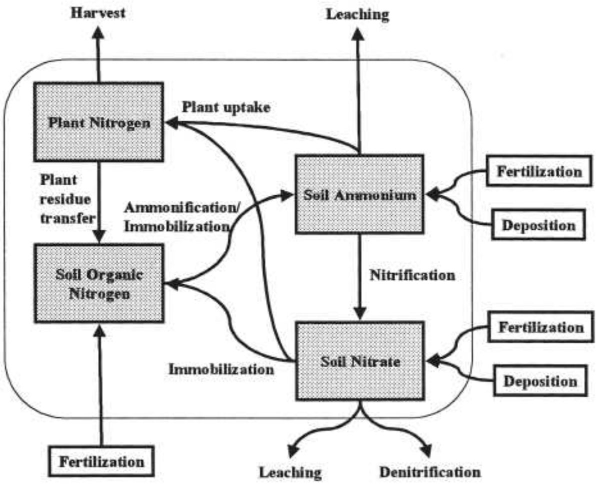

Figure 2. Schematic representation of Nitrogen cycle components included in DAISY (Abrahamsen and Hansen, 2000)

MIKE-SHE

MIKE-SHE is a fully distributed physically based hydrological catchment model which can simulate all hydrological domains within the land phase of the hydrological cycle (Refsgaard and Storm, 1995). The model can perform numerical solutions for 3D Boussinessq equation for saturated flow, 1D Richard equation for unsaturated zone, 2D Saint Venant equation for overland flow and is integrated with MIKE 11 to model the exchange flow and transport between the river and the saturated zone. In the existing DAISY-MIKE SHE model, the unsaturated zone part of MIKE SHE was substituted by DAISY calculations. DAISY calculated water and nitrogen budget in the rootzone as input for MIKE SHE. MIKE SHE modelled the groundwater component, the transport and transformation of nitrogen in the saturated zone. Tile drains was modelled using the built-in drain routing option in MIKE-SHE. If groundwater level exceeds a specified threshold height called drain level (1 m below the surface in this case study), the exceeding water is routed to the nearest river reach by first order rate specified by drain time constant (s-1).

In the saturated zone, it was assumed that no nitrate is reduced in layer above the location of the redox-interface whereas all nitrate transported to layers below the interface is removed instantaneously. In order to account for this, two water quality zones separated by the redox interface were introduced in MIKE SHE: oxidized zone and reduced zone that have very high and very low half-life parameters for nitrate respectively. The half life of 2 years was applied for oxidized zone after calibration taking into account the possibility that local anaerobic zones exist in the upper oxidised zone. It was assumed that the depth to the redox interface is related to soil types at 1 meter below the surface. Sandy areas are assumed to have higher infiltration rates than more clayey areas and therefore deeper redox interfaces. The redox interface was assumed to be located 2m below the surface in clay and organic soil areas, and 3.5 or 8m below the surface in till areas below and above an elevation of 45 m, respectively. The division between till above and below this elevation was a distinction between areas with shallow and deep groundwater tables. A deeper unsaturated zone will result in a deeper redox interface, owing to faster diffusive transport of oxidising agents, especially oxygen, above the water table (Hansen et al., 2009). Finally, the redox interface in sandy areas was set to 16m below the surface.

Coupling of DAISY and MIKE SHE models

In the DAISY-MIKE SHE model, DAISY substitutes the unsaturated zone of MIKE SHE. DAISY and MIKE SHE were coupled sequentially without any feedback from the groundwater and river to the rootzone. DAISY used groundwater level as boundary condition while MIKE SHE also simulates it in the saturated zone. Drain pipe option was applied in DAISY as one of the boundary conditions and drainage was simulated in DAISY while drain flow also was simulated in the saturated zone in MIKE SHE. The DAISY-MIKE SHE sequential modelling approach was described in figure 3. The DAISY first simulated the water and nitrogen budget of the root zone for all the specified combinations of input data. The DAISY column simulations were distributed corresponding to geo-referenced field blocks within the catchment. The outputs from field blocks were then aggregated as daily net values to MIKE SHE model grid blocks using a weighting area procedure. Subsequently, flow and transport simulation were executed in MIKE SHE.

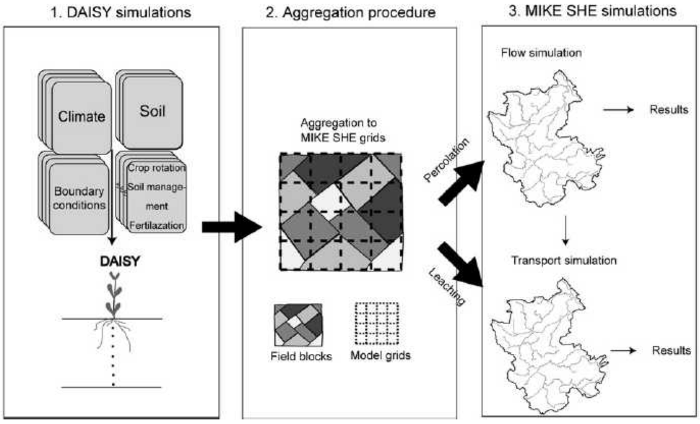

Figure 3. Flow chart of the DAISY – MIKE SHE sequential modelling approach (Hansen et al., 2007)

Result and Discussion

Performance of SWAT model in flow simulation

Comparison with measured data

As mentioned above, the SWAT model for Odense river basin was build in two versions: with and without the tile drainage. The flow calibration and validation were implemented in both cases at the location of the gauging station 45_26 which covers 86% of the whole drained area of the basin. The flow result after calibration was also compared with measured data at gauging station 45_01 and 45_21 which correspond to outlets of subbasin 17 and 4 respectively (figure 1).

Table 2. Performance criteria for the SWAT model with and without tile drainage

Period		**SWAT model without tile drainage**			**SWAT model with tile drainage**		
	Station/ Criteria	45_26	45_21	45_01	45_26	45_21	45_01
Calibration	$R_{2Q,daily}$	0.88	0.88	0.85	0.82	0.77	0.80
	$r_{Q,\ daily}$	0.94	0.94	0.93	0.92	0.92	0.91
Validation	$R^2_{Q,daily}$	0.85	0.87	0.85	0.80	0.75	0.80
	$r_{Q,\ daily}$	0.94	0.94	0.95	0.90	0.90	0.92

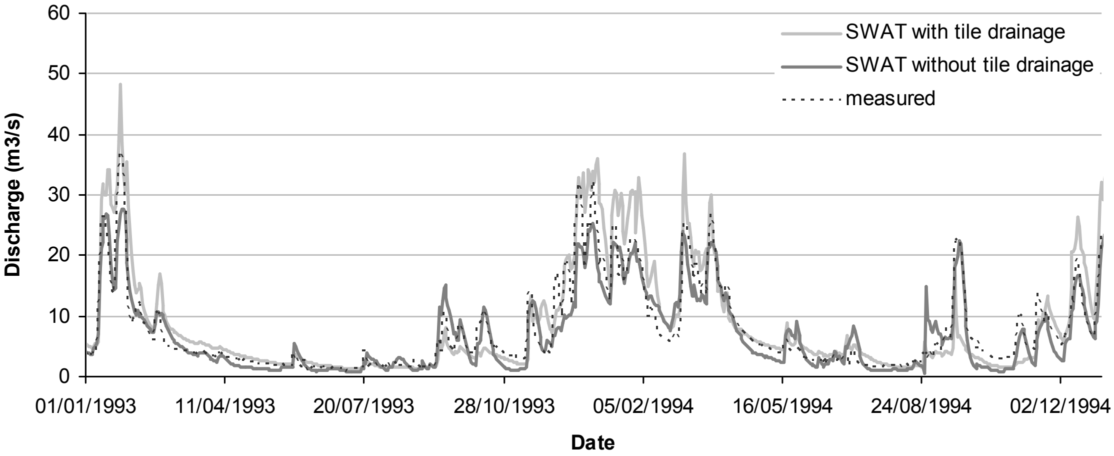

Figure 4. Comparison of discharge values after calibration in SWAT model with and without tile drainage and measured data.

In case tile drainage was not included, flow calibration was implemented by auto-calibration tool in SWAT in which the most sensitive parameters from sensitivity analysis results were chosen to be changed. After calibration, the Nash – Sutcliffe coefficient got 0.88 at the calibrated station and 0.88 and 0.85 for the other two stations. The validation result is also very good for all three stations with Nash – Sutcliffe coefficient from 0.85 to 0.87. However, this model generated very high surface runoff at 248.29 mm which is much higher than the amount of lateral flow (0.99mm) and groundwater flow (129.8mm) (table 3). For the case of Odense catchment, where tile drains are applied everywhere to remove excess water from subsurface soil, very little surface water runoff is observed. According to the water balance result from the reference model MIKE SHE provided by Geological Survey of Denmark and Greenland (GEUS), tile drainage is the most important contribution to stream discharge and much higher than surface runoff and groundwater flow (table 3). Although the simulated hydrograph in SWAT is fitted to the measured data, the high amount of surface water will cause problem when modelling erosion or nitrate loadings when fertilizer is applied on the soil surface. Therefore, tile drainage option was applied in the second version of the SWAT model.

Table 3. Annual water balance in SWAT models with and without tile drainage and MIKE SHE

Water balance components	SWAT without tile drainage (mm)	SWAT with tile drainage (mm)	MIKE SHE (mm)
Precipitation	875	875	883
Surface runoff	248	107	50
Lateral flow	1	3	
Tile drainage	0	123	183
Groundwater flow	130	105	72
Revaporation	1	2	
Evaporation	490	531	594

When tile drainage was included, flow calibration was carried out manually because parameters related to tile drainage were still not added in the auto-calibration tool. The depth of tile drains (DDRAIN) was set at 0.5m for the whole basin. Depth to impervious layer (DEP_IMP) was set at 3m after calibration to allow the rising of perched water table that can generate tile flow. The curve number was set lower to decrease the generation of surface runoff. Other sensitive parameters from sensitivity analysis results were also calibrated. After calibration, the Nash – Sutcliffe coefficient got 0.82 which is worse than the first model. It can be seen from figure 4 that SWAT model overestimated discharge in flood period and could not catch the small variation very well in the dry period. This problem is because the tile drainage in SWAT does not consider the effect of elevation.

In this model, the depth of impervious layer (DEP_IMP) was assigned the same value for every HRU, thus, when the perched water level is higher than the height of tile drains above the impervious layer, tile drainage is generated everywhere in the basin. In reality, in high elevation area where groundwater table is very far from the tile drains, it is not possible for tile drainage to generate while in low area like wetlands, tile drainage is generated very fast after the rain. Therefore, in flood periods, the SWAT model generated tile drainage from everywhere of the basin and overestimated it. This problem is possibly solved by assigning different DEP_IMP for different HRUs, however, it is difficult to assigning the value even if data is available because it is not known in which HRUs the value for DEP_IMP should be changed. HRU is the combination of soil, landuse and slope while DEP_IMP is a parameter related to elevation.

In dry periods, the simulated hydrograph in SWAT could not capture small variations very well. These small variations are possibly from tile drainage from low elevation areas where groundwater table is very near tile drains or from surface runoff in wetlands where soil is already saturated with water. However, tile drainage was not generated because there is not enough water for the water table to rise and most of water was lost by evaporation. In order to create some small variations in dry period, curve number values for HRUs that has the land use of grass were kept high to create surface runoff in dry periods but this also increased the surface runoff in this land use in flood period and increased the amount of surface runoff in the whole basin.

Compared with the existing DAISY-MIKE SHE model

The result in SWAT was then compared with the existing DAISY-MIKE SHE model. Van der Keur et al. (2008) and van der Keur et al. (in prep), simplified the DAISY-MIKE SHE model to perform uncertainty analysis of discharge and nitrate loadings varying identified model parameters that most likely contributed to uncertainty in discharge and nitrate loadings. The uncertain model parameters included in the uncertainty analysis were soil hydraulic properties which related to transport of nitrate from the rootzone, slurry amount relating to turnover processes and root depth which contributed to uncertainty related to soil water balance. 24 runs were implemented with varied parameter sets generated by Latin Hypercube Sampling technique. In this paper, to compare the performance between SWAT and DAISY-MIKE SHE in flow simulation and taking into account the uncertainty in soil hydraulic and slurry parameters, discharge from SWAT model was compared with the maximum and minimum discharges from 24 runs of DAISY-MIKE SHE model in each time step from 1990-2000.

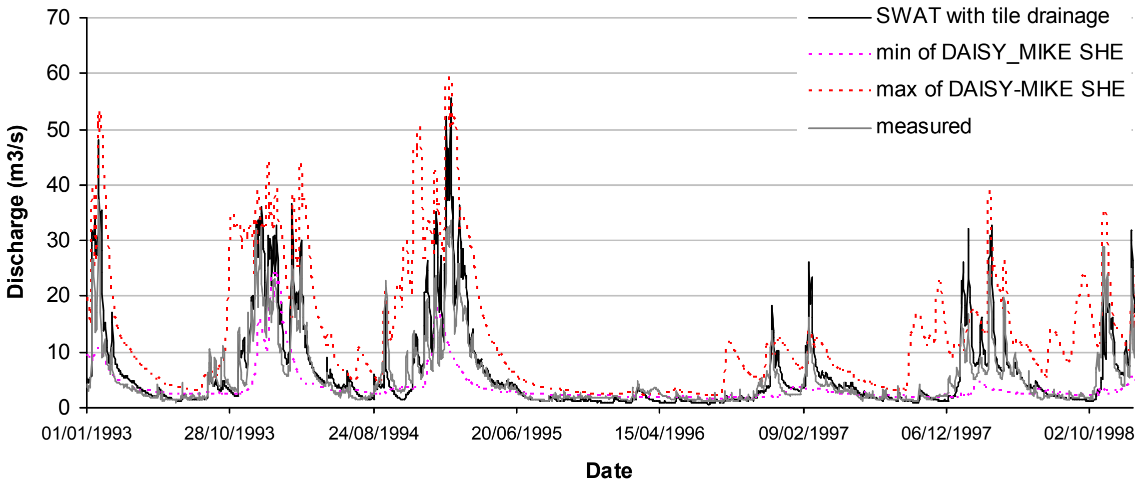

Figure 5. Comparison between discharge of SWAT with tile drainage, measured data and the range of discharge value from DAISY-MIKE SHE model

Figure 5 shows that SWAT results fit quite well inside the range of DAISY- MIKE SHE values. In the flood period, almost all the SWAT values are within the range. There is 45% of the SWAT value smaller than the minimum value of DAISY-MIKE SHE. All of them happen in the dry period; however, the difference in values is small. Mesured data also has 39% of the value lower than the range which also happens in the dry period.

The hydrograph of the SWAT model was also compared with the 50th percentile (median) ranked DAISY-MIKE SHE output from outputs of 25 simulations. The Nash-Sutcliffe coefficient for the two models is 0.85 for the period 1990-2000, which implies good correspondence between the two models. However, compared with measured data, the SWAT model gives better fit to the hydrograph than DAISY-MIKE SHE which can also be seen from higher Nash-Sutcliffe coefficient and correlation coefficient (table 4).

Table 4. Performance criteria for SWAT and DAISY-MIKE SHE

	SWAT model with tile drainage	DAISY-MIKE SHE
$R^2_{Q,daily}$	0.82	0.72
$r_{Q,\ daily}$	0.92	0.87

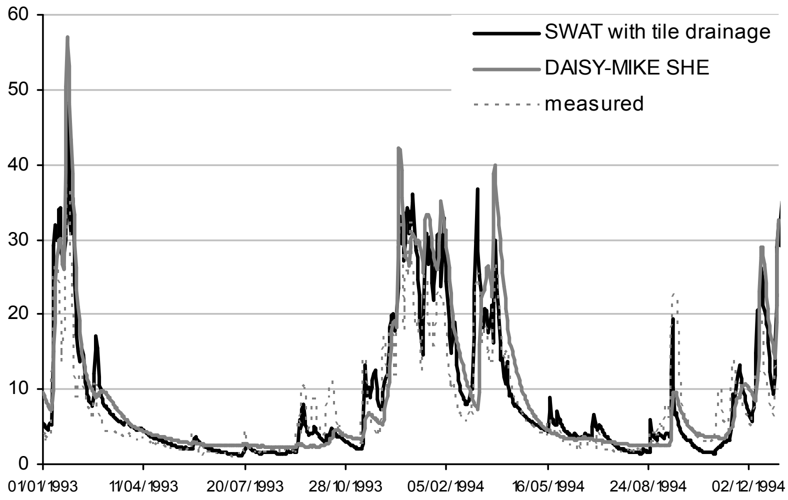

Figure 6. Comparison of simulated discharge between SWAT model, median discharge of DAISY-MIKE SHE and measured data

Performance of SWAT model in nitrogen simulation

Comparison with measured data

The SWAT model with tile drainage was chosen to model nitrogen because the water balance is more corresponding to reality and the reference DAISY-MIKE SHE model. The data for application of fertilizer was taken from the DAISY model. For each agricultural group: cattle farms, plant production, pig farms, grass, one crop rotation was applied. In the DAISY model, the cropping schemes related to cattle farms, plant production and pig farms were permutated to ensure that each crop was equally represented for each climate year. For instance, a four years scheme with A–B–C–D successive crops has permutations A–B–C–D, B–C–D–A, C–D–A–B, D–A–B–C. The permuted outputs were averaged to represent the mean cropping scheme in the agricultural land use. However, in the scope of this paper, no permutation was implemented in SWAT model.

As ammonia generally is strongly sorbed in most soils, the transport of ammonia in the catchment is not modelled in SWAT. Ammonia in the river is mostly from point sources and is affected by water quality processes in the river. However, in-stream water quality processes were not considered in this paper. Therefore, only nitrate was taken into account in the comparison. Nitrate flux at the same gauging station 45_26 was compared with measured data after calibration.

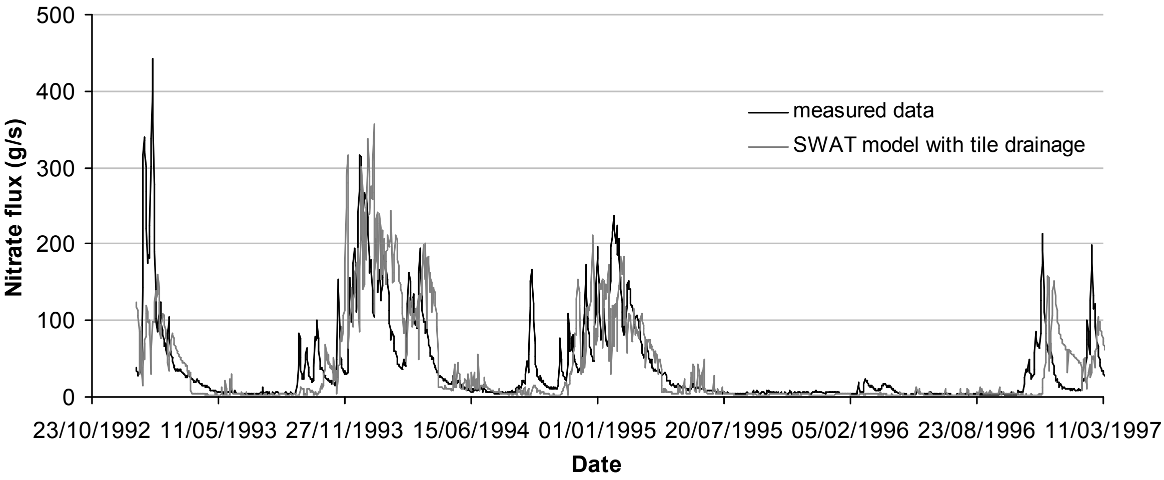

Figure 7. Comparison of nitrogen flux between SWAT model and measured data at the gauging station 45_26

Figure 7 shows that the magnitude and the trend of nitrogen flux from SWAT model are quite similar to the measured data. Nitrate in flood period is mostly from the catchment while in dry period, it mostly originates from point sources. It is clearly seen that SWAT model does not capture very well the measured values in each time step especially the flood period. The Nash-Sutcliffe coefficient between SWAT model and measured data is 0.36. However, a possible reason is that the permutation of crops was not implemented which affect the input data for SWAT model including the amount of fertilizer applied and the time of application. The model will be improved by including the permutation of crops in the next step of the study. However, with the similarity in magnitude and variation of nitrogen flux, SWAT is possibly a good tool for nitrogen simulation in this case study.

Comparison with DAISY-MIKE SHE model

Nitrate flux at gauging station 45_26 from SWAT was then compared with the DAISY-MIKE SHE model from the work of van der Keur et al. (2008) and van der Keur et al. (in prep) in which soil hydraulic and slurry parameters were varied to analyze the effect of uncertainty of these parameters. SWAT results were again compared with the maximum and minimum time series values from 24 simulations of DAISY-MIKE SHE.

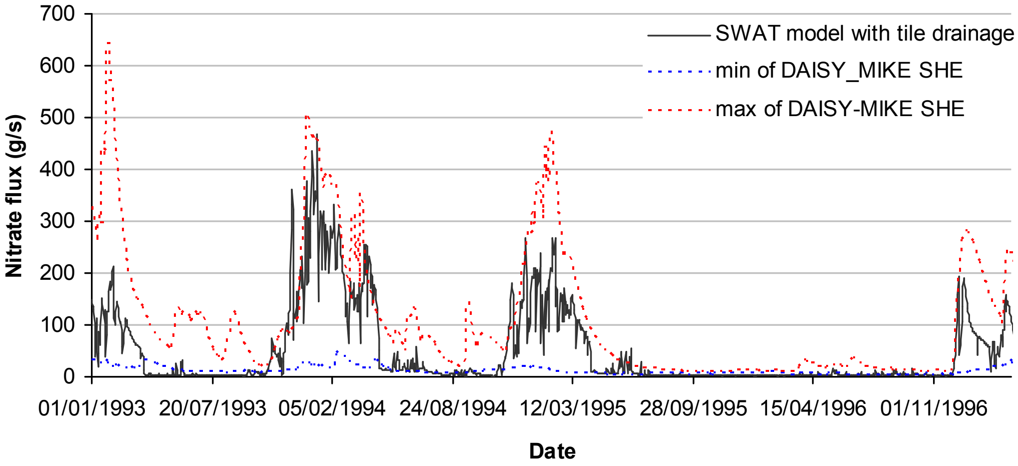

Figure 8. Comparison between nitrate flux of SWAT with tile drainage and the range of discharge value from DAISY-MIKE SHE model

According to nitrate flux, figure 8 shows that SWAT results fit quite well inside the range between maximum and minimum values from DAISY-MIKE SHE in flood period. Most of the nitrate from the catchment to the river in flood period originates from surface runoff, tile drainage and groundwater flow while in dry period, nitrate originates from point sources and groundwater. Therefore, nitrogen processes in catchment mostly affect the nitrogen flux in flood period. It is a reasonable result for SWAT that the magnitude of nitrate flux from SWAT reasonably well fits inside the range value of the reference model DAISY-MIKE SHE. 42% of the values from SWAT are smaller than the minimum value from DAISY-MIKE SHE and most of them happen in the dry period. Flow simulated from SWAT is smaller than DAISY –MIKE SHE in the dry period (figure 5), thus, nitrate flux is also smaller. Another reason is that in-stream water processes was not considered in SWAT in this paper, therefore, nitrate added from nitrification of ammonia in the river was not added into the nitrate flux.

Conclusion

The SWAT model for Odense river basin was build with and without the tile drainage in this paper. The model without tile drainage resulted in a better hydrograph than the model where tile drainage was included. However, the two models gave very different water balance. In case no tile drains were applied, the model gave very high surface runoff which is not realistic in Denmark and this can affect the result for estimating soil erosion or nitrogen loads if fertilizer is applied near the soil surface. When tile drain was included, the surface runoff was decreased due to the generation of tile drainage. Both models give reasonable result and have high correlation with the measured data. From the set up of the two models in different ways, it can be concluded that there are many ways to get a good hydrograph and obtain a good flow simulation in a hydrological model if we do not care where the water come from. However, depending on the purpose of modelling, it must be careful to choose the model. Soil erosion should not be modelled using the model without tile drainage.

Compared with measured data, SWAT gave very good result for flow in both models. The magnitude and trend in nitrate flux was comparable with the measured data, however, the value in each time step does not capture the measured data very well because permutation was not applied in the scope of this paper.

Flow and nitrate results from SWAT were also compared with the DAISY-MIKE SHE model taking into account the uncertainty of soil hydraulic properties, root depth and slurry amounts. The random change of uncertain parameters resulted in a range of flow and nitrate flux values which were then compared with SWAT model. For both flow and nitrate flux, SWAT result fitted quite well in the range of value in the flood period while SWAT gave lower result than the range in dry period, however, the difference was very small.

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A5-2

Application of SWAT for Nutrient Load Discharge Estimation

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Abstract

In recent years, water quality in lakes are tried to improve until under environmental standard by emission control of pollutant loads to lake and rivers through putting an adequate sewage system in place and development of laws, though water quality in lakes have not been improved well as we expected. One of the reasons is considered to be pollutant loads discharged from non-point sources such as agricultural land. When considering watershed management and improvement of water environment in lakes, both information of lakes and rivers will be necessary. Thus, we tried to represent nutrient load discharges from the Hii River basin to brackish lake, called Lake Shinji. The Hii River basin is located in the eastern part of Shimane Prefecture, Japan. The catchment area of the Hii River basin is about 920 km2. Forest is dominant in the area. Over 80% of the area is forest and about 10% is used for agriculture. Major crop is rice. We applied the SWAT model to the basin by a daily time step. We paid attention to SS, total nitrogen and phosphorus load discharges from the river. As a result, SWAT could simulate fluctuations of load discharges following precipitation pattern relatively well and statistically “satisfactory” in all target parameters (flow, SS, TN, TP).

KEYWORDS: SS, total nitrogen, total phosphorus, soil and water assessment tool

Introduction

Integrated managements of water environment from river basin to downstream such as lake are very important for conservation and sustainable use of its resources. In recent years, water quality in lakes are tried to improve until under environmental standard by emission control of pollutant loads to lake and rivers through putting an adequate sewage system in place and development of laws, though water quality in lakes have not been improved well as we expected. One of the reasons is considered to be pollutant loads discharged from non-point sources such as agricultural land.

There are lakes called Lake Shinji and Lake Nakaumi where have not been improved water quality well in Shimane prefecture, Japan. The Lake Shinji and Lake Nakaumi have been designated as one of the Wetlands of International Importance by the Ramsar Convention in November 2005.

Many researchers study about water quality targeted at Lake Shinji and Lake Nakaumi from several perspectives (e.g. Seike et al., 2006; Sakuno et al., 2003). As well, there are some studies targeted at Hii River (Takeda et al., 1996; Ishitobi et al., 1988). However, few studies are done about runoff analysis and quantitative analysis of pollutant loads by a model in the Hii River basin. When considering watershed management and improvement of water environment in lakes, both information of lakes and rivers will be necessary. Thus, we tried to represent stream flow and SS, TN, TP load discharges in the Hii River basin.

Study Area

The Hii River basin is in the eastern part of Shimane Prefecture, Japan (Figure 1). It covers an area of 920 km2 and the length of the river from the source to the Otsu river discharge observation station, where is outlet of whole basin, is about 63 km. According to the Chugoku Regional Development Bureau in the Ministry of Land, Infrastructure and Transport Government of Japan (MLIT: http://www.cgr.mlit.go.jp/), Yearly averaged discharge is about 40 m3/s and amount of total runoff is about 1270 Mm3. About 80 % of the land use in the basin is forest and 10 % is paddy fields. As the Hii River dominates about 75 % of watershed area flowing into the Lake Shinji, it is considered that water quality and quantity of the river will affect the Lake a lot.

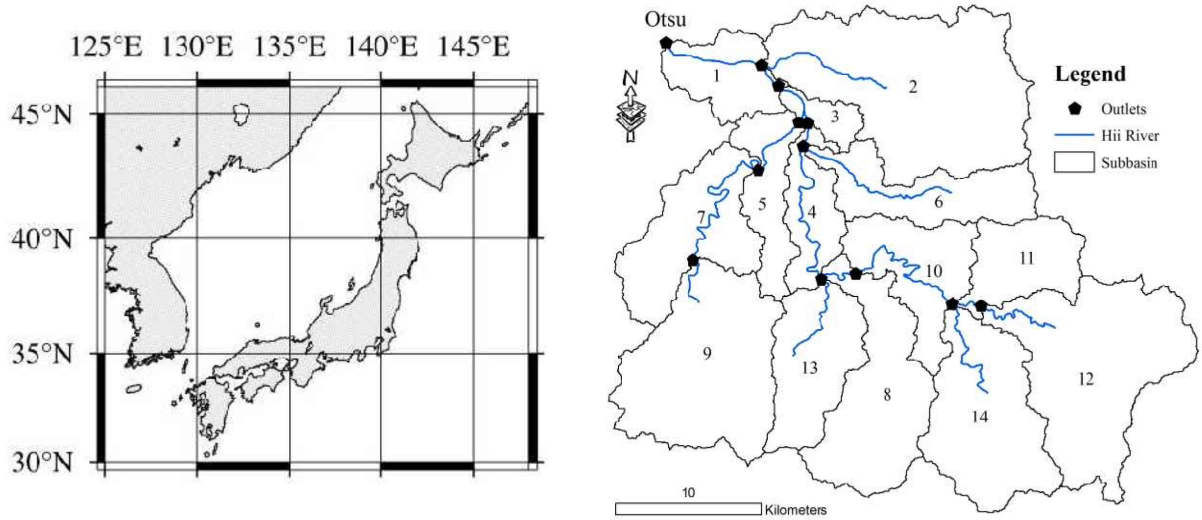


Figure 1. Hii River Basin.

Methodology

SWAT model was applied to the basin from 1985 to 2009 by daily time step. The parameters were calibrated from 1998 to 1997 (10 years) and validated from 1998 to 2009 (12 years). The first three years from 1985 to 1987 were used as a warm-up periods of the model. Model parameter values were basically calibrated manually, but Alpha_BF parameter values were determined by using a Baseflow Filter Program proposed by J. Arnold and P. Allen (1999).

Brief description of SWAT

The Soil and Water Assessment Tool (SWAT) has been widely applied for modeling watershed hydrology and simulating the movement of non-point source pollution. The SWAT is a physically-based continuous time hydrologic model with an ArcView GIS interface developed by the Blackland Research and Extension Center and the USDA-ARS (Arnold et al., 1998) to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex basins with varying soil type, land use, management conditions over long periods of time. The main driving force behind the SWAT is the hydrological component. The hydrological processes are divided into two phases, the land phase, which controls the amount of water, sediment, and nutrient loading in receiving waters, and the water routing phase which simulates movement through the channel network.

The SWAT considers both natural sources (e.g. mineralization of organic matter and N-fixation) and anthropogenic contributions (fertilizers, manures and point sources) as nutrient inputs. The SWAT delineates watersheds into sub basins interconnected by a stream network and each sub basin is divided further into hydrologic response units (HRUs) based upon unique soil / land class characteristics, without any specified location in the sub basin. Flow, sediment, and nutrient loading from each HRU in a sub basin are summed and the resulting loads are then routed through channels, ponds, and reservoirs to the watershed outlet (Arnold et al, 2001). The model includes a number of storage databases (i.e. soils, land cover/ plant growth, tillage, and fertilizer) which can be customized for an individual basin. A single growth model in SWAT is used for simulating all crops based on the simplification of the EPIC crop model (Williams et al., 1984). Phenological development of the crop is based on daily heat unit accumulation. The model can simulate up to 10 soil layers if sufficiently detailed information is available. The SWAT is expected to provide useful information across a range of timescales, i.e. hourly, daily, monthly, and yearly time-steps (Neitsch et al., 2002).

Input data description

The SWAT model requires meteorological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity, and solar radiation data. In addition, the model requires spatial data sets including a digital elevation model (DEM) and maps of land cover and soil. Because there were some inconsistencies and missing climate data for the system evaluated in this study, the weather generator included in the SWAT was used for filling in gaps in the measured climatic records.

Meteorological data were obtained from the Japan Meteorological Agency (JMA: http://www.jma.go.jp/jma/index.html). In addition, data from five gauges for precipitation and three gauges for air temperature and wind speed that were located in and around the basin were used. However, there were no gauges in the basin to monitor relative humidity; therefore, the relative humidity data from Matsue City, which is located approximately 30 km away from the basin, was used instead. In addition, there were no monitors in the basin to collect solar radiation. Therefore, the solar radiation data were calculated by the Angstrom formula (FAO, 1998) using data collected by Shimane University (http://www.ipc.shimane-u.ac.jp/weather/i/home.html) and the actual sunshine duration in the basin, which was obtained by the JMA. The average values of the climatic data recorded at each gauge are shown in Table 1.

Table 1. Average annual precipitation and climatic variables from 1985 to 2009 at each gauge.

Gauge name	EL.	Annual precip.	Max. air temp.	Min. air temp.	Wind speed	Relative humidity	Solar radiation (cal.)
	(m)	(mm)	(deg. C)	(deg. C)	(m/s)	(%)	(MJ/m2)
Matsue	16.9	-	-	-	-	75.4 (9.9)	-
Izumo	20	1711.8	19.0 (8.3)	10.3 (8.1)	2.2 (1.2)	-	11.1 (7.6)
Daito	56	1770.1	-	-	-	-	-
Sada	100	2069.6	-	-	-	-	-
Kakeya	215	2021.2	18.1 (8.9)	8.8 (8.3)	1.3 (0.7)	-	-
Yokota	369	1759.3	17.4 (9.3)	7.6 (8.9)	1.2 (0.7)	-	-

Note: The values in the parenthesis indicate one standard deviation

Discharge data were provided by the Izumo River Office in the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

SS, TN, and TP data were monitored at the Otsu outlet once a month by the Izumo River Office in the MLIT. In addition, the data were collected from the outlet approximately once a week by our laboratory from 1991 to 2006. Both sets of data were used in this analysis.

DEM data were prepared using a digital map 50-m grid (elevation) created from a 1:25,000 topographic map published by the Geographical Survey Institute (GSI).

Land-use data based on digital national information that identified categories such as paddy fields, upland fields, orchards, denuded land, forests and water were used in this study. All land-use data were obtained from the National Land Information Office in the MLIT (http://nlftp.mlit.go.jp/).

Soil type data were obtained from soil map GIS information from a 1:500,000 Fundamental Land

Classification Survey prepared by the MLIT (http://tochi.mlit. go.jp/tockok/index.htm). The land-use and soil GIS map were shown in Figure 2.

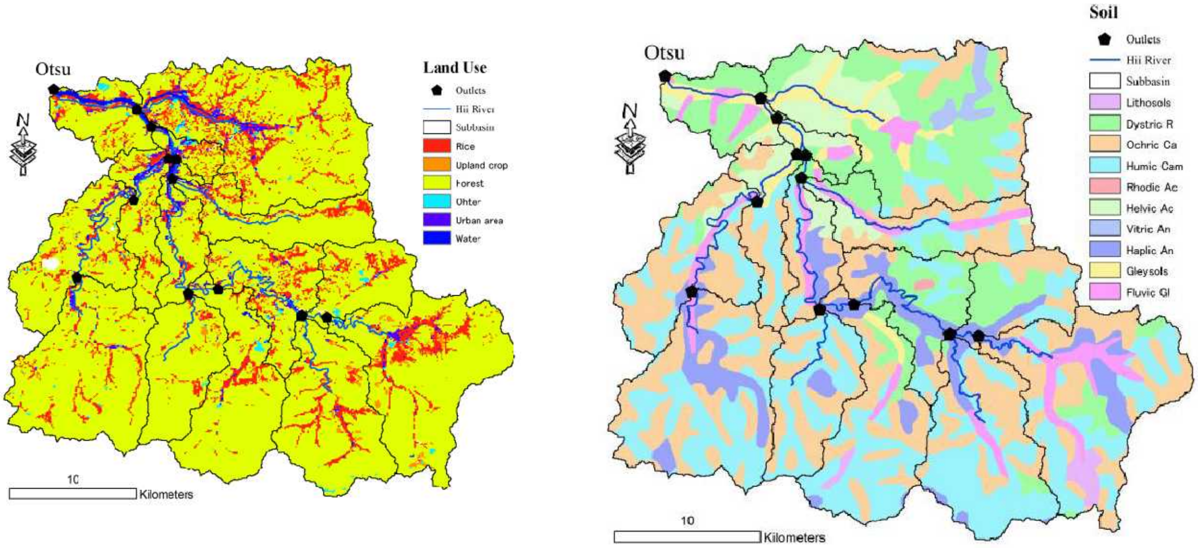


Figure 2. Land-use and soil GIS map.

Model performance evaluation

The SWAT model was calibrated and validated using observed data based on daily evaluations of the river, and SS, TN, TP discharges that were determined almost monthly. Initial assessment of the results are performed using graphical techniques, which provide a visual comparison of simulated and observed constituent data and a first overview of the model performance (ASCE, 1993). The coefficient of determination (*R*2), Nash-Sutcliffe efficiency (*NSE*), root mean square error (*RMSE*) – observations standard deviation ratio (*RSR*), and percent bias (*PBIAS*) were then used to statistically evaluate the model performance.

The *R*2 value is an indicator of the strength of the relationship between the observed and simulated values. *R*2 ranges from zero to one, with a value of zero indicating no correlation and a value of one indicating that the predicted dispersion equals the measured dispersion (Krause et al., 2005). Gassman et al. (2007) reported that daily *R*2 statistics have been used in many previously conducted SWAT studies. The *NSE* value (Nash and Sutcliffe, 1970) indicates how well the plot of the observed values versus the simulated values fits the 1:1 line. The *NSE* values range from – ∞ to one, with values less than or very close to zero indicating unacceptable or poor model performance and values equal to one indicating perfect performance. The *NSE* value is calculated using the following equation:

$$NSE = 1.0 - \left(\sum_{i=1}^{n} (Y_{obs,i} - Y_{cal,i})^2 \Big/ \sum_{i=1}^{n} (Y_{obs,i} - Y_{obs\_mean})^2 \right) \quad (1)$$

where *n* is the number of registered data, *Yobs,i* is the observed data at time *i*, *Ycal,i* is the simulated data, and *Yobs_mean* is the mean value of the observed data.

The *RSR* value is calculated as the ratio of the *RMSE* and the standard deviation of the measured data (Moriasi et al., 2007). The *RSR* value incorporates the benefits of error index statistics and includes a scaling/ normalization factor. The value varies from the optimal value of zero, which indicates zero *RMSE* or residual variation, to a large positive value (Moriasi et al., 2007). The *RSR* value is calculated using the following equation:

$$RSR = RMSE / STDEV_{obs} = \left(\sqrt{\sum_{i=1}^{n} (Y_{obs,i} - Y_{cal,i})^2} \right) \Big/ \left(\sqrt{\sum_{i=1}^{n} (Y_{obs,i} - Y_{obs\_mean})^2} \right) \quad (2)$$

where *n* is the number of registered data, *Yobs,i* is the observed data at time *i*, *Ycal,i* is the simulated data, and *Yobs_mean* is the mean value of the observed data.

The *PBIAS* is used to determine if the average tendency of the simulated data is larger or smaller than their observed counterparts (Gupta et al., 1999). The optimal value of *PBIAS* is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, while negative values indicate model overestimation bias (Gupta et al., 1999). The *PBIAS* is calculated using the following equation:

$$PBIAS = \left(\sum_{i=1}^{n} (Y_{obs,i} - Y_{cal,i}) \times 100 \middle/ \sum_{i=1}^{n} (Y_{obs,i}) \right) \quad (3)$$

where *n* is the number of registered data, *Yobs,i* is the observed data at time *i*, and *Ycal,i* is the simulated data.

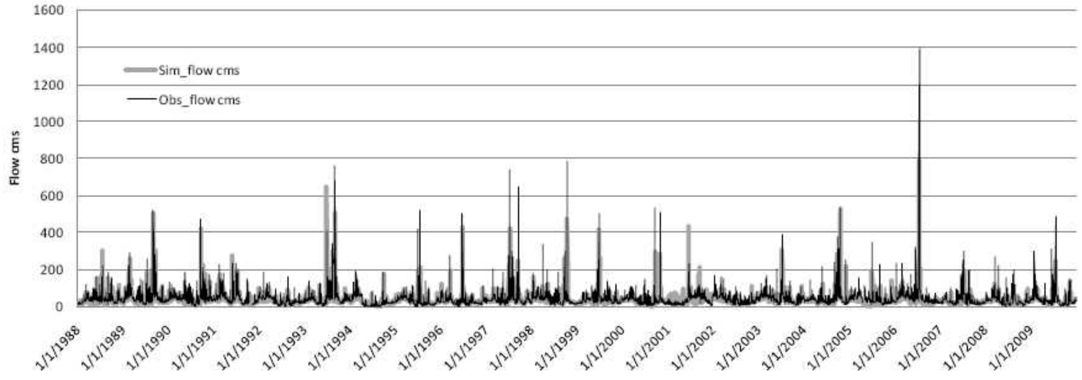
Moriasi et al. (2007) developed the model evaluation guidelines for the systematic quantification of accuracy in watershed simulations and found that the model simulation could be judged as "satisfactory" if *NSE* > 0.5, *RSR* ≤ 0.70, and the *PBIAS* is ± 25% for stream flow, if *NSE* > 0.5, *RSR* ≤ 0.70, and the *PBIAS* is ± 55% for sediment, and if *NSE* > 0.5, *RSR* ≤ 0.70, and the *PBIAS* is ± 70% for TN and TP for the monthly time step. In this study, the daily river discharge, and SS, TN, TP load data collected on an almost monthly basis were used for evaluating the simulation results. Typically, model simulations are poorer for shorter time steps (daily) than for longer time steps (monthly or yearly) as discussed by Engel et al. (2007); thus, the guidelines for the monthly time step were used to judge the model performance.

Results and Discussions

Reproducibility of flow, SS, TN, and TP

The simulated discharges of flow, SS TN, and TP were compared with observed values shown in Figure 3. As well, the statistical evaluations of the model performance are shown in Table 2. According to a criteria proposed by Moriasi et al., 2007, the model represented observed values of flow, SS, TN, TP loads satisfactory, in both of calibration and validation periods.

Compared with monthly basis, the simulated average flow, SS, TN, TP loads on each month represented the monthly fluctuations of them, but especially in August for flow and SS, in June for TN, in September for TP, the deference between observed and simulated values became largest among months. As well, the monthly average of TN load showed that the simulated results had a tendency to be larger values than observed values during winter seasons from October to January and to be smaller values during summer seasons. Moreover, simulated results of TP load showed lower values than observed values through a year, especially the difference became larger during summer season.



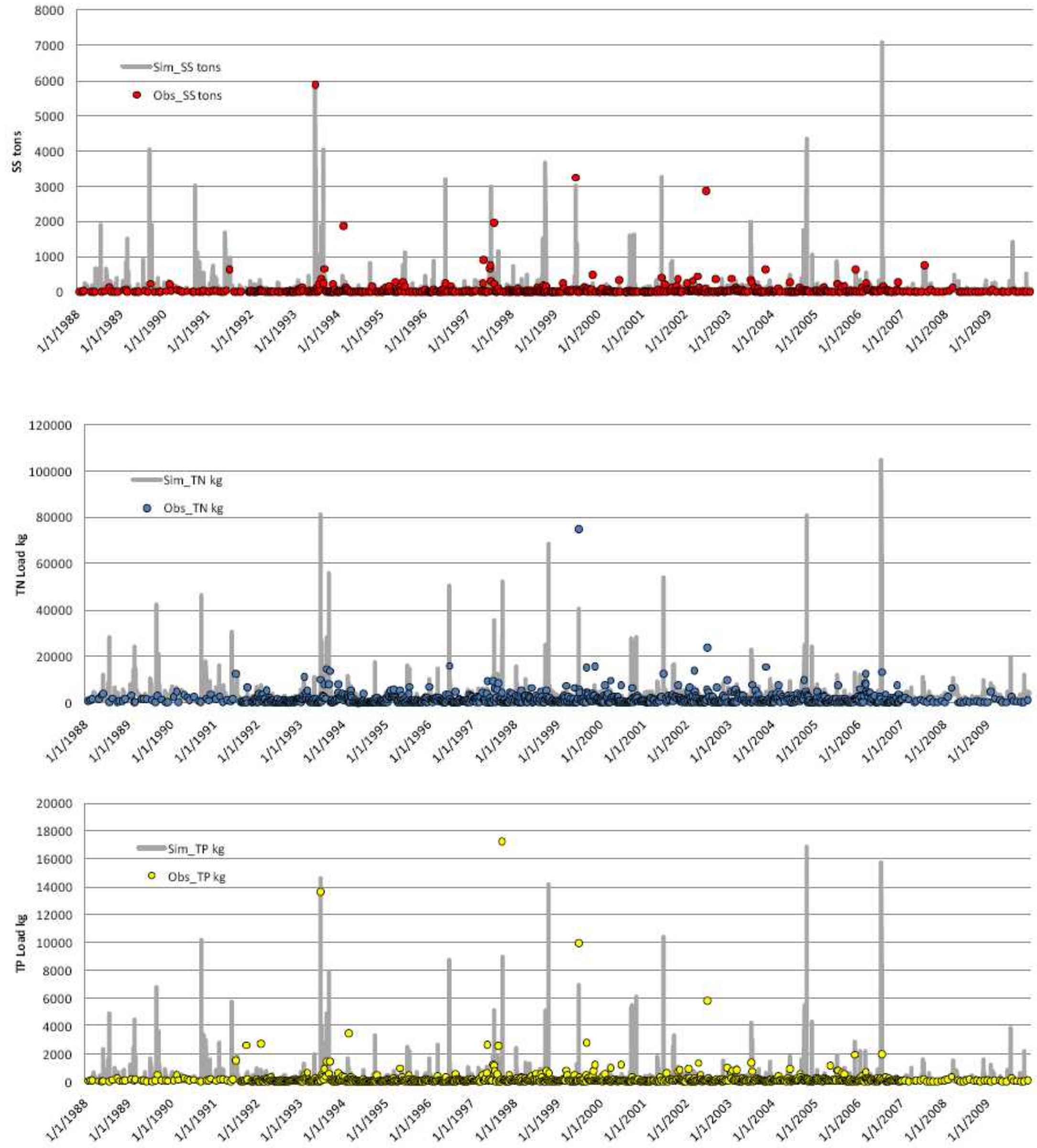


Figure 3. Simulated vs observed flow, SS, TN, and TP loads from 1988 to 2009.

Table 2. Evaluations of the model performance.

	Calibration: 1988-1997				Validation: 1998-2009			
	NSE	R2	RSR	PBAIAS	NSE	R2	RSR	PBAIAS
Flow	0.62	0.63	0.61	1.06	0.55	0.56	0.67	1.12
SS	0.84	0.84	0.40	10.78	0.53	0.53	0.69	12.31
TN	0.85	0.86	0.39	4.71	0.56	0.61	0.66	4.27
TP	0.80	0.82	0.45	10.64	0.60	0.64	0.64	7.81

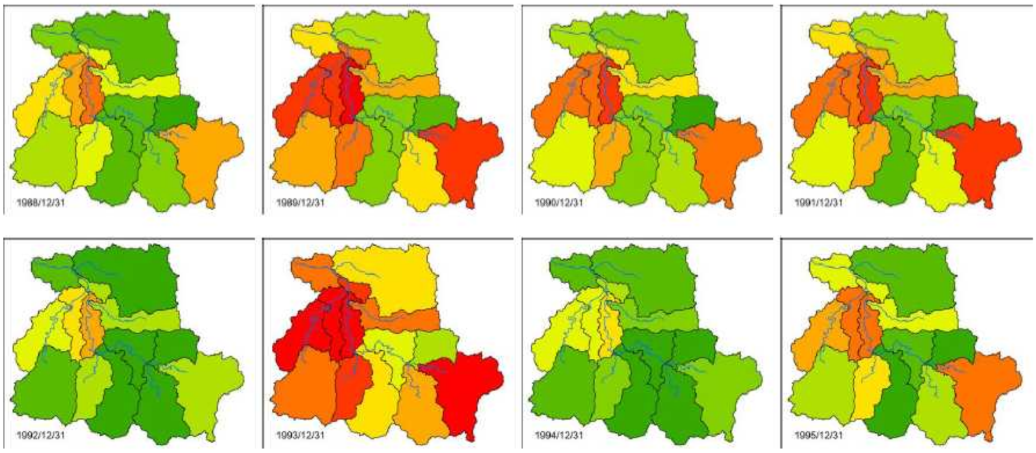
Criteria of satisfactory: NSE > 0.5, RSR ≦ 0.7, PBAIAS Flow ± 25%, SS ± 55%, TN&TP ± 70% (Moriasi et al., 2007)

Annual yields of SS, TN, and TP in each subbasin

The fluctuations of annual yields of SS, TN, and TP loads in each subbasin are shown in Figures 4-6. From the figures, it was grasped that there were big variations of annual yields of them in each subbasin, not only in temporally but also in spatially. In SS load, annual yields were varied from about 6.0 to 220.0 tons/km2. It is not always high yield in downstream. Especially in No.12 subbasin where is the upstream of main channel, SS yields showed higher values in many years. Also, in No. 5, 7, 9 subbasins where is one of the branch and west side of the Hii River, the annual yields tended to be higher among the subbasins in many years. The average annual yield of SS load in the entire basin was 63.3 tons/km2 and No. 3, 4, 5, 6, 7, 12, and 13 subbasins exceeded the average value in average annual yield in each subbasin. In TN load, annual yields were varied from about 653 to 1949 kg/km2. As same as SS load, it is not always high yield in downstream. The average annual yield of TN load in the entire basin was 1150 kg/km2 and No. 3, 4, 5, 7, 12, 13, and 14 subbasins exceeded the average value in average annual yield in each subbasin. The largest value was about 1505 kg/km2 in average values in subbasin No.5 and the lowest value was about 919 kg/km2 in average in subbasin No.1. In TP load, annual yields were varied from about 8.6 to 168.6 kg/km2. As same as SS and TN loads, it is not always high yield in downstream. The average annual yield of TP load in the entire basin was 61 kg/km2 and No. 1, 3, 4, 5, 7, 12, and 13 subbasins exceeded the average value in average annual yield in each subbasin. The largest value was about 97.2 kg/km2 in average values in subbasin No.5 and the lowest value was about 29.9 kg/km2 in average in subbasin No.11.

Annual discharge of SS, TN, and TP Loads to downstream

Annual SS load discharges from 1988 to 2009 were estimated. SS load discharge varied from 15.3 tons/km2 (1994) to 49.6 tons/km2 (1993) year by year and the average value during these periods was 28.0 tons/km2. As yearly SS load discharge and yearly precipitation were high correlative (R2: 0.90), the fluctuations of yearly SS load discharge were caused by amount of precipitation. In TN load, TN load discharge varied from 792.7 kg/km2 (1988) to 1498.2 kg/km2 (2004) year by year and the average value during these periods was 1118.4 kg/km2. Unlike SS load discharge, the yearly TN load discharge and yearly precipitation were not high correlative (R2: 0.45), the relation showed positive, though. As well, in TP load, the load discharge varied from 29.3 kg/km2 (1992) to 104.8 kg/km2 (1993) year by year and the average value during these periods was 57.3 kg/km2. As yearly TP load discharge and yearly precipitation were high correlative (R2: 0.76) and also correlation between SS and TP load discharges was 0.85 in the coefficient of determination (R2), the fluctuations of yearly TP load discharge were caused by amount of precipitation and SS load discharges.



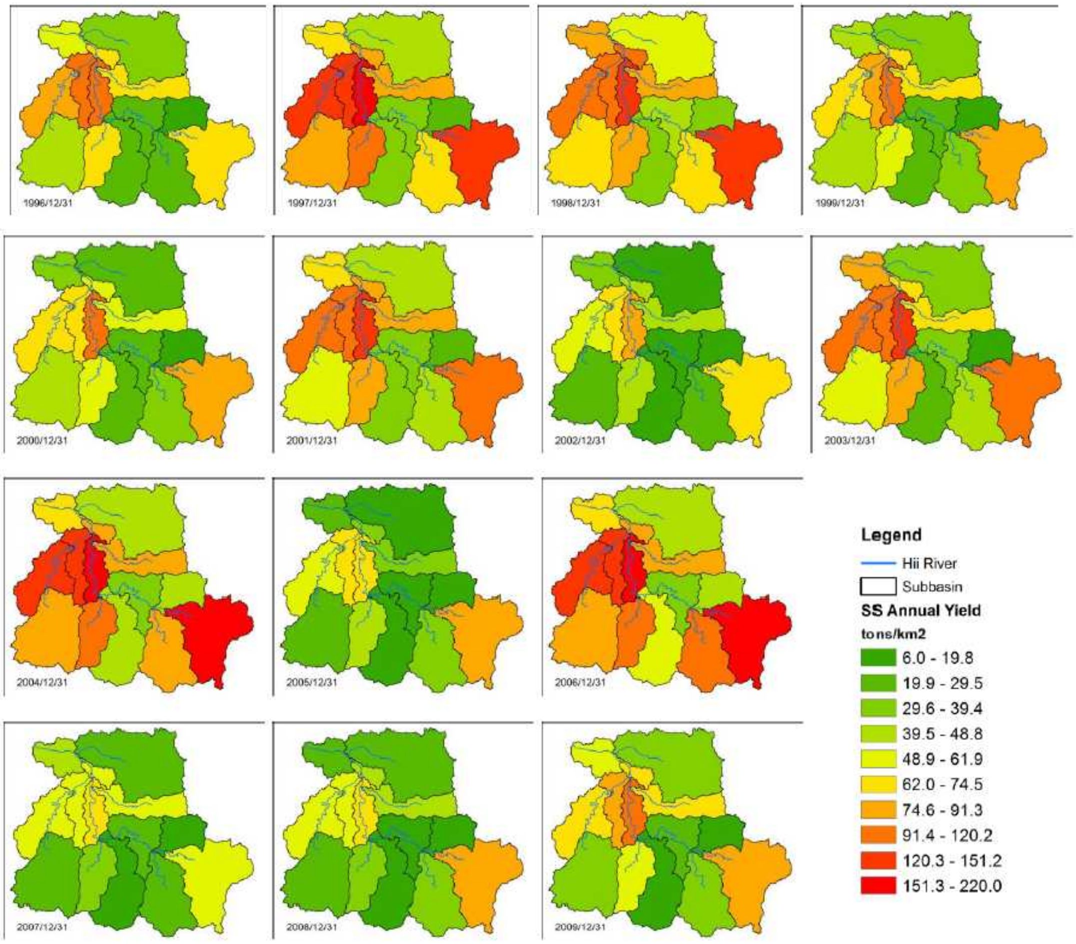
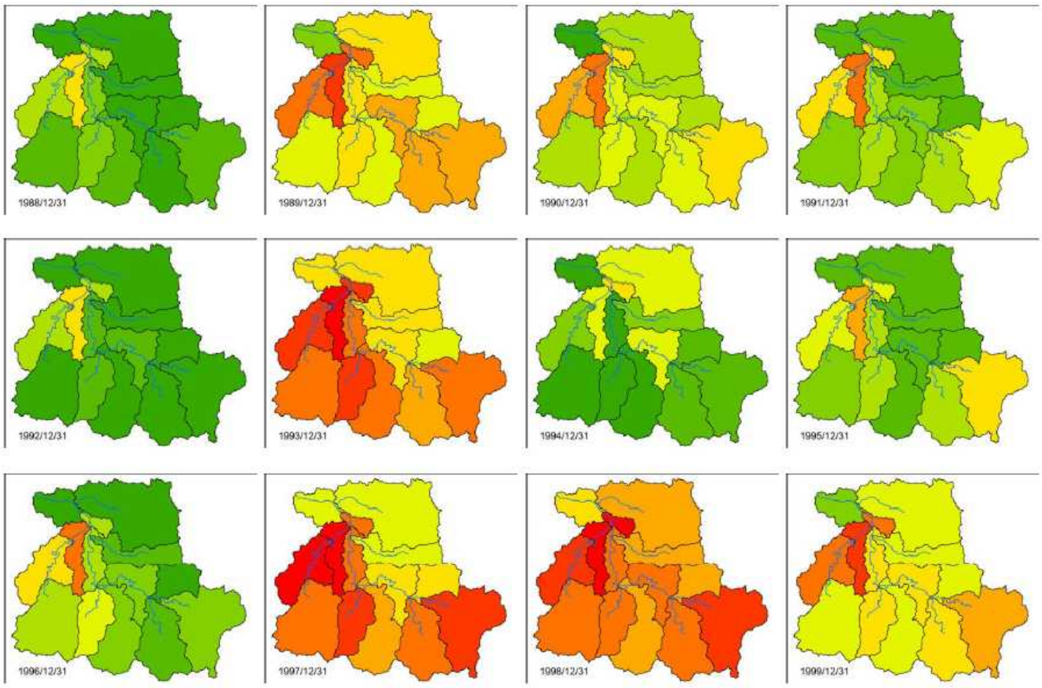


Figure 4. Spatial distribution of SS annual yields in each subbasin.



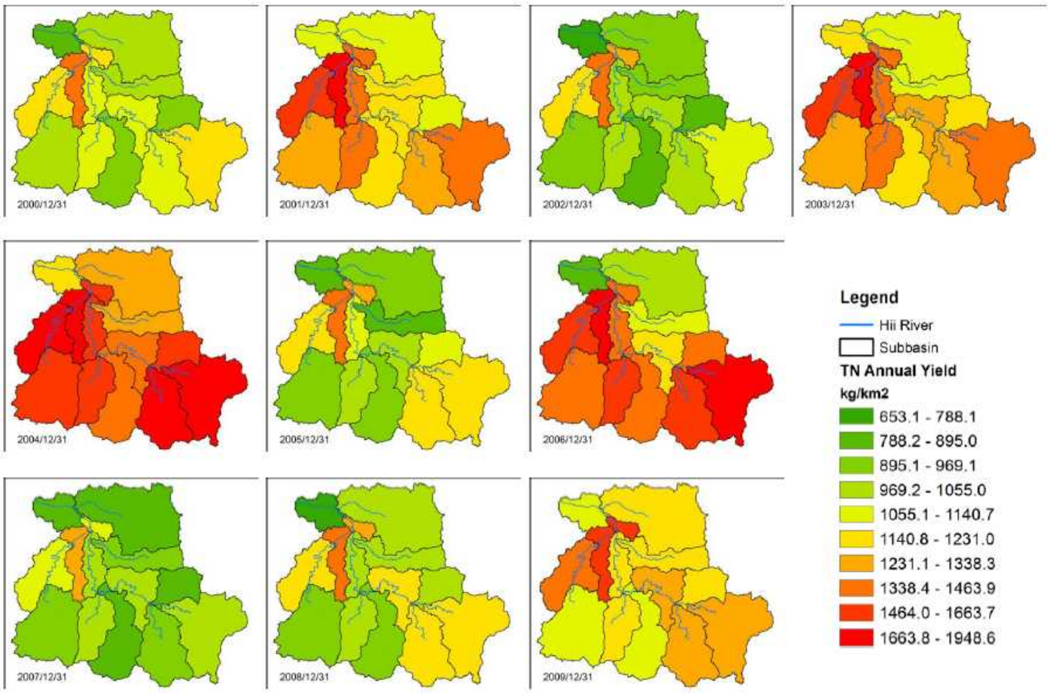
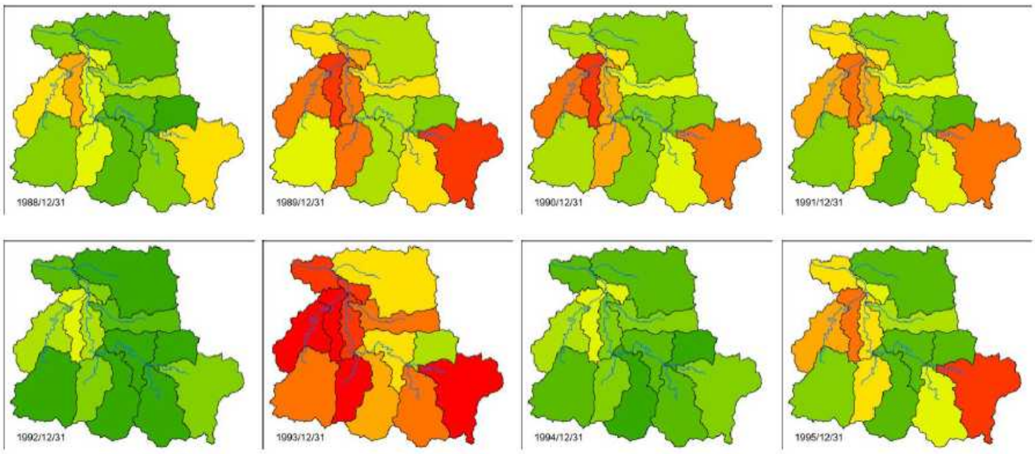


Figure 5. Spatial distribution of TN annual yields in each subbasin.

Conclusion

SWAT model was applied to the Hii River basin in daily time step and simulated flow, SS, TN, and TP loads discharges from 1988 to 2009 statistically satisfactory. It was grasped that the annual yields of loads were varied among subbasins, not only temporally but also spatially. In this simulations, subbasin No.12 where is upstream of main channel and subbasins No. 5, 7, and 9 where are one of the branch of the Hii River, tended to be higher values in the basin. Oppositely, subbasin No.2 tended to show lower values in the basin. In annual total discharges of the loads from the basin (outlet No.1) to downstream (Lake Shinji), average values showed 28.0 tons/km2 in SS, 1118.4 kg/km2 in TN, and 57.3 kg/km2 in TP, respectively.



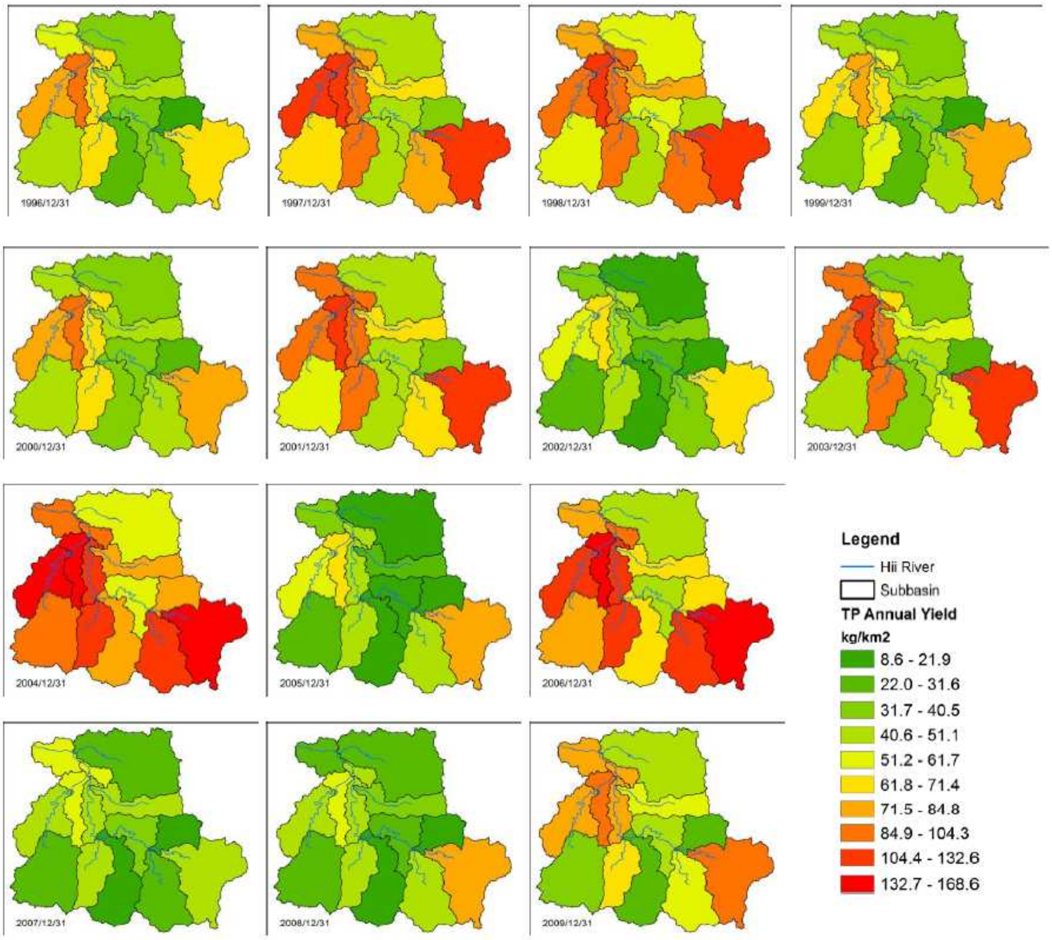


Figure 6. Spatial distribution of TP annual yields in each subbasin.

Acknowledgement

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A5-3

Study on Setting Appropriate Size of Riparian Buffer Zone in Urban Basin by Using SWAT Model

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The riparian buffer zone plays an important role in water quality, wildlife habitat and disaster prevention, and improves the water quality by removing suspended matters and filtering pollutants. Especially, as the arrival rate of pollutants influences directly the water quality in this area where is the transition zone between the aquatic ecosystem and terrestrial ecosystem, the riparian buffer area plays an important role in the ecological aspect. The efficiency of pollutant emission mitigation in riparian buffer zone is greatly influenced by the size of riparian buffer zone and it is necessary to set an appropriate size of riparian buffer zone in the area whose land is highly used such as urban area. In this study, we applied SWAT model to Yudeungcheon, Daejeoncheon and Gapcheon, the three biggest rivers in Daejeon Metropolitan city of korea which is a typical urban area, and analyzed the nutrients reduction effect according to the size of riparian buffer zone, by setting the size (width) of riparian buffer zone in 15m, 30m, 50m, 100m, 200m, 300m, 500m and 1000m. We examined the applicability of SWAT model by the nutrients loadings in Boksu, Indong and Hoeduck which were measurement stations of Yudeungcheon, Daejeoncheon and Gapcheon respectively from 2002 to 2005. As a result, Estimation Efficiency Analysis(COE) of monthly loadings were 0.59 to 0.78 for T-N, and 0.59 to 0.73 for T-P respectively, which shows the high applicability and reproducibility of SWAT model. We calculated the mitigation amount of nutrient emission loadings by varying the size (width) of riparian buffer zone. The decision criteria of the size of riparian buffer zone was determined as 10% of mitigation amount of nonpoint pollution source in 2010, target year, according to the water pollution maximum load system in Daejeon Metropolitan City. As a result, the emission amount of total nitrogen and total phosphorus were reduced by 10% and 12% respectively with deciduous tree and by 15.1% and 15.9% respectively with evergreen tree on the condition of 100m of riparian buffer zone in Boksu station, by 14.9% and 15.9% with deciduous tree and by 12.9% and 12.9% respectively with evergreen tree on the condition of 100m of riparian buffer zone in Indong station, and by 9.8% and 16.3% with deciduous tree on the condition of 300m of riparian buffer zone in Hoeduck where the evergreen tree was not effective. In conclusion, the size of riparian buffer zone and the mitigation effect varied with the stations: Boksu station where were lots of farmlands in the watershed of river; Indong station which was urban area for residence and commerce; Hoeduck station where urban area and farmland were mixed. In view of the fact that the evergreen tree was not effective, the mitigation effect, the size and the species of tree of riparian buffer zone were to be differently decided according to the conditions of land use in the watershed of river in target stations.

Keywords: SWAT model, Riparian buffer zone, Gapcheon, nutrients, total nitrogen, total phosphorus.

Introduction

The riparian buffer zone plays an important role in water quality, wildlife habitat and disaster prevention, improves the water quality by removing suspended matters and filtering pollutants (Wenger, 1999). Especially, riparian buffer zone is an area which the arrival rate of pollutants influences directly the water quality and at the same time, it plays an important role in the ecological aspect as a transition zone between the aquatic ecosystem and terrestrial ecosystem. However, despite the importance of riparian buffer zone, it has been damaged indiscreetly by developing into agricultural site, residential area, constructing roads, urban development and recreational facilities. Fortunately, recognizing the importance of riparian buffer zone, the government designates riparian areas as a part of measures for improving water quality centering 4 big rivers by introducing riparian area system.

The efficiency of riparian buffer zone is greatly influenced by the size. Small-sized riparian buffer zone cannot protect water quality, soil or ecological system and can reduce the safety of rivers. It would be good for riparian areas to be as wide as possible, but it is necessary to set an appropriate size of riparian buffer zone in the area where land is highly used for such as urban area. The closer to water system it is, the shorter flow time is, and nonpoint sources cause instant pollution by flowing into the water system without reduction through self-purification. Water system close to main stream which flows into water source directly needs to be wide for protection, and as for tributaries or narrow water body having small stream flow, riparian green belt is relatively narrow. For expressing this, it is necessary to set the size of riparian buffer zone by distinguishing important water systems including main stream and others water systems.

Major factors which influence on deciding the size of appropriate riparian green belt are (1) characteristics of basin or the surrounding area, (2) characteristics of rivers including the width and cutoff, (3) distribution of soil and vegetation, and (4) the intensity of adjacent land-use. In addition to these factors, socio-economic variable and ecological health can be considered when deciding the size of riparian green belt. For example, as the intensity of adjacent land-use is higher, the need for riparian green belt is more important. The size or importance of riparian buffer zone is bigger according to the increase of potential production of nutrients, chemical substances, deposit and flowing water from adjacent land-use. Also, loads of nutrients such as total nitrogen or total phosphorus can be different according to characteristic of basin, that is, land-use.
As shown in the research in Chesapeake Bay in USA, farmland has higher loads of nutrients such as total nitrogen or total phosphorus than those in forest or pastureland, and also urban areas in our country is shown to have high loads of nutrients. According to this, we would assess removal efficiency of nutritents targeting basins where composition rate of farmland and urban area by using the appropriate size of riparian buffer zone. Riparian buffer zone has great ability to remove nitrates through denitrification, assimilation with plants and physical-chemical cropping of soil, and it can also remove a respectable amount of other deposit, phosphorus and pesticide which flow into the riparian buffer zone by being included in

flowing water through precipitation, filtering, microbial breakdown and absorption by plants (Cooper et al. 1987). Therefore, this study aims to assess the removal efficiency of nutrients according to the size of riparian green belt by using SWAT model targeting Gapcheon watershed in Geum river basin and based on that assessment, to suggest the size of appropriate riparian green belt in Gapcheon watershed in Daejeon Metropolitan City.

Literature review

The most important criteria for deciding the width of riparian buffer zone is how much riparian buffer zone can reduce loadings of pollution source flowing into the water system (Kim, 2000).

Wilson (1967) conducted a study on the distance of precipitation of smaller alien substance than soil included in the flowing water in flatland, and Vanderholm et al (1979) conducted a study on vegetation belt which can filter the flowing water generated in pastureland. Palfrey and Bradley (1982) suggested that the most appropriate width of buffer zone (natural vegetation) in coastal areas in Maryland was 91m, and Roman and Good (1983) suggested 91m of buffer zone width for preserving wetland and waterway considering the regional characteristics of Pinelands in New Jersey.

Xiang (1933) modified and supplemented the model developed by Phillips and suggested that effective and efficient decision-making can be available by using GIS, an analyzing tool to calculate the appropriate width of buffer zone.

Also, the size of riparian buffer zone is suggested differently according to the regional characteristics or function. As a typical example of appropriate width for preserving water body from nonpoint pollution source, Analysis of effect of riparian buffer zone conducted by Illinois State Natural Survey suggests that when the width of riparian buffer zone is up to 300m, buffer effect is striking. Chesapeake in Maryland in USA describes that 30m of riparian green belt should be made for removing nitrogen and 50m for removing deposit and phosphorus based on documentary research. When putting the results of overseas researches together, in case that terrestrial habitat is not considered, at least 15-30m width of riparian green belt should be made. Like this, though deciding the width of riparian green belt has many variables according to the regional characteristics and is hard to be quantified from many researches, general suggestion is 5-47m for nutrients, 15-53m for flowing water, 27-95m for colon bacillus and 5-110m for deposit (JiYong-Choi, JiHyeon-Lee, 2001).

In the country, study on the width of riparian vegetation buffer zone is not quite satisfactory despite the importance. By using AGNPS, water quality model of farmland basin, the effect of vegetation buffer zone on water quality in rivers was examined targeting Neungwoncheon, a tributary of Kyeongancheon, and as a result of simulation using condition for drainage, slope and patterns of land-use of rivers for seeking the appropriate site for vegetation buffer zone as factors, appropriate width of 60m was derived (Kim, 2000).

Recently, as the importance of managing nonpoint pollution source has increased, studies on riparian buffer zone, one of effective managing plans are conducted deeply in and outside the country. Especially, studies on how we can decide the appropriate width are focusing on assessing the removal rate of N (Nitrogen), P (Phosphorus) and sediment in the process where flowing water passes the buffer zone under natural physical conditions. Reviewing previous researches, factors considered when deciding the width of riparian buffer zone are land-use, status of vegetation and ground covering, slope, soil, regional characteristics and function, and these factors are judged to influence on filtering efficiency of pollution substances directly. Accordingly, studies on deciding appropriate width of riparian buffer zone considering these factors is concerned with the problem of securing qualified water resources and at the same time, attracts social interests. We should seek a plan for enhancing efficiency of land-use by re-deciding the appropriate width set excessively among riparian managing areas designated as a water conversation zone suitable to the situation of basin and surrounding areas.

Materials and Method

As for plan for managing water quality, our country is managing water quality through control system of total water pollution which is a system to manage water quality by dividing rivers into basin unit and small basin and by assigning total amount to each unit basin under the judgment that we cannot deal with the decline of water quality only through the application of criteria for water quality environment and for permitting discharge. But, as water quality steadily declines despite no special pollution sources regionally and effort by a reducing plan, it can be found that water pollution caused by nonpoint pollution sources influences on the water quality. Therefore, as USA, Europe and Japan make riparian buffer zone as reduction facilities of nonpoint pollution sources and suggest a certain amount of setting width; we decided the setting width of riparian buffer zone appropriate to regional characteristics in our country by applying SWAT model based on GIS in the basin of Gapcheon.
For calculating total loads of pollution, loads of point pollution source discharged from each small basin by multiplying discharge loads to households, industry and livestock set by Daejeon Metropolitan City according to technological guideline of managing total water pollution by share rate and delivery coefficient in each small basin was input to SWAT model as a point pollution source data, and as for generating loadings on nonpoint pollution source, delivery loads estimated in SWAT model is compared with that measured in rivers actually, conducting model verification, and reducing efficiency of discharged loads of outflow discharge, total nitrogen and total phosphorus caused by setting riparian green belt.

Targeting watershed

Targeting areas were small subbasins in Gapcheon watershed where three big rivers in Daejeon Metropolitan City meet, Indong (Daejeoncheon), Boksu (Yudeungcheon) and Hoeduck(Gapcheon) subbasins are composed of mountains, farmland and urban area, For verifying applicability of SWAT model to calculation of pollution loads, survey of both water quantity and water quality conducted at the same time, used as a basic materials and the area of subbasin in Boksu is 16,046ha, that in Indong is 6,144ha and that in Hoeduck is 64,903ha.

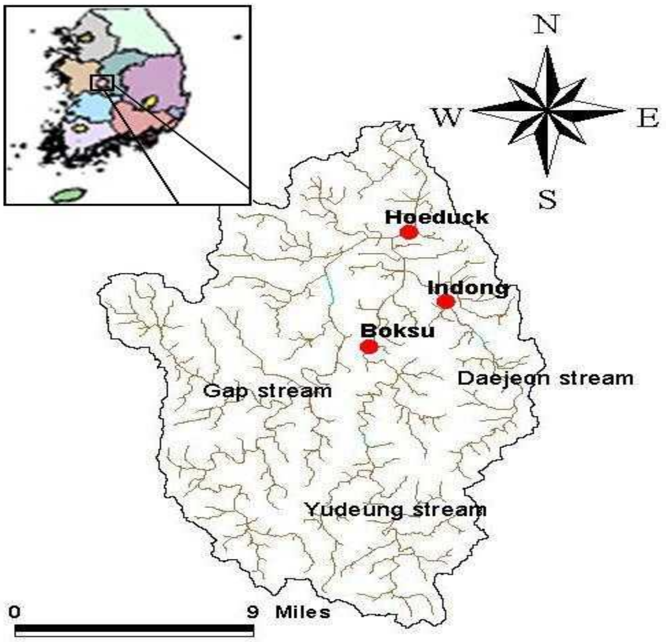

Figure 1. Gapcheon(Stream) watershed map

Survey of current situation of pollution sources

For calculating generating loads and discharging loads of pollution sources in Gapcheon watershed in Daejeon Metropolitan City, amount of generated pollution and discharged pollution from household, industry and livestock by each administrative district was examined and attained data on generating loads and discharging loads of pollution sources set according to technical guideline of managing total amount of pollution in watershed already suggested by Daejeon Metropolitan City and Chungcheongnam-do was used as an input data to the model.

Table 1. Target level of total influent and effluent loads for administrative districts

Administrative Districts		2002 Year					
		BOD_5(kg/day)		T-N(kg/day)		T-P(kg/day)	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Total		172,624	30,119	32,629	14,431	4,245	1,227
Daejeon City Sum		168,618	29,092	31,324	13,679	4,032	1,163
Daejeon City	Donggu	23,157	3,440	5,017	881	572	95
	Junggu	18,780	2,460	4,476	555	501	65
	Seogu	36,838	5,716	8,538	1,387	1,054	153
	Yuseonggu	27,191	11,253	6,508	9,354	722	653
	Daeduckgu	62,652	6,222	6,785	1,501	1,183	197
Chungcheongnamdo Sum		4,006	1,027	1,305	752	213	64
Chungcheong-g Namdo	Kyeryong City	2,560	538	768	407	89	31
	Keumsangun	137	54	53	38	8	3
	Nonsan City	1,308	435	484	308	117	31

Administrative Districts	Target Year of 2010					
	BOD_5(kg/day)		T-N(kg/day)		T-P(kg/day)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent

Total		194,705	34,219	37,481	15,083	4,889	1,298
Daejeon City Sum		189,782	33,099	35,846	14,150	4,633	1,229
Daejeon City	Donggu	21,934	3,235	4,628	779	529	88
	Junggu	21,315	2,686	5,044	528	565	69
	Seogu	42,615	6,286	10,017	1,388	1,252	168
	Yuseonggu	36,172	14,201	8,534	9,881	967	691
	Daeduckgu	67,745	6,691	7,622	1,574	1,321	212
Chungcheongnamdo Sum		4,923	1,120	1,635	933	256	69
Chungcheong-namdo	Kyeryong City	3,225	458	982	492	113	35
	Keumsangun	153	58	46	29	8	3
	Nonsan City	1,545	577	607	412	135	32

Survey of water quality and amount of outflow

For calculating delivery loads of nonpoint pollution sources, calibration and verification of SWAT model was conducted with monthly data of water quality (2002~2005) provided by information system of water environment of the Ministry of Environment installed near Indong, Boksu and Hoeduck station. Also, for securing the data on amount of outflow, data of outflow in Indong, Bokus and Hoedeok station were constructed by using water level-amount of flow relation curve suggested in the annual report of survey of hydrological data and report of measuring the amount of flow in Geum river basin issued by the Ministry of Land, Transport and Maritime Affairs from 2003 to 2005, and for creating materials of amount of outflow in 2005, independent survey of amount of flow in Indong and Boksu station was conducted.

Yearly water level-flowrate curve applied to the water level in Indong from 2002 to 2005 for securing the data of amount of outflow for verifying the model is shown in table 2.

Table 2. Yearly stage-discharge equations for stations

Station	Year	Stage - Discharge Equation	Range
Indong	2002 ~ 2003	$Q = 7.627h^{0.892}$	$0.01 \leq h \leq 0.26$
		$Q = 44.17h^{2.191}$	$0.26 < h \leq 1.89$
	2004 ~ 2005	$Q = 0.231H^{7.376}$	$0.96 < H \leq 2.75$ $(H = h + 1)$
Boksu	2002	$Q=0.041(h+0.782)^{7.027}$	$0.16 \leq h \leq 1.14$
		$Q=-45.840h^2+472.963h-476.06$	$1.14 < h \leq 2.88$
	2003 ~ 2004	$Q=35.166(h-0.430)^{3.672}$	$0.78 \leq h \leq 1.80$
		$Q=248.070(h-1.290)^{1.182}$	$1.80 \leq h \leq 2.95$
	2005	$Q = 1.725(h + 0.172)^{8.01}$	$1.00 < h < 1.57$
		$Q = 318.469(h - 1.247)^{0.693}$	$1.57 < h < 2.67$
Hoeduck	2002~2003	$Q = 227.841(h-0.614)^{1.549}$	$0.67 \leq h \leq 3.95$
	2004~2005	$Q = 234.477 \times (h-0.68)^{1.667}$	$0.73 \leq h \leq 2.65$
		$Q = 436.918 \times (h-1.1)^{1.1589}$	$2.65 < h \leq 4.07$

For calibration of the model, parameter calibration on the amount of outflow with flow discharge data of Boksu, Indong and Hoeduck from 2002 to 2003 was conducted.

Status of land-use

In Boksu subbasin, forest and farmland account for 93% and urban area accounts for 44% and in Indong subbsin, forest and farmland 78% and urban area 14%. In Hoeduck subbasin which shows total status of subbasins in Gapcheon watershed, forest and farmland account for 75% and urban area 19%.

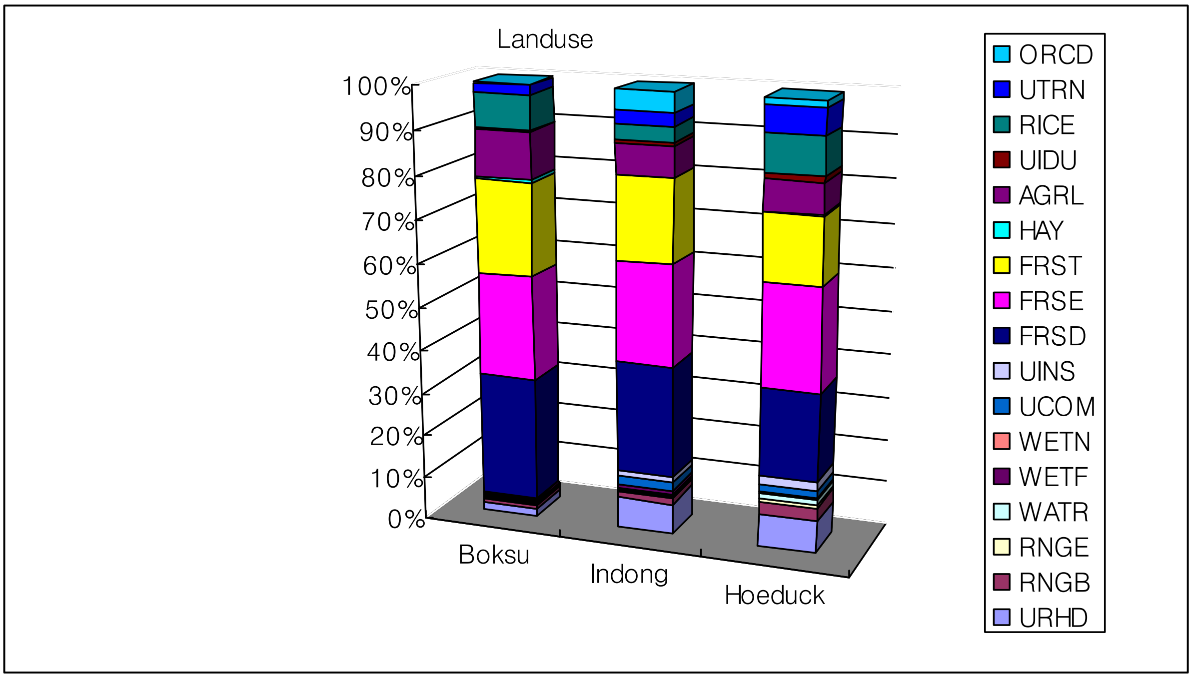

Figure 2. Status of land-use in Boksu, Indong and Hoeduck subbasin in Gapcheon watershed

SWAT model

SWAT model is a big-basin-sized long-term continuous distribution-type parameter hydrologic and water quality model. This model can predict long-term management of water resources, sediment discharge and nonpoint pollution source loadings in un-estimated basins. Also, this is a model which can predict long-term amount of outflow and nonpoint pollution source loads by simulating various hydrologic processes inputting data considered with space and time, a nonpoint pollution source model suggested by EPA.

GIS input data

DEM data on Gapcheon watershed has resolution of 30m and DEM data generated in a same way as that by USGS are provided by the Ministry of Environment.

Land-cover map is provided by the Ministry of Environment and reviewed appropriate to the actual condition of Korea, being made considering environmental cooperation between nations including OECD environmental statistics work. As for classification of rice paddy, for distinguishing from general farmland in USA, it is classified using land-use of RICE. As for making a soil map, a soil map (1:25,000) provided by National Academy of Agricultural Science of Rural Development Administration and Korea Institute of Construction Technology and database (USERSOIL) involved in the property of soil were used in korea. Also, river reach map in Gapcheon watershed was provided by Korea Water Resources Corporation.

Construction of GIS data on riparian buffer zone

GIS data on riparian buffer zone set 15m, 30m, 50m, 100m, 200m, 300m, 500m, 1000m from both banks of a river as forest and input data was constructed by dividing species of trees into deciduous trees and evergreen trees.

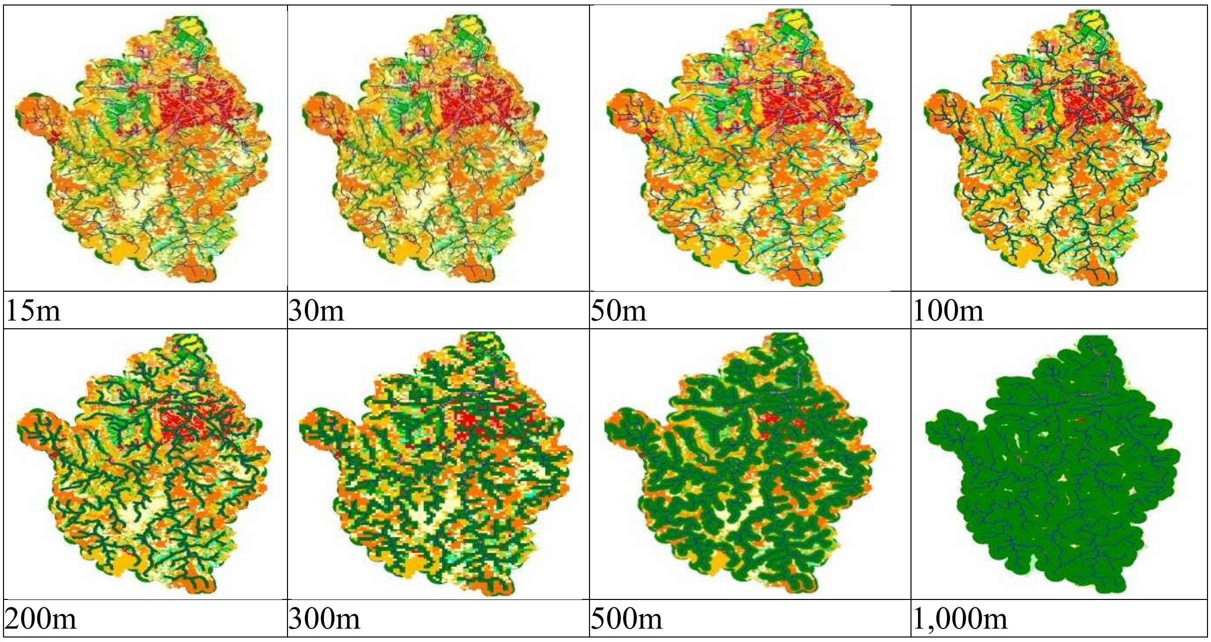
15m 30m 50m 100m
200m 300m 500m 1,000m

Figure 3. GIS input data by the size of riparian buffer zone.

Hydrometeological data

Daily precipitation data and climatic data of Daejeon Observatory from Jan. 2002 to Dec. 2005 were input and as meteorological , temperature (maximum, minimum) and radiation data were used. Also, data of wind speed and relative humidity in Daejeon and Geumsan area were used.

Calculation of discharging loads of point pollution source and delivery coefficient

Discharging load of pollution sources except land was considered as point pollution sources and input to SWAT model, delivery load into rivers from land, that is, nonpoint pollution sources was made to be generated in the model simulatively. Considering increase rate of total discharging loads generated by each administrative district in Daejeon Metropolitan City from 2002 to 2005, discharging loads by each administrative district from 2002 to 2005 were input and discharging load by each small watershed was calculated by multiplying discharging load by each administrative district by administrative district share rate. As discharging loads are different from delivery load into rivers, arithmetical mean of delivery rate by each small wateshed in Gapcheon watershed suggested when water quality modeling of a basic plan for managing total amount of pollution in Geum river in Daejeon Metropolitan City was used.

Table 3. Administrative occupied ratio for subbasins

SWAT2000 Subbasin(ID)	Administrative Occupied Ratio (Subbasin area / Daejeon city area)
Gapcheon(Stream) Upstream(2)	Seogu(0.76)+Yuseonggu(0.40)+Nonsan City, Kyeryoungsity, Keumsnakgun(Gapcheon A)
Gapcheon(Stream) Downstream(6)	Seogu(0.16)+Yooseonggu(0.41)+Daeduckgu(0.14)
Yudeungcheon(Stream) upstream(1)	Junggu(0.58)+Keumsangun(yudeung A)
Yudeungcheon(Stream) Downstream(3)	Seogu(0.080)+Junggu(0.24)

Daejeoncheon(Stream) Upstream(4)	Donggu(0.70)+Junggu(0.16)
Daejeoncheon(Stream) Downstream(5)	Donggu(0.29)+Junggu(0.02)+Daeduck(0.04)

Table 4. Nutrients delivery ratio for subbasins

Subbasin(ID)	Nutrients Delivery ratio	
	T-N	T-P
Gapcheon Upstream(2)	0.84	0.41
Gapcheon Downstream(6)	0.67	0.20
Yudeungcheon Upstream(1)	0.48	0.11
Yudeungcheon Downstream(3)	0.57	0.15
Daejeoncheon Upstream(4)	0.52	0.13
Daejeoncheon Downstream(5)	0.52	0.13

Also, daily discharged amount generated in Daejeon sewage treatment plant and waste water treatment plant in 3, 4 industrial complex, environmental basic facilities, was excluded from discharging loads by each administrative district, used as an input data of point pollution source.

Amount of applied fertilizer and amount of agricultural chemical usage

In SWATmodel, amount of applied fertilizer and type of cultivation are supposed to be input in mgt files, so major crops and amount of applied fertilizer and agricultural chemical usage by each vegetative period were input.

Method for assessing model performing result

Evaluation index method is mainly used for hydrologic model's evaluation and COE defined like the following.

$$COE = 1 - \frac{\sum_{i=1}^{n} (\beta_{mi} - \beta_{ci})^2}{\sum_{i=1}^{n} (\beta_{mi} - \overline{\beta}_{m})^2}$$

COE means evaluation index of discharge amount, n means comparison days, , β_{mi} means observed discharge amount, β_{ci} means presumed discharge amount, and $\overline{\beta}_{m}$ means average discharge amount through the whole period.

COE has the value from -∞ to 1, in ideal case it is 1, and this means in the relationship between presumed value and observed value there is a identical relationship of 1:1.
As for supplementation for evaluation index, value of coefficient of determination (R^2) was suggested additionally and in order to assess total loadings of pollution sources during revision period, a relative error was used.

Application of SWAT model by the size of riparian green belt

Division of small basins and materials on the amount of outflow

Dividing the target watershed into 8 small subbasins, delivery loads were calculated by using the amount of outflow and data on water quality in Boksu, Indong and Hoeduck areas and 6 small basins which are upper basins in Hoedeok, the final verifying outlet were analyzed.

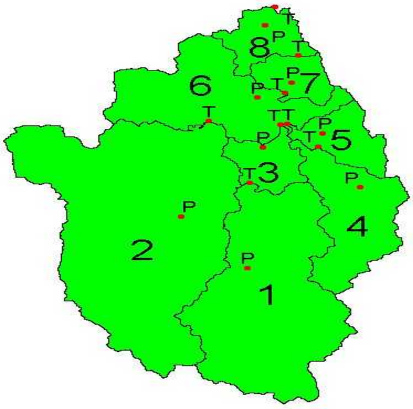

Figure 4. Water quality investigation sites and point source locations
(P : point source location, T : water quality investigation Site)

Determination of optimum parameter

Determination of parameter for outflow

For calibration of surface water flow and undergound water flow, baseflow days and alpha factor were determined with daily amount of outflow in 2002 and 2003 through baseflow program.

Table 5. Optimized outflow parameters for 3 subbasins

Parameter	Subbasin		
	ID 4 (Indong)	ID 1 (Boksu)	ID 6 (Hoeduck)
CN	Initial CN + 4	Initial CN +8	Initial CN + 2
SLOPE	0.328	0.264	0.096
SLSUBBSN	0.038	0.050	60.976
SOL_AWC	Initial SOL_AWC + 0.05	Initial SOL_AWC	Initial SOL_AWC
ALPHA FACTOR	0	0.0087	0.0075
GW_DELAY	0	115	132

Determination of optimum parameter for T-N and T-P load

By using data on water quality of information system of water environment observed by the Ministry of Environment in Indong, Boksu, Yuseong and Hoeduck, calibration was conducted with the monthly observed data from 2002 to 2003.

In T-N calibration, NPERCO was used and in T-P calibration, PPERCO and PHOSKD were used and determined optimum parameters are as follows.

Table 6. Optimized parameters for T-N and T-P loading of SWAT simulation for subbasins

Parameter	Gapcheon watershed
	All subbasins (8 Subbasins)
Phosphprus Percolation Coefficient (PPERCO)	14
Phosphorus Soil Partitioning Coefficient (PHOSKD)	150
Nitrate Percolation Coefficient (NPERCO)	0.4

Calibration and verification of the model

First of all, for calibration of the model, calibration of parameter on loads of T-N and T-P with data from 2002 to 2003 was conducted.

Result of calibration and consideration

Calibration was conducted to reach at most the observed value by comparing observed amount of outflow in Indong, Boksu and Hoeduck stations during the calibration period (2002~2003) with daily and monthly total amount of outflow estimated by SWAT, but it could not be improved more than values shown in table 7 and determined optimum parameter was used to verify the model. COE index on daily amount of outflow showed the value from 0.48 to 0.70 and coefficient of determination (R^2) had the value from 0.51 to 0.69. As a result of assessing monthly amount of outflow, COE index showed the value from 0.61 to 0.86 and coefficient of determination (R^2) showed the value from 0.77 to 0.87. Relative error on total amount of outflow was from 11% to 22.5%.

Table 7. Calibration result for streamflow (2002 ~ 2003)

Station	Estimated Calibration Results for Streamflow				
	Daily		Monthly		Total volume
	COE	R^2	COE	R^2	R.E.
Indong	0.48	0.51	0.62	0.77	11%
Boksu	0.50	0.52	0.74	0.80	22.5%
Hoeduck	0.67	0.69	0.86	0.87	11%

As a result of model calibration, as for monthly T-N loads, COE index was 0.67~0.72 and coefficient of determination was 0.68~0.73. Total loads during the calibration period had 11%~20% of relative error. As for monthly T-P loads, COE index was 0.70~0.78, coefficient of determination was 0.74~0.82, and total loads showed 7%~18% of relative error.

Table 8. SWAT calibration results for T-N and T-P loading (2002~2003)

Site	Monthly loading				Total loading	
	COE		R^2		R.E.	
	T-N	T-P	T-N	T-P	T-N	T-P
Indong	0.72	0.78	0.73	0.79	15%	7%
Boksu	0.67	0.70	0.68	0.74	20%	18%
Hoeduck	0.69	0.73	0.73	0.82	11%	16%

For calibration of the model, as share rate of mountains of all three subbasins within the watershed was high, initial concentration of organic nitrogen and organic phosphorus delivered by the amount of suface soil particle drift generated in the mountain was adjusted and calibrated. And as the lower areas except upper subbasins of the three areas are almost non-water permeable areas in urban areas, soil drift is less generated, so initial concentration of nitrite nitrogen and water soluble phosphorus was adjusted and permeable coefficients of nitrogen and phosphorus were also adjusted.

Result of verification and consideration

1) Amount of outflow

Verification of total daily and monthly amount of outflow was conducted, and the result of verification was assessed with COE index and coefficients of determination of daily and monthly amount of outflow. In order to assess the total amount of outflow, relative error was used and the result is as follows.

Table 9. Verification result for outflow (2004 ~ 2005)

Station	Estimated Verification Results for Outflow				
	Daily		Monthly		Total Volume
	COE	R^2	COE	R^2	R.E.
Indong	0.45	0.55	0.71	0.74	3%
Boksu	0.55	0.57	0.90	0.93	18%
Hoeduck	0.80	0.79	0.96	0.97	16%

Actually observed amount of outflow in Indong, Boksu and Hoeduck stations during the verification period (2004~2005) was compared with total amount of daily and monthly outflow estimated by SWAT. COE index of daily amount of outflow showed the value between 0.45 and 0.80 and a coefficient of determination was 0.55~0.79. As a result of assessing amount of monthly outflow, COE index showed the value from 0.71 to 0.96 and a coefficient of determination (R^2) was between 0.74 and 0.97. Relative error of total amount of outflow was from 3% to 18%. In case of amount of daily outflow, all areas showed COE index of more than 0.5 except Indong station, showing that they had applicability and amount of monthly outflow and total amount of outflow were very feasible.

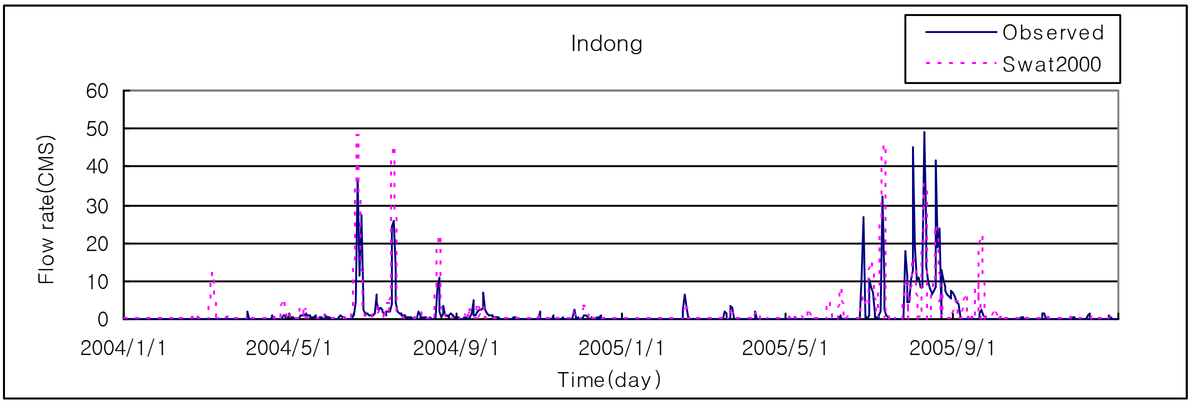

Figure 5. Daily comparison between SWAT flow and observed flow for Indong

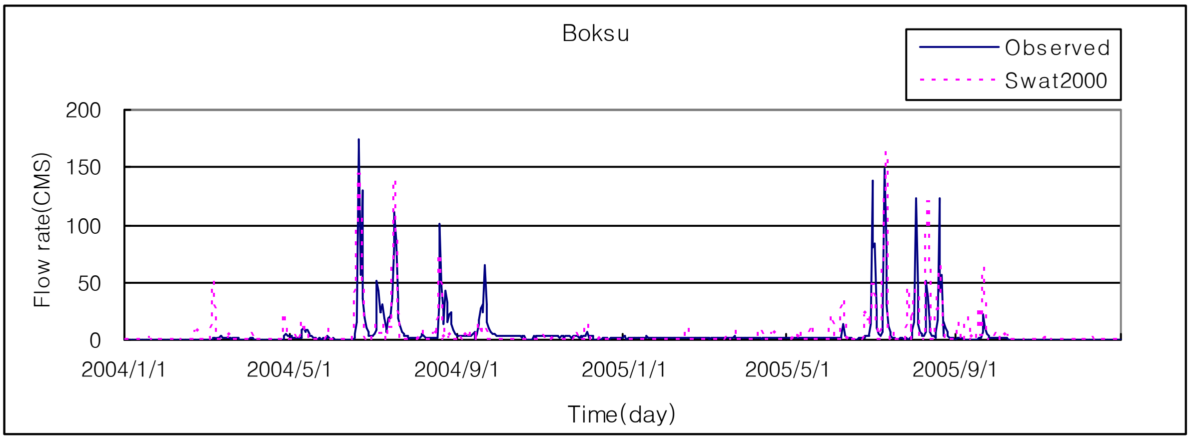

Figure 6. Daily comparison between SWAT flow and observed flow for Boksu

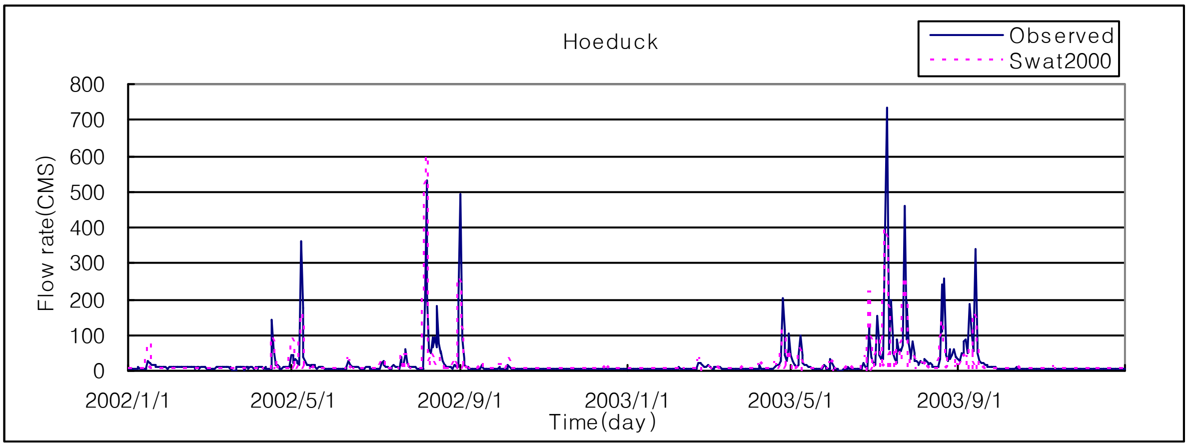

Figure 7. Daily comparison between SWAT flow and observed flow for Hoeduck

2) T-N and T-P loadings

With optimum parameter determined in the calibration process, amount of outflow and T-N and T-P loadings was applied to that in 2004 and 2005. Also, by using optimum parameter determined in the calibration process, monthly loads and total loads of data in 2004 and 2005 were verified and the result is as follows.

Table 10. SWAT verification results for T-N and T-P load (2004~2005)

Site	Monthly load				Total load	
	COE		R^2		R.E	
	T-N	T-P	T-N	T-P	T-N	T-P
Indong	0.79	0.68	0.84	0.67	4%	3%
Boksu	0.69	0.59	0.65	0.80	11%	25%
Hoeduck	0.63	0.73	0.75	0.73	9%	9%

As a result of verifying T-N loads, monthly T-N loads estimated by SWAT2000 model showed a satisfactory result and correlationship among months was judged to be somewhat high.

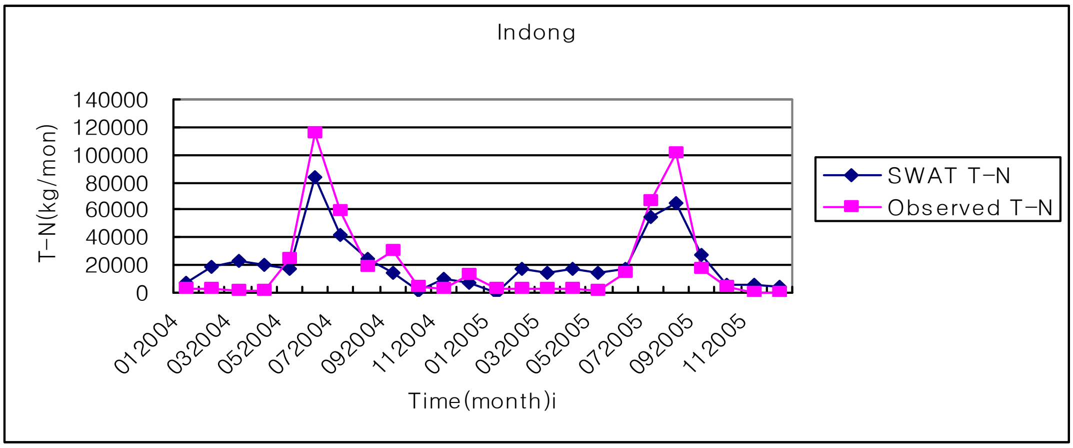

Figure 8. Comparison between monthly SWAT T-N and observed T-N load for Indong

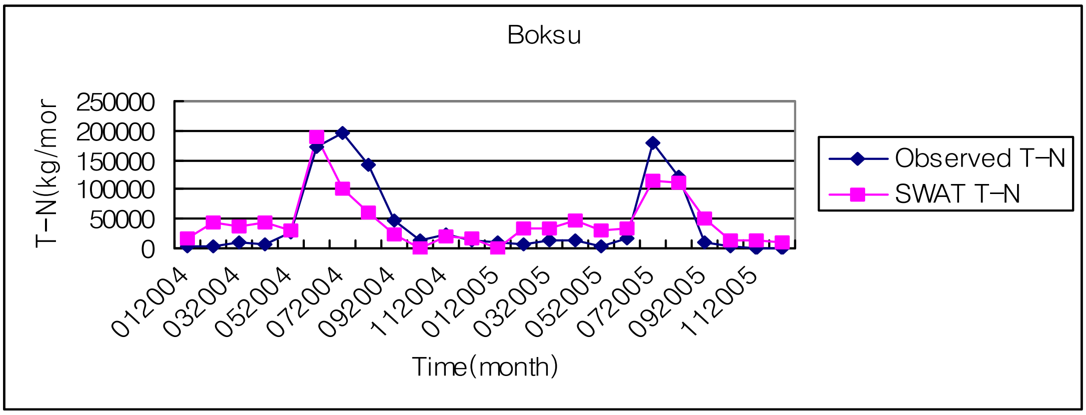

Figure 9. Comparison between monthly SWAT T-N and observed T-N load for Boksu

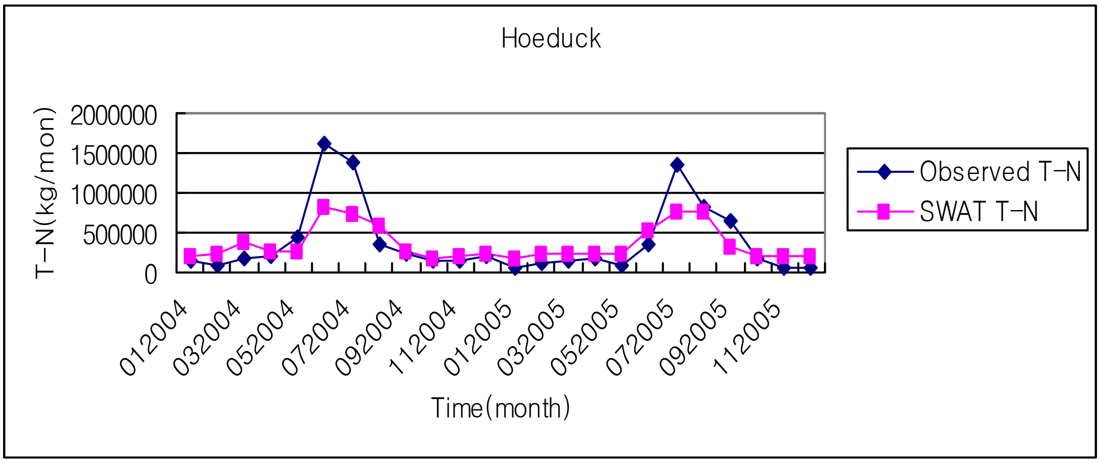

Figure 10. Comparison between monthly SWAT T-N and observed T-N load for Hoeduck

It was found that T-N loads estimated in Hoeduck area was set low during flood season and set high during the dry season, and estimation tendency of monthly loadings was similar to that of actually observed value.

As a result of verification, estimated value of monthly T-N loads showed 0.63~0.79 of COE index and a coefficient of determination was 0.65~0.84. And as for total loadings, relative error was from 4% to 11% but estimated amount of nitrogen was a little small during the flood season and a little large during the dry season.

As for monthly T-P loads, the result of verifying the model was quite satisfactory like that during the calibration period, and correlationship among months was also very high.

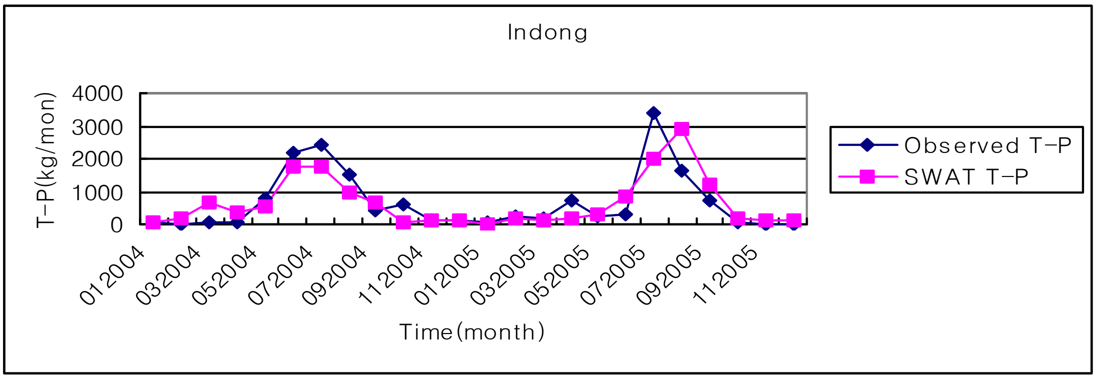

Figure 11. Comparison between monthly SWAT T-P and observed T-P load for Indong

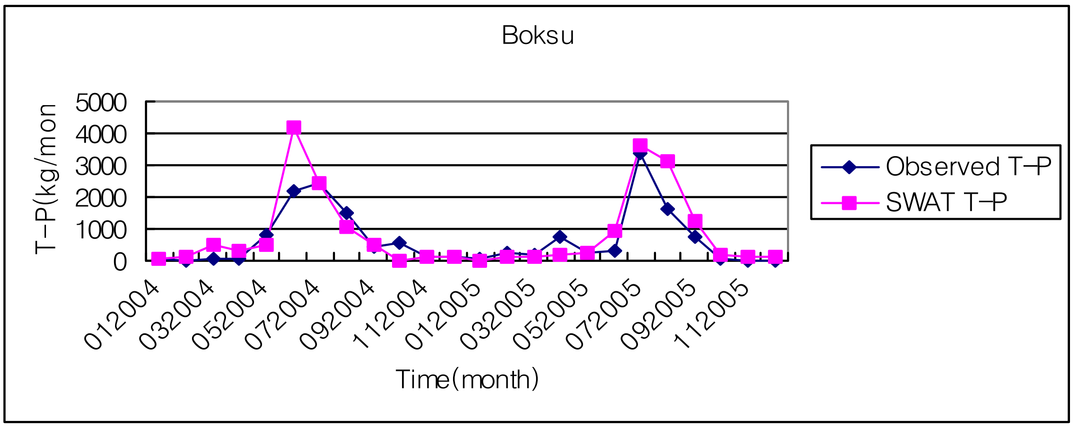

Figure 12. Comparison between monthly SWAT T-P and observed T-P load for Boksu

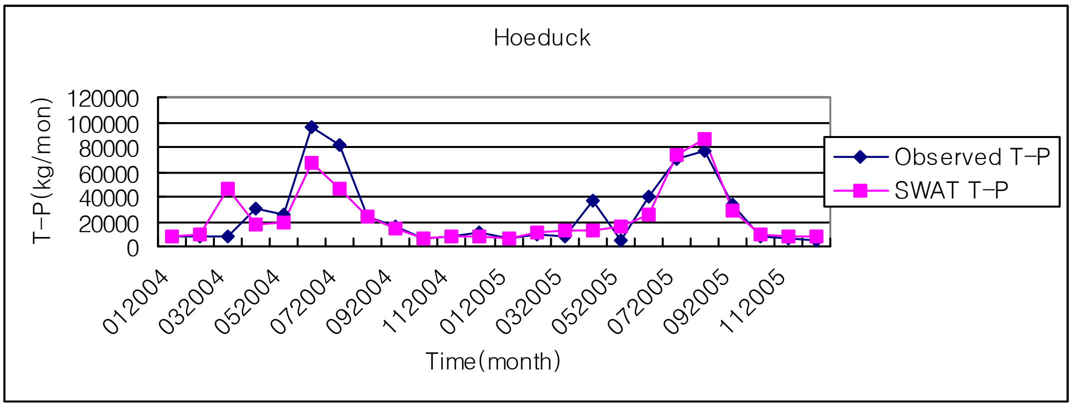

Figure 13. Comparison between monthly SWAT T-P and observed T-P load for Hoeduck

Also, COE index on monthly loads of T-P showed 0.59~0.73 and e coefficient of determination showed the value between 0.67 and 0.80. Relative error of total loads was from 3% up to 25%. Estimation of loads of phosphorus was generally fine and it was found that it was estimated quite accurately during both the flood season and the dry season.

Result and consideration

Application of riparian buffer zone

As a result of application of SWAT model in order to calculate the amount of outflow and loads of pollution in three outlets of Gapcheon watershed, Boksu, Indong and Hoeduck, it was found that its applicability and reproducibility was very high. And based on this, by setting the width of riparian buffer zone as 15m, 30m, 50m, 100m, 200m, 300m, 500m and 1,000m, that was applied to SWAT model and the result of application when making riparian buffer zone as forest and composing the forest with evergreen trees and deciduous trees was analyzed.

Boksu

Land-use for Boksu subbasin is composed of 10% of farmland and stretches over the whole subbasin, so in case that 500m width of riparian buffer zone is set, farmland accounts for 2.6% of the zone, showing the gradual effect. It was found that for reducing 10% of discharging loads of T-N and T-P, 80m of deciduous trees or 70m of evergreen trees are needed. Amount of outflow is constant in case of deciduous trees regardless of the size of riparian buffer zone and in case of evergreen trees, the amount has reduced.

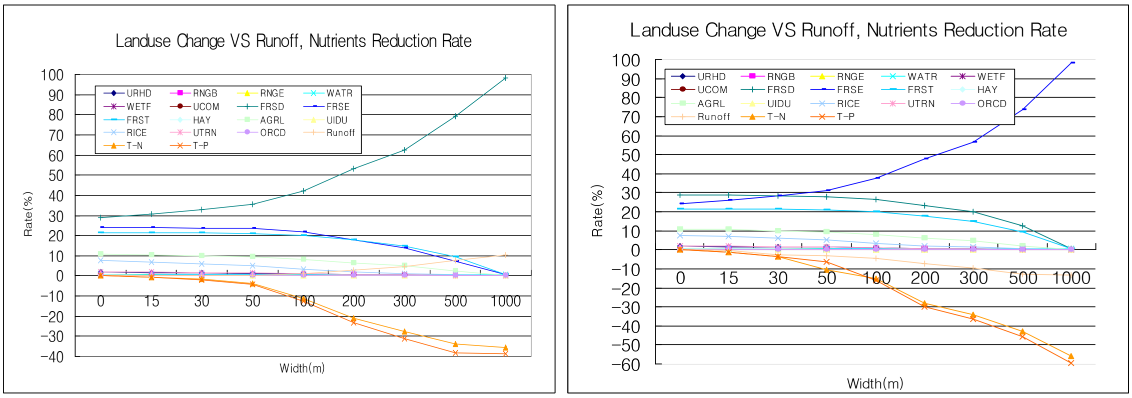

Figure 14. Change of amount of outflow, reducing rate of total nitrogen and total phosphorus according to the size of riparian buffer zone in Boksu area

Indong

Land-use in Indong subbasin is composed of 14% of urban area and is located near a river. So, when making 500m width of riparian buffer zone, urban area accounts for 1.7%, showing very high reducing effect. Also, in order to reduce 10% of discharging loads of T-N and T-P, 70m of deciduous trees or 60m of evergreen trees are needed. When making riparian buffer zone with evergreen trees, amount of outflow can be reduced.

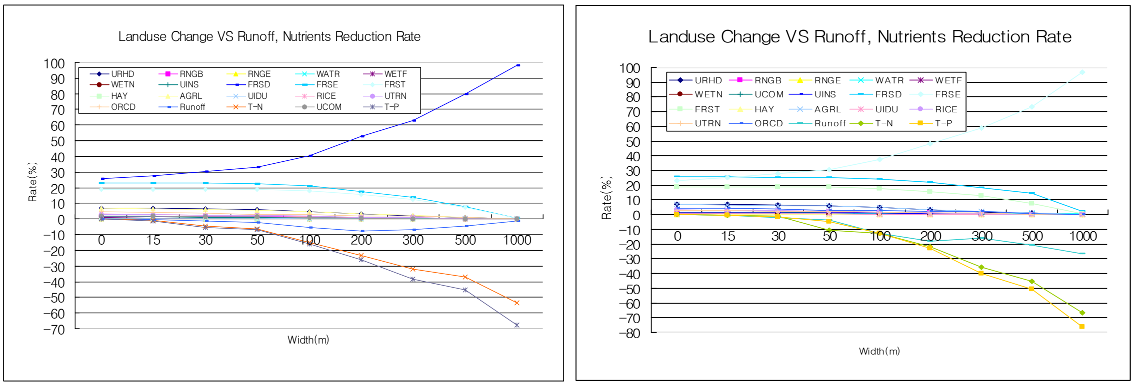

Figure 15. Change of amount of outflow, reducing rate of total nitrogen and total phosphorus according to the size of riparian buffer zone in Indong area

Hoeduck

In Hoeduck subbasin, urban area accounts for 19%, but this area is concentrated in the lower area of Gapcheon, having not so high effect. Also, in order to reduce 10% of discharging loads of T-N and T-P, 300m of deciduous trees can be effect but evergreen trees do not have effect on reducing the loadings. Amount of outflow was constant with deciduous trees regardless of the size of riparian buffer zone and it reduced with evergreen trees.

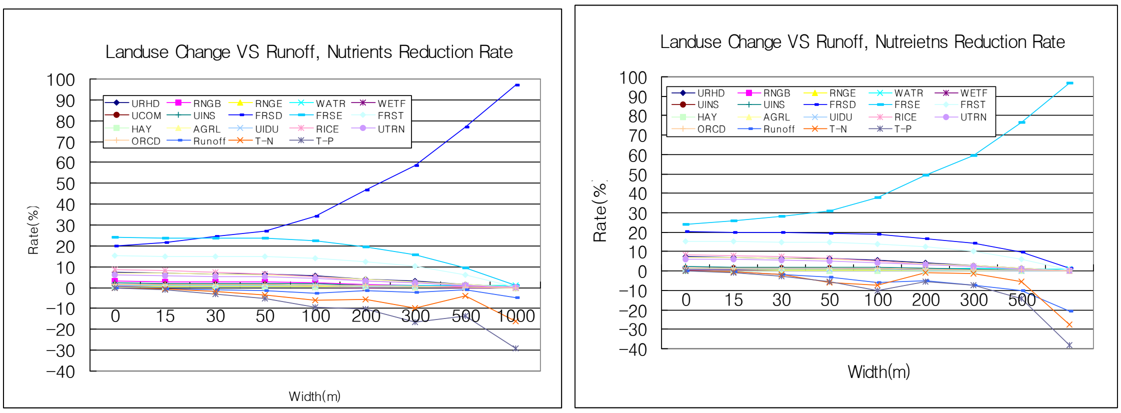

Figure 16. Change of amount of outflow, reducing rate of total nitrogen and total phosphorus according to the size of riparian buffer zone in Hoeduck area

Conclusion

This study applied SWAT model targeting three big rivers, Yudeungchean (Boksu), Daejeoncheon (Indong) and Gapcheon (Hoedeok) in Daejeon area, a typical urban area, set the size of riparian buffer zone (width) as 15m, 30m, 50m, 100m, 200m, 300m, 500m and 1000m, and analyzed the reducing effect of nutrients and amount of outflow according to the size of riparian buffer zone. In order to review the applicability of SWAT model, it was calibrated and verified with discharging loads of nutritionals in Boksu, Indong and Hoeduck subbasin, observing outlets of Yudeungcheon, Daejeoncheon and Gapcheon from 2002 to 2005. COE index of monthly loads of T-N showed the value between 0.63 and 0.79 and that of T-N was 0.59~0.78, confirming that SWAT model has great applicability and reproducibility. And by varying the size (width) of riparian green belt, reduced amount of discharging loads of nutritions was calculated. The criteria for deciding the size of riparian green belt was 10% reduced amount of nonpoint pollution sources of 2010, target year according to total amount system of water pollution in Daejeon Metropolitan City. As a result, the width of deciduous trees in riparian buffer zone in Boksu subbasin was 80m and that of evergreen trees was 70m. That of deciduous trees in Indong subbasin was70m and that of evergreen trees was 60m. In case of Hoeduck subbasin, when the width of deciduous trees was 300m, reduced amount of discharging of total nitrogen and total phosphorus was -9.8% and -16.3% respectively and evergreen trees had shown to have no effect. As a result, in Boksu subbasin where the upper basin of discharging outlet point is almost composed of farmland, Indong subbasin which is for resident area and urban area, and Hoeduck subbasin where both urban area and farmland co-exist, the size of riparian buffer zone and reducing effect is shown differently. As reducing effect, the size and species of trees of riparian green belt of riparian buffer zone are decided differently according to the status of land-use of the upper basins of target areas, the size should not be decided without consideration or foreign cases should not be introduced as it is. By selecting the analyzing method which can reflect the status of watersheds in our country well, it is needed to decide the optimum size of riparian buffer zone considering reducing efficiency of nonpoint pollution sources, securing of water resources and economic effect.

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A5-4

Land Use Change Effects on Discharge and Sediment Yield of Song Cau Catchment in Northern Vietnam

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Abstract

The purpose of this paper is to implement the "Soil and Water Assessment Tool" model to examine the effects of land use change scenarios exert on runoff discharge and sediment yield from Song Cau catchment in Northern Viet Nam. Prior to the scenarios, the particular hydrological and erosion regime of the catchment, representative of the tropical climate, was fully demonstrated. SWAT successfully predicted soil losses from different HRUs that caused significant sediment yield.

Facing the problem of reservoir inadequacy in the near future, this study attempted to assess the impact of pre-specified land use change scenarios, in terms of quantifying the results from the application of crop rotations and special cultivation techniques that was most susceptible to erosion. All scenarios resulted in a decrease in soil losses and sediment yield comparing to the current land use status. The model predicted explicitly the consequences of non-structural mitigation measures against erosion. The understanding of land use changes in relation to its driving factors provides essential information for land use planning and sustainable management of soil resources, under the special conditions of Viet Nam.

KEYWORDS: SWAT, Agricultural land, Sediment yield, Land use change scenarios

Introduction

Impact assessments of land use changes, population increases and urban development to water quantity and quality are one of the most important topics in a watershed management. Integrated management of water resource environment from river basin to downstream facilities such as dam or lake is also important for conservation and sustainable use of natural resources. Findings arising by catchment experiments provide clear evidence of the strong relation of erosion rates, land use, and human activities (Walling, 1999). Interventions along rivers, such as dams, clearly affect the dynamic equilibrium of materials exchanged between the land and the water body. Changes of the flow and sediment discharges can become influential in the evolution of the coastline, and sedimentation in reservoirs can rapidly decrease the dead storage capacities (Bonora *et al*, 2000). This is currently taking palce in Song Cau catchment in northern Viet Nam, where the sedimentation patterns of the downstream part of the catchment have significantly changed mainly due to land use change within the catchment. In addition, seasonal extreme meteorological phenomena have caused significant soil losses and sediment deposited in reservoirs has increased the operational inadequacy for water supply.

Facing the aforementioned problems, considerable efforts are needed to achieve the required improvements of surface water, primarily focusing on those areas likely to present the greatest risk. Agricultural land that is usually susceptible to soil losses is considered to be the most favorable land use type where low cost mitigation measures against erosion can be applied. Land use changes which are biophysically, or more commonly in the last years, artificially based (Skole and Tucker, 1993), often have significant effects on the surrounding environment and consequently on the hydrological cycle. Although the empirical knowledge of the consequences of a land use change is generally common (i.e. crops cultivation under rotations, strip-cropping, contours or terrace systems can decrease soil loss and sediment yield), it is often difficult to make an explicit quantification of these consequences.

The purpose of this study is to quantify the impacts of specific land use changes on runoff discharge and sediment yield through case study of Song Cau catchment in northern Viet Nam. Therefore, the objectives of this study are:

1. To apply SWAT in Song Cau catchment to analyze the impact of land use changes on runoff discharge and sediment yield, and;
2. To make policy recommendations for decision makers regarding the impacts of land use changes on runoff discharge and sediment yield.

Methodology

Study area

The Song Cau catchment is located in northern Viet Nam, between $21^0$07' – $22^0$18'N and $105^0$28' – $106^0$08'E (figure 1). The catchment has an area of 2940 km^2 and is predominantly agricultural land (arable and pasture). The elevation ranges from 24 to 1498m above sea level with the mean elevation being 284.8m. The length of the main stream is 125 km. High rainfall events in combination with less permeable soil formations cause significant runoff and subsequently high soil losses and sediment yield. Data from Thai Nguyen Meteorological and Gauging station show that the study area is influenced by tropical monsoon climate with an average temperature of 22^0C. The winter (dry) season (November to March) is cold and mostly dry with the average temperature under 15^0C and the lowest temperature during recent years is 3^0C. The summer (rainy) season (April to October) is hot with the average temperature of 26^0C while highest temperature is 39^0C. The average annual rainfall is 2000 - 2500 mm. The highest rainfall usually occurs from June to August which occupies more than 70% total annual rainfall (GSOV, 2008).

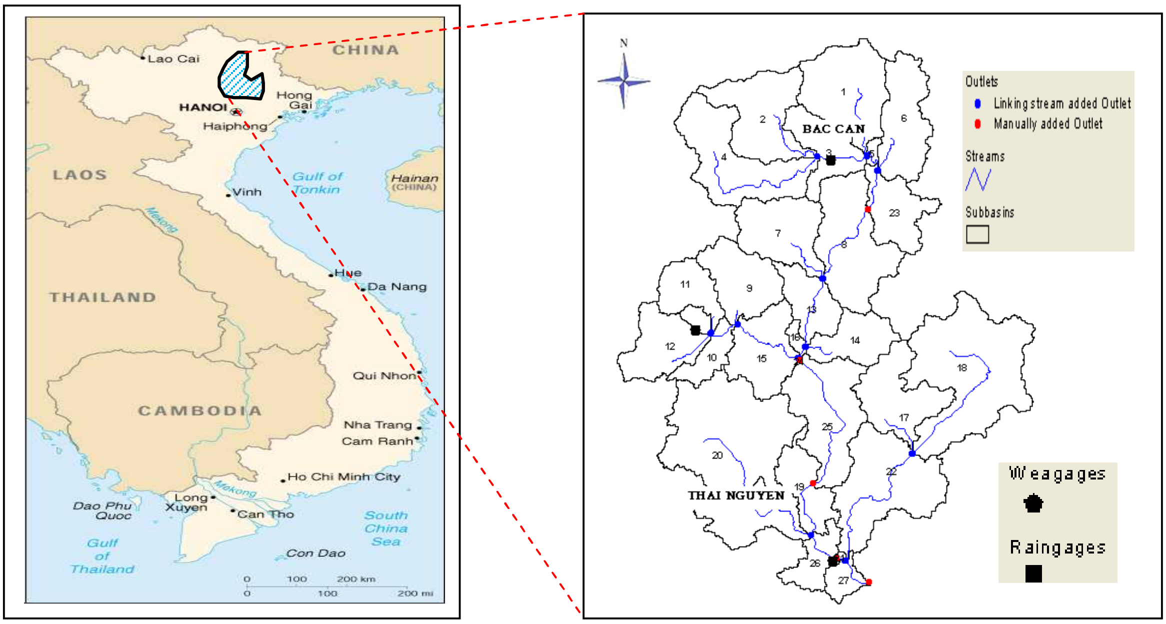


Figure 1. Location of Song Cau Catchment in Northern Viet Nam.

Brief descriptions of SWAT model

SWAT is a physically based, continuous-time hydrologic model with an ArcView-GIS interface developed by the Blackland Research and Extension Center and the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) (Arnold *et al*., 1998) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex basins with varying soil type, land use and management conditions over long periods of time (Mimikou *et al*., 2000, Varanou *et al*., and Panagopoulos *et al*., 2007). The main driving force behind SWAT is the hydrological component. The hydrological processes are divided into two phases (Hiroaki, and Ikuo, 2009): 1) the land phase, which controls the amount of water, sediment and nutrients received by a water body and 2) the water routing phase, which simulates water movement through the channel network. SWAT considers both natural sources of nutrient inputs (e.g., mineralization of organic matter and N-fixation) and anthropogenetic contributions (fertilizers, manures, and point sources). SWAT delineates watersheds into sub-basins interconnected by a stream network. Each sub-basin is further divided into hydrologic response units (HRUs) based upon unique soil and land class characteristics separated from any specified location in the sub-basin. SWAT sums the flow, sediment and nutrient loading from each sub-basin HRU and the resulting loads are then routed through channels, ponds, and reservoirs to the watershed outlet (Arnold *et al*, 2001). A single growth model in SWAT, based on a simplification of Erosion Productivity Impact Calculator (EPIC) crop model, is used for simulating all crops (Williams *et al*., 1984). Phenological development of the crop is based on daily heat unit accumulation. SWAT also uses WXGEN weather generator model (Sharpley and Williams, 1990) to generate climate data or to fill gaps in the measured records.

Data collection

SWAT requires meteorological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity, and solar radiation. Furthermore, spatial datasets including digital elevation model (DEM) as well as land cover and soil maps are required. We collected available data and information related to SWAT for Song Cau catchment including maps, statistic data, forest area, forest cover, precipitation, runoff discharge, sediment yield, and other related data. The sources and main types of data collected are shown in Table 1.

Table 1. Sources and Types of Data Collected for SWAT.

N^0	Types of data	Sources of data
1	Precipitation (rainfall)	Thai Nguyen, Bac Can, and Dinh Hoa weather stations
2	Temperature and others meteorological data	Thai Nguyen, Bac Can,and Dinh Hoa weather stations
3	Runoff discharge (observed data)	Gia Bay, Thac Buoi, and Thac Gieng gauging stations
4	Sediment yield (observed data)	Gia Bay gauging station
5	Topography (DEM)	Department of Information and Communication technology for Natural Resources and Environment, Ministry of Natural Resources and Environment
6	Soil map	Viet Nam Soil and Fertilizers Research Institute
7	Land use map	Department of Information and Communication technology for Natural Resources and Environment, Ministry of Natural Resources and Environment plus field survey data
8	Forest, Agricultural land	Department of Natural Resources and Environment of Thai Nguyen and Bac Can provinces

Land use scenarios

The principal objective of this case study was to assess an efficient land use planning for the future of Song Cau catchment. Therefore we formulated different planning scenarios based upon the recommendations addressed in "***Report on Land use planning***" (TNPC, 2008 and BCPC, 2008). Table 2 shows four land-use planning scenarios formulated for Song Cau catchment, and the baseline scenario is the land use currently implemented. (2008).

SWAT model requires methodological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation data (Nguyen *et al*., 2009). Spatial datasets including digital parameter layers such as topography (LS) and parameters R, K, C and P (Wischmeier and Smith, 1978) were digitized from the associated maps. The watershed LS factor was derived from digital elevation model (DEM) obtained from topography data.

Table 2. Land Use Planning Scenarios for Song Cau Catchment.

SWAT Code*	Baseline		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
WATR	39948.11	13.58	39948.11	13.58	39948.11	13.58	39948.11	13.58	39948.11	13.58
URMD	16384.72	5.57	16384.72	5.57	16384.72	5.57	16384.72	5.57	43075.18	14.65
FRSD	15214.7	5.17	15214.70	5.17	15214.70	5.17	0.00	0.00	15214.70	5.17
FRSE	38391.23	13.05	38391.23	13.05	38391.23	13.05	38391.23	13.05	38391.23	13.05
FRST	17332.68	5.89	17332.68	5.89	84867.29	28.86	0.00	0.00	17332.68	5.89
RICE	26690.46	9.08	26690.46	9.08	26690.46	9.08	26690.46	9.08	0.00	0.00
PAST	135069.2	45.93	67534.61	22.96	67534.61	22.96	135069.21	45.93	135069.21	45.93
AGRL	126.82	0.04	126.82	0.04	126.82	0.04	126.82	0.04	126.82	0.04
AGRR	4928.73	1.68	72463.34	24.64	4928.73	1.68	37476.11	12.74	4928.73	1.68
	294086.66	**100**	**294086.66**	**100**	**294086.66**	**100**	**294086.66**	**100**	**294086.66**	**100**

[*] SWAT code were based on Neitsch et al., 2002 with WATR: Water bodies including natural and manmade ponds and reservoirs, URMD: Urban residential medium density, FRSD: Forest-Deciduous, FRSE: Forest-Evergreen, FRST: Forest-Mixed, RICE: Rice cultivation, PAST: Pasture, AGRL: Agricultural Land-Generic, AGRR: Agricultural Land-Row Crops (almost occupied by Tea).

Model performance evaluation

We used the Nash-Sutcliffe efficiency (NSE), root mean square error (RMSE), observation's standard deviation ratio (RSR) and percent bias (PBIAS) to evaluate model performance.

The NSE value is calculated using the following equation (1):

$$\text{NSE} = 1 - \{\Sigma^{n}_{i=1}(Q^{i}_{obs} - Q^{i}_{sim})^{2}\} \Big/ \{\Sigma^{n}_{i=1}(Q^{i}_{obs} - Q_{obs\text{-}mean})^{2}\} \qquad (1)$$

Where: n is the number of registered data points, Q^{i}_{obs}, and Q^{i}_{sim} are the observed and simulated data, respectively, on the i^{th} time step, and $Q_{obs\text{-}mean}$ is the mean of observed data (Q^{i}_{obs}) across the n evaluation time steps.

The NSE value indicates how well the observed data versus simulated results fit the 1:1 line (Nash and Sutcliffe, 1970). NSE values range from $-\infty$ to one, with values less than or very close to zero indicating the unacceptable or poor model performance and values equal to one indicating perfect performance.

The RSR value is calculated as a ratio of the RMSE and standard deviation of the measured data (Moriasi *et al*., 2007). RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor. The RSR value varies from the optimal value of zero, which indicates zero RMSE or residual variation, to a large positive value (Moriasi *et al.,* 2007). The RSR value is calculated using the following equation:

$$\text{RSR} = \text{RMSE}/\text{STDEV}_{obs} = \{\sqrt{\Sigma^{n}_{i=1}(Q^{i}_{obs} - Q^{i}_{sim})^{2}}\} \Big/ \{\sqrt{\Sigma^{n}_{i=1}(Q^{i}_{obs} - Q_{obs\text{-}mean})^{2}}\} \qquad (2)$$

in which all parameters in the equation share the same definitions as that in Equation (1).

The PBIAS is used to determine if the average tendency of the simulated data is either larger or smaller than its observed counterparts (Gupta *et al.,* 1999). The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive PBIAS values indicate model underestimation bias, while negative values indicate model overestimation bias (Gupta *et al.,* 1999). PBIAS is calculated using the following equation:

$$\text{PBIAS} = \left\{\sum_{i=1}^{n}(Q_{obs}^{i} - Q_{sim}^{i}) \times 100 \Big/ \sum_{i=1}^{n}(Q_{obs}^{i})\right\} \qquad (3)$$

Similarly, all parameters shares the same definitions as that shown in Equation (1).

Results and Discussions

Watershed Delineation

Model simulations were performed using a delineation consisting of 27 sub-basins to account for the climatic, soil, topographic, and land cover variations within Song Cau catchment (Figure 1). A total of 9 land covers and 5 soil types were employed in the project. Table 3 presents a listing of the respective land cover types, sub-basin areas, ranges in curve number values, and USLE C factors for each land cover type delineated.

Table 3. Areas, Land Cover Types, Range in Curve Number and USLE C Factor Delineated in the Song Cau Catchment.

SWAT Code	Land Use Type	Area		Curve Number Range	USLE C Factor
		(ha)	(%)		
WATR	Water	39948.11	13.58	92 - 92	0.00
URMD	Urban	16384.72	5.57	74 - 92	0.008
FRSD	Forest-Deciduous	15214.7	5.17	45 - 83	0.001
FRSE	Forest-Evergreen	38391.23	13.05	25 - 77	0.001
FRST	Forest-Mixed	17332.68	5.89	36 - 79	0.001
RICE	Rice	26690.46	9.08	62 - 84	0.030
PAST	Pasture	135069.2	45.93	49 - 84	0.003
AGRL	Agricultural Land-Generic	126.82	0.04	67 - 87	0.200
AGRR	Agricultural Land-Row Crops	4928.73	1.68	67 - 89	0.200
	Total	**294086.66**	**100**		

Model Calibration and Validation

Based on available climatic, streamflow, and sediment data collected from the catchment, model parameters in SWAT were calibrated and validated using 44 years period of record, of which data collected from 1964 to 1984 was designated for model calibration, and a period of record from 1985 to 2008 was designated as the validation period for runoff discharge. For sediment, 19 years data recorded from 1972 to 1990 and 18 years from 1991 to 2008 for calibration and validation, respectively. To account for spatial variability in topographic, soil types, and land use factors among Song Cau catchment, parameters governing streamflow response in SWAT were calibrated in a distributed fashion. We used the model's manual calibration procedure in which observed and simulated outputs are compared at the same outlet points (Gia Bay) on the catchment.

Simulation Results

Streamflow

A comparison of measured versus simulated monthly hydrographs from the Gia Bay gauges on the main stem of Song Cau showed very good agreement as that shown in Figures 2 and 3. For the calibration period from 1964 to 1984, monthly Nash-Sutcliffe coefficient of efficiency (NSE) was 0.822, observation's standard deviation ratio (RSR) and percent bias

(PBIAS) were 0.438 and -1.587. For the validation period (1985 – 2008) all the parameters (NSE, RSR, PBIAS) were little lower than calibration period with value of 0.767, 0.425 and 5.928, respectively (Table 4).

Table 4. Monthly streamflow Coefficient of Nash-Sutcliffe Efficiency (NSE), Observation's Standard Deviation Ratio (RSR), and Percent Bias (PBIAS) of Song Cau.

N^0	Items	Period of Record	Monthly NSE	RSR	PBIAS (%)
1	Calibration	1964 - 1984	0.822	0.438	- 1.587
2	Validation	1985 - 2008	0.767	0.425	5.928

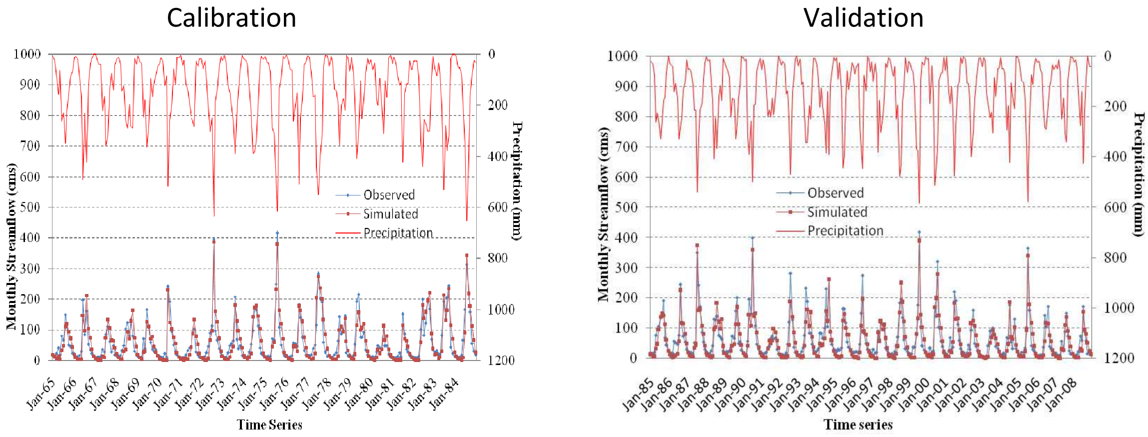


Figure 2. Observed versus Simulated Monthly Streamflow and Precipitation of Song Cau during Calibration and Validation Periods.

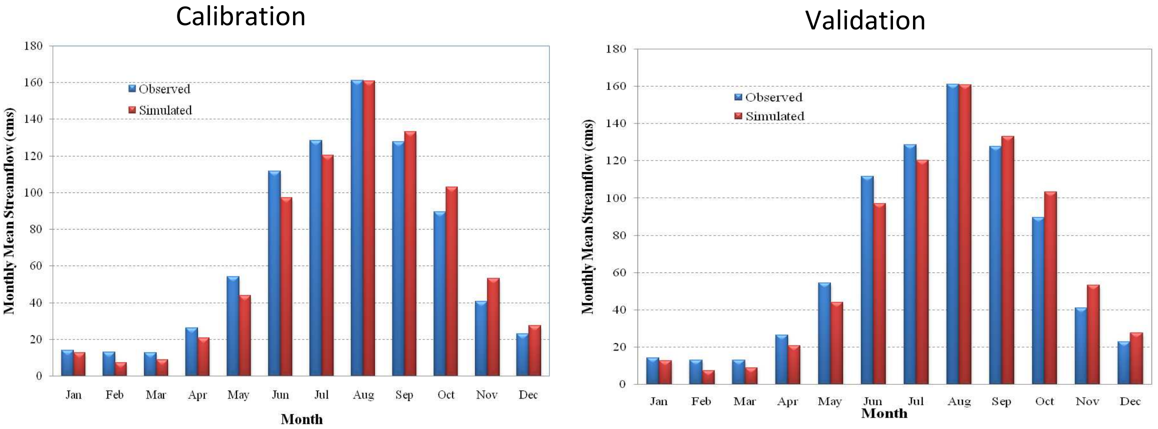


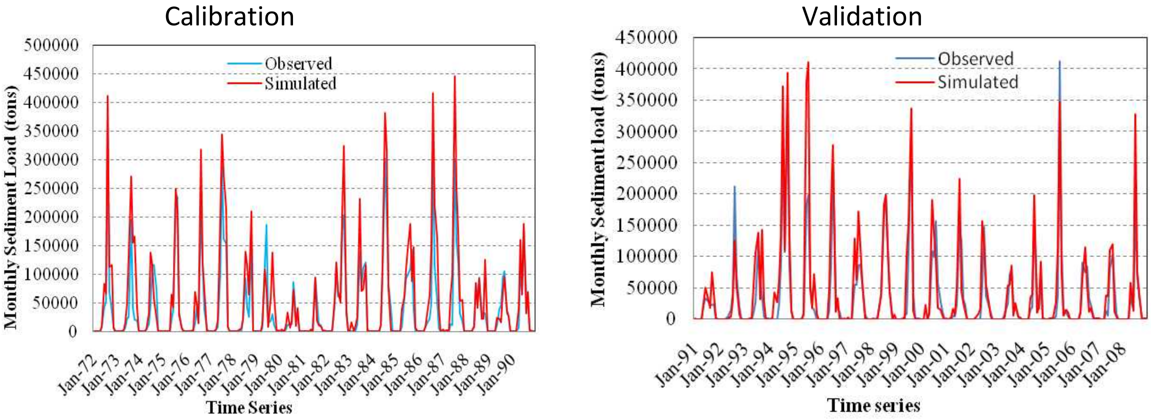
Figure 3. Observed versus Simulated Average Monthly Streamflow during the Calibration and Validation periods of Song Cau Catchment.

Sediment

The sediment data collected from 1972 to 2008 were used to compare with SWAT simulation results. In general, the simulation results showed that SWAT tended to overestimate sediment loads for all months of year, except the August of the validation period (Figure 4, and 5). SWAT performance in simulating sediment response in the watershed was considered good based on monthly NSE values for the calibration and validation periods, which were 0.660 and 0.690 respectively. The Percent Bias (PBIAS) value was satisfactory (-36.127%) for calibration and good (-26.443%) for validation period (Table 5).

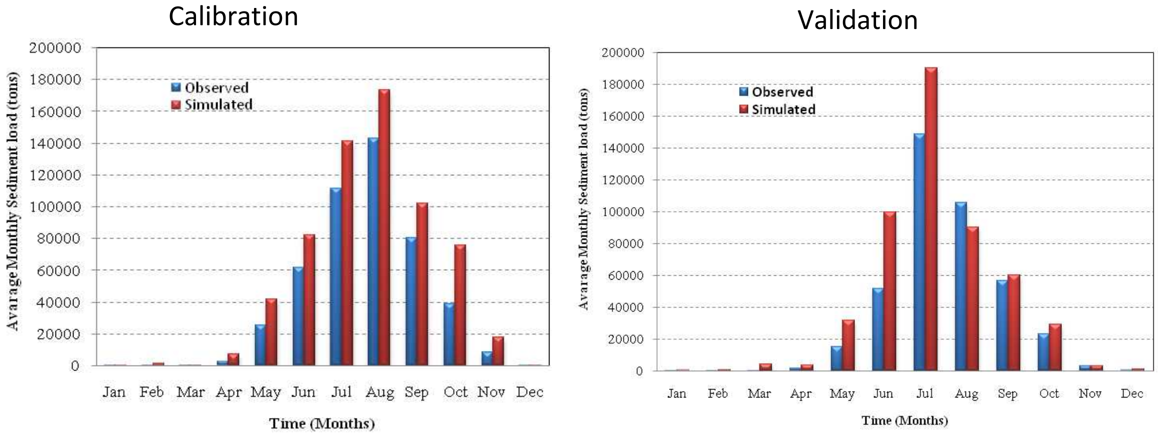
Table 5. Sediment Load Percent Bias (PBIAS), Monthly Coefficient of Nash-Sutcliffe Efficiency (NSE) and Observation's Standard Deviation Ratio (RSR) of Song Cau.

N^0	Items	Period of Record	Monthly NSE	RSR	PBIAS (%)
1	Calibration	1972 - 1990	0.660	0.583	- 36.127
2	Validation	1991 - 2008	0.690	0.555	- 26.443


Calibration

Validation

Figure 4. Observed versus Simulated Monthly Sediment Load of Song Cau during Calibration and Validation Periods.


Calibration

Validation

Figure 5. Observed versus Simulated Average Monthly Sediment Load during the Calibration and Validation periods of Song Cau Catchment.

Evaluation of model sensitivity to land use

Model's sensitivity to land use changes was tested using 4 hypothetic scenarios. Each scenario was generated based on Reports of land use planning of Bac Can and Thai Nguyen provinces (BCPC and TNPC, 2008). Current land use was considered as baseline scenario, and other scenarios include: (1). Scenario 1: converted 67534.61 ha (22.96%) Pasture land into Agricultural Land-Row Crops but other land uses remained unchanged; (2). Scenario 2: transferred 67534.61 ha (22.96%) Pasture land to Forest-Mixed land; (3). Scenario 3: converted 15214.7 ha (5.17%) Forest-deciduous and 17332.68 ha (5.89%) Forest-Mixed land into Agricultural Land-Row Crops; and (4). Scenario 4: transferred 26690.46 ha (9.08%) Rice land to Urban area (Table 2 and Figure 6). SWAT model was used to simulate basin hydrology under different land use scenarios using a common meteorological time series (i.e., time series of 1964~2008 for streamflow and 1972~2008 for sediment), from which impacts of land use changes on river flows and sediment loads were evaluated.

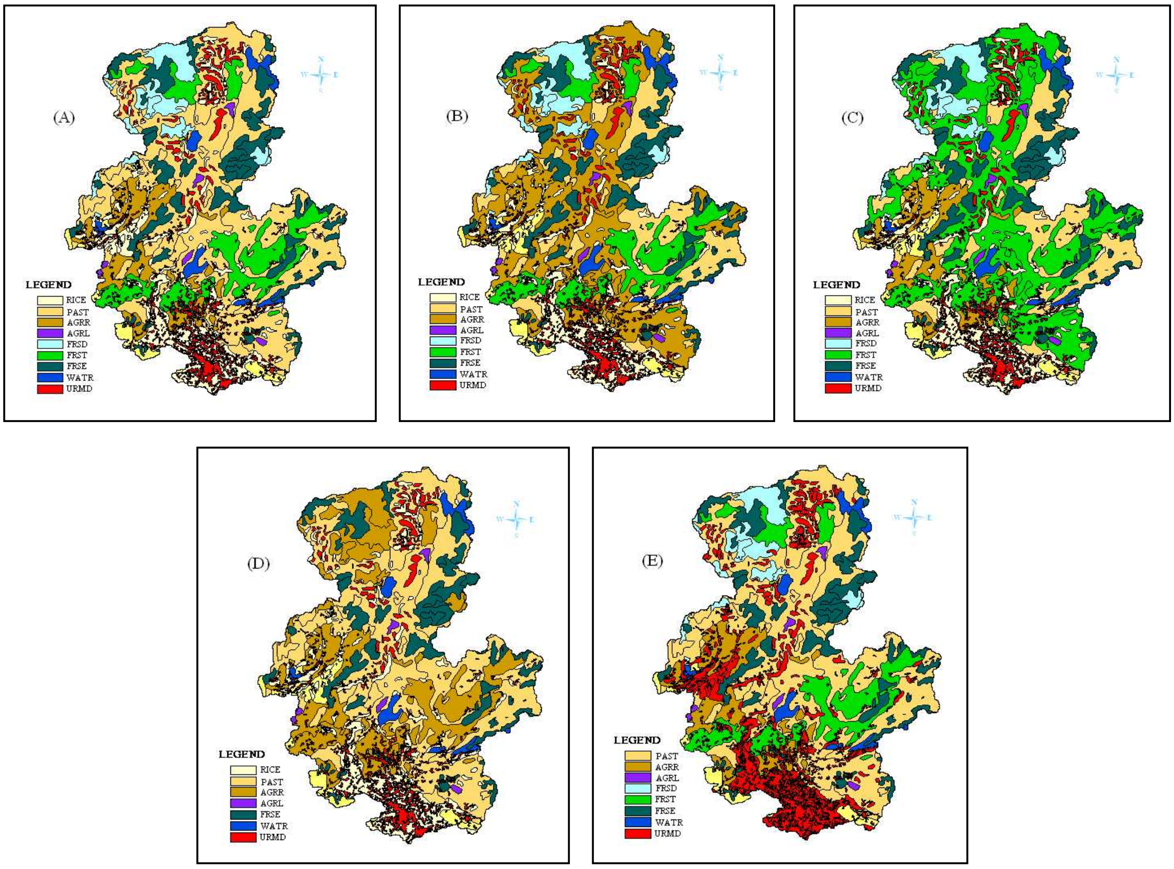


Figure 6. Different Land-use Scenarios Generated for Song Cau Catchment: (A) Baseline Scenario; (B) Scenario 1; (C) Scenario 2; (D) Scenario 3; (E) Scenario 4.

Table 6 and Figure 7 show that decreasing the area covered by forestry plantations will in general reduce the mean annual streamflow, whereas increasing the area under agriculture will increase mean annual flows. This result is consequent with that obtained by Thanapakpawin, *et al* (2007) and Stehr, *et al* (2007). The results from different scenarios that presenting the highest increase in mean annual streamflow was scenario 3, in which 11.07% of forestry (FRSD and FRST) areas were converted into agriculture land row crop (AGRR). Scenario 3 causes 3.93% increase in mean annual flows as compared to Baseline scenario. On the other hand, the lowest decrease of mean annual flows was occurred in scenario 2 with -1.37% decrease when 22.96% of pasture (PAST) was converted into forestry (FRST). Additionally, a specific comparison of simulated results for different scenarios was conducted for both dry (mean values for November to April) and wet period (mean values from May to October) as that shown in Table 6. It is worth of notice that scenario 2 produces -3.15% mean annual streamflow during mean wet season while 8.31% increase during mean dry season as compared to Baseline scenario. The effect of conserving water resources is mainly due to the significant role of forestry within catchment, which may avoid flood and drought in wet and dry season; respectively.

Table 6. Percentage (%) of Flow Change from Baseline (current land use) Scenario for Mean Annual, Wet Season (May – October) and Dry Season (November – April).

Items	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean Annual	2.90	-1.37	3.93	1.61
Mean Wet season (5-10)	2.84	-3.15	5.08	2.41
Mean Dry season (11-4)	3.20	8.31	-2.32	-2.73

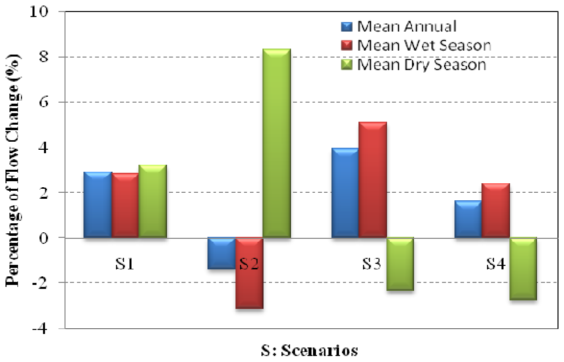


Figure 7. Percentage of Change in Mean Annual, Wet Season (May – October) and Dry Season (November – April) Flow with Respect to Baseline Scenario.

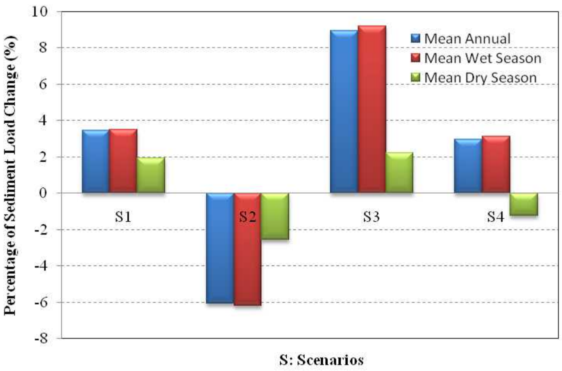


Figure 8. Percentage of Sediment Load Change in Mean Annual, Wet Season (May – October) and Dry Season (November – April) with Respect to Baseline Scenario.

Referring to sediment loads in Song Cau, three factors were mentioned, they were: Mean Annual, Mean Wet Season (May – October) and Mean Dry Season (November – April) (Table 7 and Figure 8). It can be seen that decreasing the area covered by forestry plantations will in general reduce mean annual sediment load (scenario 2), while an increase of area under agriculture will increase mean annual sediment loads (scenario 3). Results from 4 scenarios illustrate that scenario 2 produces a significant decrease in sediment loads with Mean Annual of -6.08%; Mean Wet Season of -6.21%, and Mean Dry Season of -2.56% as compared to Baseline scenario. Meanwhile, scenario 3 increases sediment loads with Mean Annual, Mean Wet Season, and Mean Dry Season 8.94%, 9.18%, and 2.21%, respectively. That illustrates the disadvantage of cultivated method on hillslopes in the mountain range of Vietnam.

Table 7. Percentage (%) of Sediment Load Change from Baseline Scenario for Mean Annual, Wet Season (May – October) and Dry Season (November – April).

Items	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean Annual	3.45	-6.08	8.94	2.98
Mean Wet season (5-10)	3.51	-6.21	9.18	3.13
Mean Dry season (11-4)	1.92	-2.56	2.21	-1.25

Conclusions

SWAT was able to successfully simulate streamflow discharge and sediment loads for Song Cau catchment. The results showed that monthly Nash-Sutcliffe coefficient of efficiency (NSE) ranged from 0.66 to 0.822, observation’s standard deviation ratio (RSR) and percent bias (PBIAS) ranged from 0.425 to 0.583 and -36.127 to 5.928, respectively.

Land use change scenarios based on application of crop conversion on parts of the study catchment seemed to be an efficient mitigation measure to minimize soil loss. Although financial and social consequences of these changes were not taken into consideration in this study, the results strongly suggested the incorporation of pasture with forest-mixed (scenario 2) and pasture with agriculture land low crop (scenario 1) cultivation in the study catchment are among the lists of BMPs . Moreover, cultivation of pasture with forest-mixed resulted in the highest mean annual reduction in sediment yields (-6.08%), and 8.31% increase of stream flows in dry season.

Acknowledgement

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SESSION B8

Urban Processes and Management

Hydrologic Modeling of the White Rock Creek Watershed with SWAT-SWMM

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Abstract

The development of a watershed area can significantly impact the natural flow in a stream network mainly due to an increase in surface runoff and an alteration of spatial flow pattern. In the field of hydrology, there have been extensive studies assessing the effect of urbanization on watershed runoff using hydrologic models. The storm water management model (SWMM) developed by the US Environmental Protection Agency (EPA) is a widely used dynamic rainfall-runoff model for analyzing quantity and quality problems in urban area. However, the SWMM can not sufficiently account for land uses other than urban area. To overcome this shortcoming and to better represent characteristics of both urban and natural area, a comprehensive integrated hydrologic model, SWAT-SWMM has been developed in which the RUNOFF block of SWMM is linked to the Soil and Water Assessment Tool (SWAT). The SWAT-SWMM model can be regarded as an advanced SWAT because it has a capability to simulate flow routing in urban drainage system such as pipe network. The main aim of this work was to apply SWAT-SWMM to the White Rock Creek watershed in USA for assessing hydrologic impact of urbanization. Through some case studies with the SWAT-SWMM model, the relationship between hydrological components and development were illustrated.

KEYWORDS: SWAT, SWMM, urbanized area

Introduction

SWAT (Arnold et al., 1993; Neitsch et al., 2002) was developed to evaluate the impacts of various land use and land management conditions on water yield, sediment yield, and non-point source loadings in the watershed. SWAT is a powerful model because it is capable of simulating almost all the components such as hydrology, erosion, plant growth, nutrients, etc. The main advantage of this model is that it can consider various land use types and various land management practices. However, SWAT model is not good for representing the characteristics of urban areas. Because an urban drainage system is not able to be considered with SWAT. While, SWMM (Huber and Dickinson, 1988) has been widely used to simulate runoff and water quality processes within urban areas. The main advantage of this model is that it can consider the routing processes through a system of pipes, channels, storage/treatment devices, etc. However, SWMM has a difficulty in accounting for rural areas. For example, SWMM can not simulate the crop growth within agricultural lands. Therefore, to overcome the shortcomings of both models, and eventually to better represent the characteristics of both urban and rural areas, an integrated SWAT-SWMM model was developed. In this paper, the procedure to integrate SWAT and SWMM was implemented with emphasis on the schematics of bridging two models. The main aim of this work was to apply SWAT-SWMM to the White Rock Creek watershed in USA for assessing hydrologic impact of urbanization. Through some case studies with the SWAT-SWMM model, the relationship between hydrological components and urban development were illustrated.

SWAT-SWMM Model Description

SWMM consists of four functional program blocks. In the current version of SWAT-SWMM, only the Runoff block was combined with the SWAT model. The first procedure to integrate SWAT and SWMM is that, both models were divided into three parts; reading, computing and writing parts. Then, each part of SWMM was embedded into the corresponding part of SWAT. When bridging their computation parts, some modification was made for the subroutine “HYDRO”. The subroutine “HYDRO” calculates water quantity and quality components, and it is composed of several subroutines. These subroutines were re-arranged to be consistent with the SWAT’s structure. That is, we separated the "HYDRO" into the land phase routing part and the channel/pipe routing part. The decomposed parts were inter-connected with the subroutines of subbasin and route within SWAT, respectively.

In the SWAT-SWMM model, only one subwatershed is governed by the SWMM algorithm, and the rest sub-watersheds follow the SWAT algorithm. To this end, we linked one subwatershed of SWAT and the catchment of SWMM. SWAT calculates hydrological components on the basis of HRUs, while, SWMM operates on a collection of subcatchments. So, we further linked HRUs and subcatchments. The SWAT-SWMM allows the channel flow to be mutually transferable to each other. Subcatchments of SWMM take information on precipitation, temperature, potential evapotranspiration from the HRUs of SWAT. Then the computed values of hydrological components are transferred to the HRUs of SWAT.

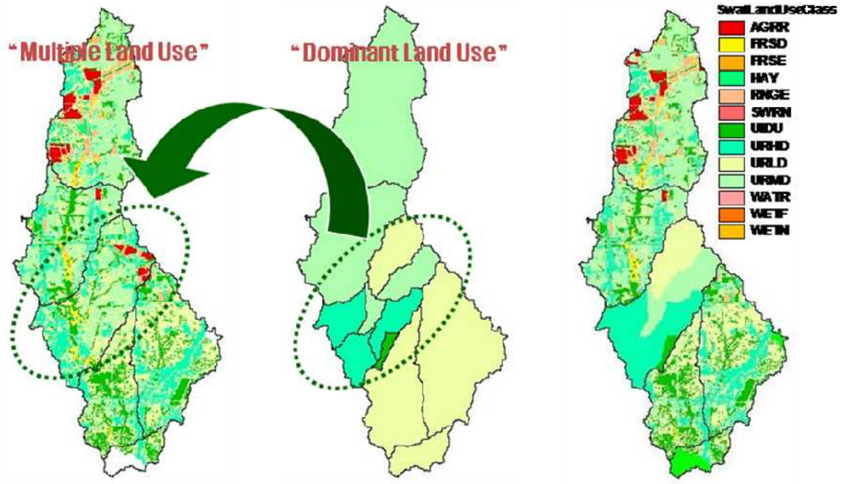


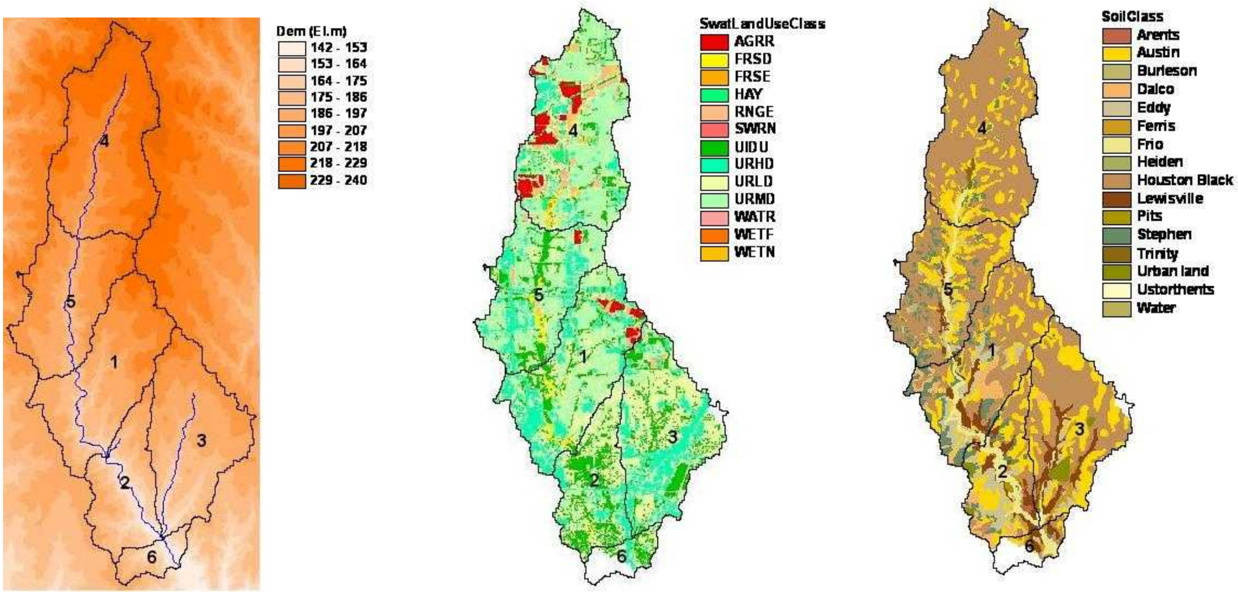
Figure 1. Preprocess for land use map

The catchment for SWMM modeling is further divided into a number of subcatchments. To spatially match the subcatchment map with the HRU distribution map, preprocessing works are required for the land use and soil maps. Landuse types of the SWMM catchment should be replaced by a dominant land use type. Figure 1 is an example of the preprocessed landuse map for SWAT-SWMM modeling. Likewise, the soil map should be adjusted.

Application of SWAT-SWMM to White Rock Creek Watershed

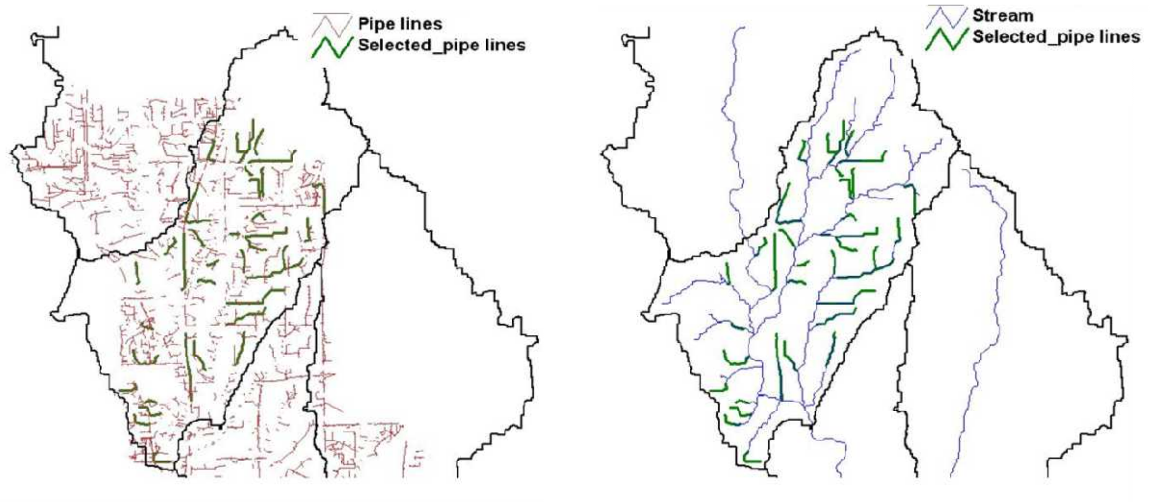
Study Area and Input data

The SWAT-SWMM model was applied to the White Rock Creek watershed in USA, which is located in southern Collins County and northern Dallas County. The study area covers about 172.6 square kilometers. The area ranges in altitude from about 140 to 240 m. Daily precipitation and temperature data for 3 gauging stations within and around the watershed were collected. The study area has a mean annual precipitation of 1,050 mm as recorded over the past 20 years. The watershed is divided into 6 sub-watersheds as shown in Figure 2. The digital elevation model (DEM) in 30m×30m in resolution was used for the simulation. The land use data was classified by 13 levels showing highly urbanized feature. The 16 hydrologic soil groups within the study watershed were used for simulation. Figure 3 shows the sewer lines in Dallas. Among these pipe lines, we just considered sizable major lines. In Figure 3(a), thick green lines represent the selected pipe lines for modeling. By combining the selected pipe lines and natural channels, we finally made a channel/pipe drainage system as shown in Figure 3(b). The hydraulic properties of channel/pipe system were entered into the SWMM model. Based on the drainage system and the topographic features, the catchment was discretized into 85 subcatchments. For SWMM modeling, a lot of input data such as drainage area, imperviousness, catchment slope, channel width and slope, soil properties are required. These data could be easily obtained from the SWAT input data.



(a) DEM **(b) land use map** **(c) soil map**

Figure 2. White Rock Creek watershed

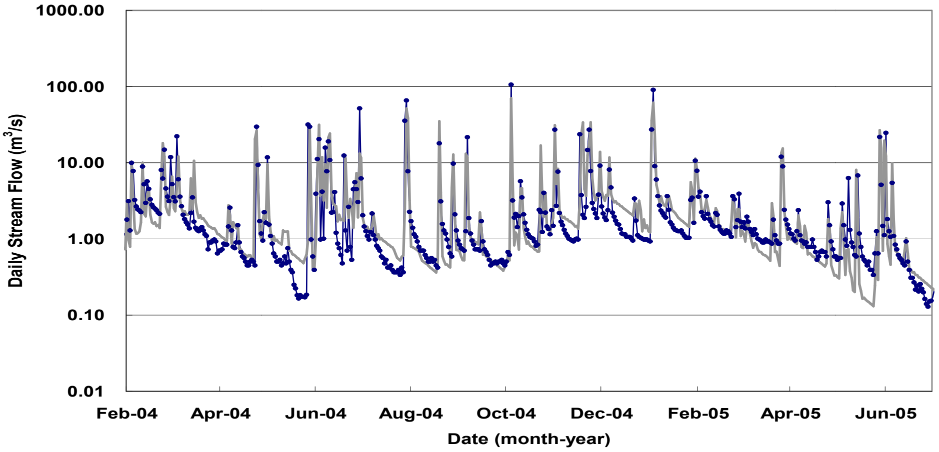


(a) Sewer lines (b) combination of stream and selected sewer lines

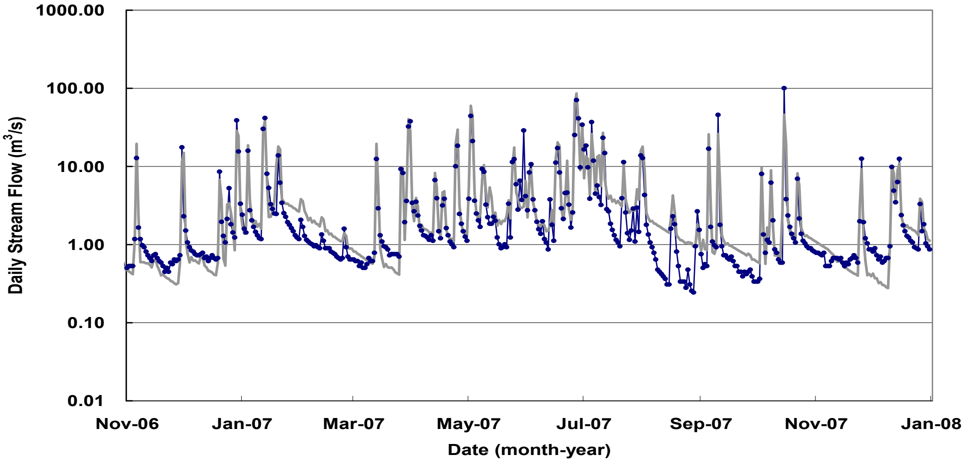
Figure 3. Channel and pipe drainage system for SWMM modeling

Model calibration and validation

Simulations were conducted for a period of 5 years from 2003 to 2007. We set the years of 2004 and 2005 as a calibration period, and the next two years as a validation period. The model parameters were calibrated until the simulated daily flows agreed well with the observed values at the outlet. To make a calibration process easier, SWAT calibration was performed in advance for the entire watershed, and then SWMM parameters were additionally calibrated for the subwatershed No.1. The major parameters used in the calibration process include CN2 (the CN value at the AMC-II condition), GWALPHA (ground water attenuation coefficient), EPCO (plant uptake compensation factor) and ESCO (soil evaporation compensation coefficient), saturated hydraulic conductivity of soil layers in SWAT, and maximum/minimum infiltration rate, Manning's roughness, groundwater coefficients in SWMM. As shown in Figure 4, the calibrated SWAT-SWMM model demonstrated good agreement between observed and simulated streamflows. The coefficient of determination is about 0.9, and volume error is lower than 5%. Likewise, the simulated results also show a good performance for the validation period.



(a) 2004-2005



(b) 2006-2007

Figure 4. Comparison of simulated daily stream flow and the measure flow

Effects of urbanization on hydrology

One of the significant alterations due to urban development is the increase in impervious area. In the present study, the variations of hydrological components in entire watershed were assessed as the imperviousness in sub-watershed No.1 increases. Including the current state, we performed 6 cases of simulations. For example, case 5 means that the imperviousness is 100 percent greater than the current state. Figure 5 shows the simulated annual mean hydrological components of surface flow, groundwater flow, evapotransipiration, and total yield according to the increase rate of impervious area. The clear difference is shown between their simulated hydrological components even though the degree of variations is not significant. Slight increase in total yield can be seen in the figure with the increase of impervious area. The amount of surface flow simulated by the SWAT-SWMM increases by 8% as the increase rate in impervious area reaches up to 100%. The noticeable changes are shown in percolation. The amount of percolation is reduced to about 84% of the result for an original simulation condition (current), which causes the decreases in groundwater flow and evapotranspiration. Figure 6 shows the comparison of simulated daily stream flows at the outlet between the current state and fictitious scenario of 100% increase in impervious area in sub-watershed No.1. As expected, the total runoff from the entire watershed for scenario 5 shows higher peaks and lower recession than for current state, which is mainly attributed to the changes in infiltration rate.

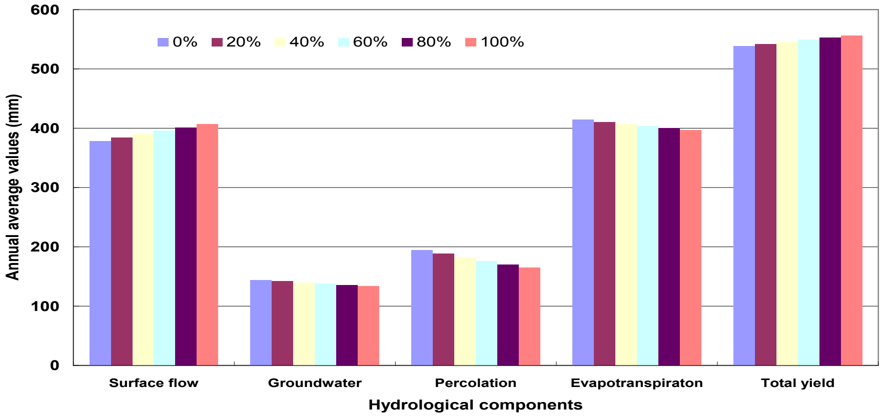
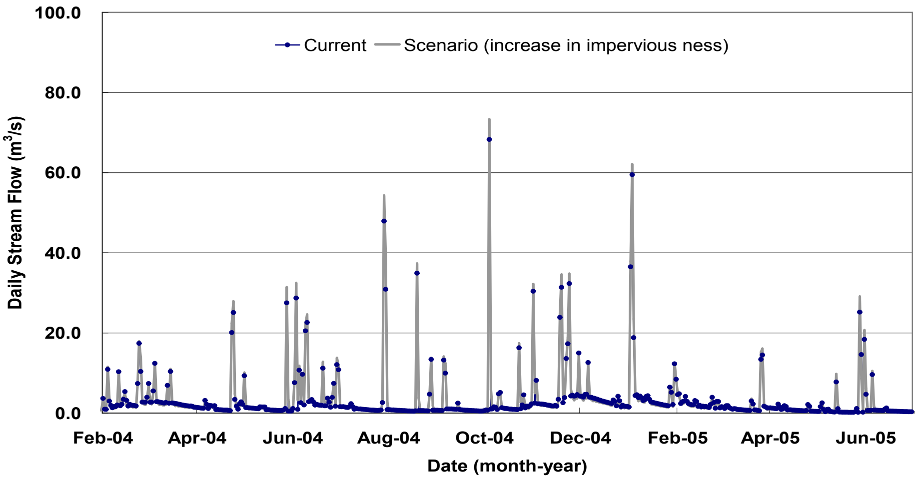
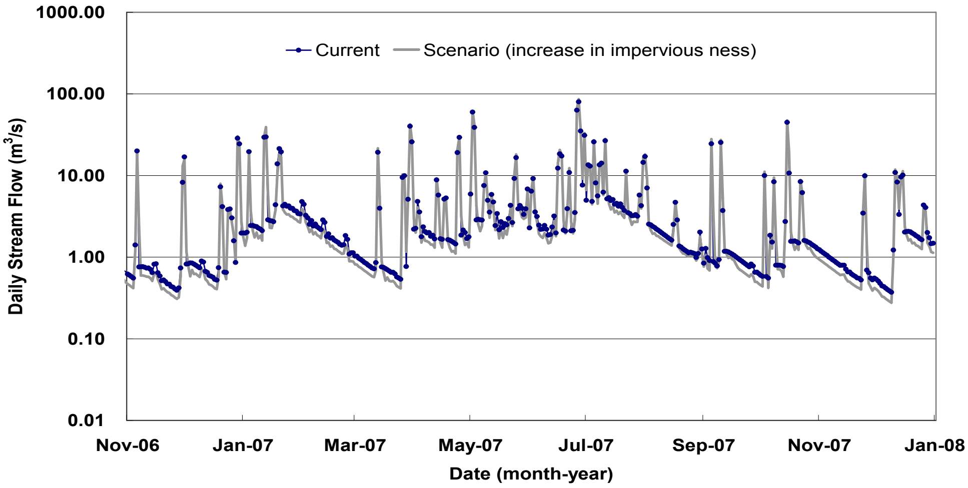


Figure 5. Effects of urbanization (increase in impervious area) on annual hydrological components



(a) 2004-2005 (highlighted high flow)



(b) 2006-2007 (highlighted low flow)

Figure 6. Effects of urbanization(increase in impervious area) on stream flow at the outlet of the watershed

Conclusion

The SWAT-SWMM model was applied to the White Rock Creek watershed in USA for assessing hydrologic impact of urbanization. The used model in the present work is an integrated continuous long-term rainfall-runoff simulation model SWAT-SWMM in which SWAT and the RUNOFF block of SWMM are bridged to better reflect the characteristics of urban watershed as well as natural watershed. Through some case studies with the SWAT-SWMM model, the urbanized effects such as increase in impervious area on the hydrological components could be evaluated. The amount of surface flow in studied area can be increased by 8% (annual increase of 30 mm) as the increase rate in impervious area reaches up to 100%. The percoloation and groundwater flow were found to be reduced to about 84% and 92% of current state, respectively. Consequently, the SWAT-SWMM model can be effectively used for composite land use area.

Acknowledgements

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B8-2

Use of SWAT for Urban Water Management Projects in Texas

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The SWAT model is being used for a number of urban water quality and storm water management projects in Texas. As a result, a number of improvements have been made in the model and in techniques used to represent urban landscapes and urban stormwater management practices, and urban water management technologies. Major activities that have recently been completed or are under way include the following:

Modeling of Urban Watersheds and Stormwater Best Management Practices (BMPs). In highly urbanized areas impervious surfaces produce rapid runoff in response to heavy rainfall. Working with the City of Austin, Texas, SWAT has been adapted and calibrated using sub-hourly time steps to simulate runoff, erosion, and sediment transport in both rural and urban watersheds around Austin. Process-based SWAT algorithms for conventional/innovative urban BMPs such as wet pond, retention-irrigation, sedimentation-filtration, and detention pond are under development to evaluate these BMPs and their impacts on downstream flooding and water quality. A guide line for modelling low impact developments (e.g., porous pavement, cistern, rain garden) will also be made in collaboration with Water Environment Research Foundation – an ongoing national BMP/LID modelling initiative.

Trinity River Basin Environmental Restoration Initiative. The Dallas-Fort Worth Metropolitan Area is home to over 6 million people, almost all of whom live in the Upper Trinity River watershed. SWAT has been used to simulate the impacts of urban development, small flood control reservoirs, and agricultural practices on nutrient and sediment loading of 12 water supply reservoirs in the area. Detailed water quality monitoring, sediment surveys, and economic modeling are being used to develop watershed protection plans for three of these reservoirs.

The North Central Texas Council of Governments developed the integrated Storm Water Management (iSWM^{TM}) design *manual* for construction, a systematic methodology for minimizing water pollution associated with construction in cities. The "Conservation Practices Modeling Guide for SWAT and APEX" has been developed to facilitate simulation of iSWM and other conservation practices with SWAT. Work has begun to facilitate simulation of these and other stormwater management practices using SWAT interface software.

Projects have recently begun to use SWAT in the design of several “new urbanism” multi-use developments, municipalities, and their extraterritorial jurisdictions.

SESSION B9

Sensitivity Calibration and Uncertainty

B9-1

Analysis of the Impacts of Spatial Input Data Quality on Determination of Runoff and Suspended Sediment in the Imha Watershed using SWAT Model

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This study attempted to assess the impacts of different spatial data quality and the efficiency of a SWAT model that was established to identify runoff and suspended sediments in the Imha watershed of the Nakdong River basin, South Korea. For the purpose of this, the impacts of five DEM grid sizes (i.e. 30m, 60m, 90m, 120m and 150m) on model inputs (e.g. geomorphologic inputs) and outputs (e.g. water budgets and sediment yields) were examined in the first place. And a further analysis was undertaken using 8 different scenarios based on the combination of 30m and 120m DEMs with different scales of land cover maps (i.e. 1:25,000 and 1:50,000) and soil type maps (i.e. 1:50,000 and 1:250,000). A statistical analysis for the goodness-of-fit tests of data measured at two field stations revealed that model efficiency improved in terms of the estimation of runoff and sediment yields when 30m resolution DEMs was used. No significant improvement in such estimation, however, was found when all finer scales of land cover and soil maps were used.

Keywords: SWAT, spatial data resolution, runoff, suspended sediment, Imha watershed.

Introduction

Model parameterization using spatial data is a standard process for specifying and testing a watershed model. An advance in computers and geographic information system (GIS) has made it possible to describe watershed characteristics through modeling based on automated spatial analysis scheme.

There are several previous studies on the quality of spatial input data used in watershed modeling. Chaplot et al. (2005) assessed the impacts of DEM grid size and soil map scale on the determination of runoff, sediment and NO_3-N in one of agricultural basins in the USA using Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2000). Di Luzio et al. (2005) analyzed the sensitivity of spatial input data using uncalibrated SWAT for runoff and suspended sediment simulations. They found that DEM resolution contributed to the description of watershed, sub-basins and geological attributes that would, consequently, alter model prediction. In this study, the authors reported that the impacts of land cover maps were greater than those of soil maps; actually, this finding is the opposite of Chaplot (2005). This can be explained by the fact that hydrologic and water-quality processes are determined by the representative, unique characteristics of each basin.

The principal purpose of this study is to conduct a quantitative analysis to assess the quality level of input data required for establishing a SWAT model. Based on sensitivity analyses to propose how to adequate input data, model efficiency focused on runoff and sediment yields monitored in the Imha watershed in Korea that had frequently suffered from the issues of water turbidity.

Modeling and Assessment Method

Modeling for the Imha Watershed

The Imha watershed is located upstream of the Banbyon stream, one of the primary tributaries of the Nakdong River in Korea (Figure 1). The Imha multipurpose reservoir has been operated to meet various water uses (e.g. irrigation water, industrial water, etc.) for residential area downstream of the Nakdong River since its construction in 1982. The watershed is mostly occupied by forest area (79.8 % of catchment area in total) which has still conserved relatively natural conditions without excessive anthropogenic activities.

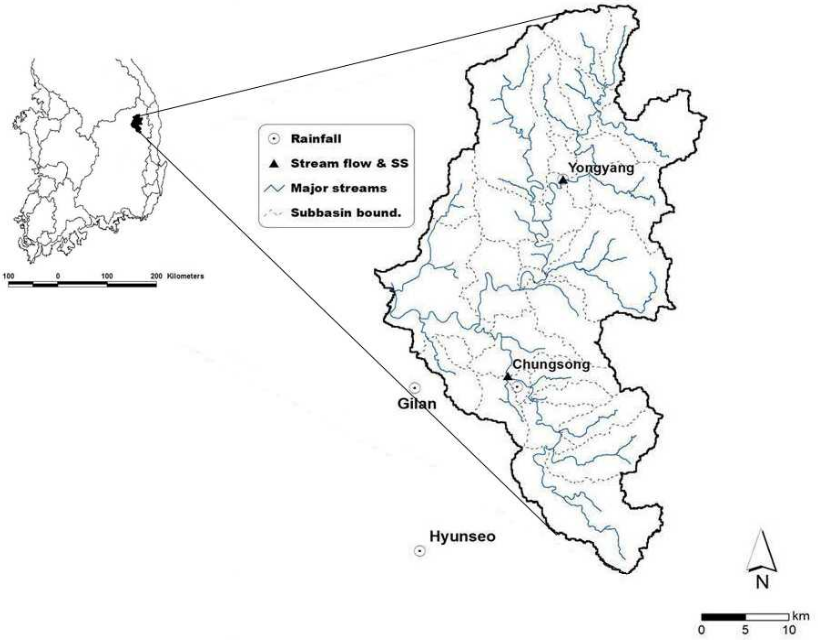


Figure 1. Location of study area with gauging stations, stream flow and suspended sediment

As shown in Figure 1, the watershed was subdivided into 28 sub-basins based on stage (i.e. water level) gauging stations and other major streams. Geographic data (including 30m DEM, land cover maps (1/25,000 and 1/50,000), and soil maps (1/50,000 and 1/250,000)) were collected using Water Management Information System (WAMIS) (http://www.wamis.go.kr), and meteorological data covering 8 years (from January 1, 1999 to October 12, 2006) were collected from the Andong Weather Station. Daily rainfall data were collected from 5 rainfall gauging stations.

Figure 2 shows land use & land cover (LULC) data for the target watershed through two different scales of maps (i.e. 1:50,000 and 1:25,000). The biggest difference between the two scales of maps lies in the division of a forest: the latter scaled map divides the forest into 3 sub-categories (i.e. deciduous, evergreen and mixed), while the former scaled map assumes the entire forest as a single group of mixed forestry. Similar to the case with soil maps, a

1:50,000-scaled one accommodates 33 soil types. This is 3 times as much detailed as a 1:250,000-scaled one. Figure 3 shows that Major soil types in the watershed include litho soil, sedimentary materials (MS : 59.2%); alluvial soil, river wash, floodplain (Af : 4.8%); and complex of soil and narrow valleys (An : 12.0%). They are found along the channel as shown in Figure 3. Tables 1 and 2 show soil types in a 1/250,000-scaled map and a 1/50,000-scaled map, respectively.

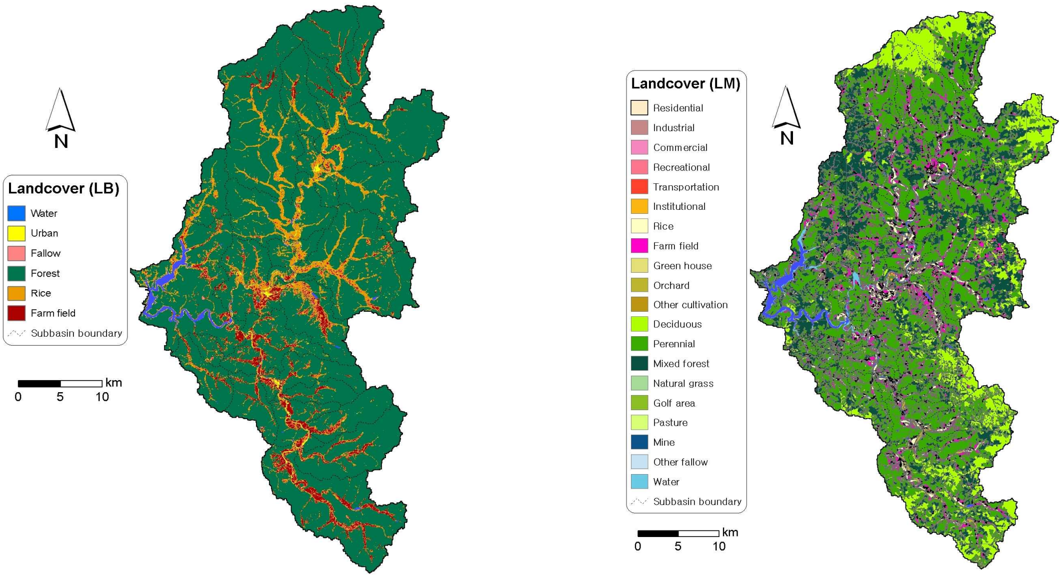


Figure 2. Land cover distributions in the Imha watershed at different scales: 1/50,000 (left, LB) and 1/25,000 (right, LM)

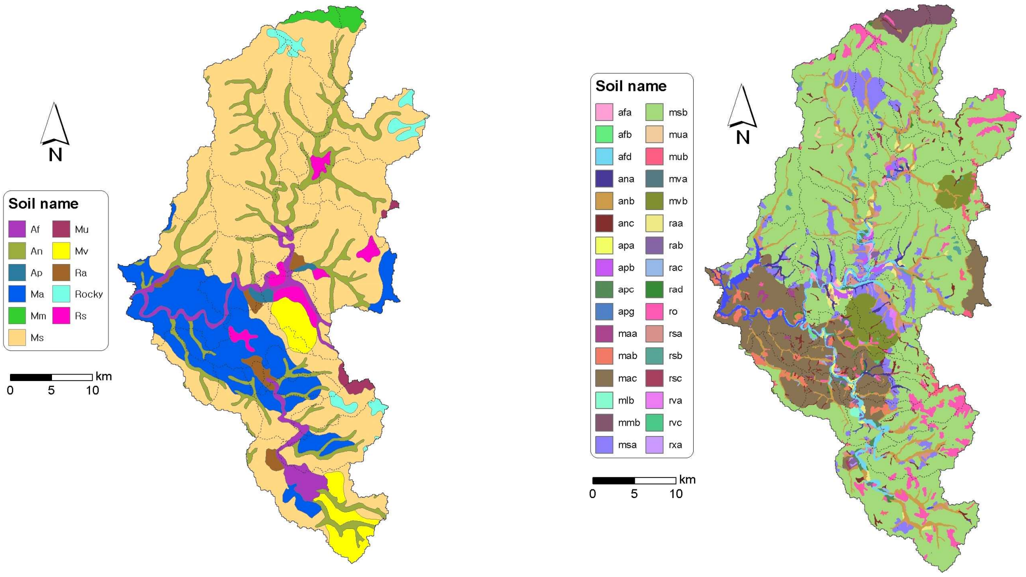


Figure 3. Soil type distributions in the Imha watershed at different scales: 1/250,000 (left, SB) and 1/50,000 (right, SM)

Runoff simulation was carried out for the period of 2000 to 2006; 1999 was assumed as a start-up period. A flow depth & rate curve estimated at the station points (including the Chongsong Gauging station and the Yongyang Gauging station with data coverage of 2003 and 2004, respectively) was used to assess modeling results. And then, the model prediction of suspended sediments was compared with that of measured data focusing on the qualitative analysis of time variations in suspended sediments, due to of a lack of sampling continuum.

The following statistical indexes were used to assess the runoff prediction of the model:

Results and Discussion

Impacts of Soil Types, Land Use and DEM Resolution

The impacts of DEM resolution on model response was analyzed with various DEM grid sizes in the first place since DEM data were regarded as the most basic spatial input data in assessing the prediction of runoff components and suspended sediments. The coefficients of variation (CV) were estimated at the final outlet of the Imha watershed using 5 different DEM resolutions. For the purpose of this analysis, the scale of land use and soil maps was fixed at 1: 250,000. Table 1 shows major parameters used for sensitivity analyses.

Table 1. Major parameters of SWAT model analyzed in this study

Name	Definition
SOL_Z	Depth from soil surface to bottom of layer
SOL_BD	Moist bulk density (cm^{-3})
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)
SOL_K	Saturated hydraulic conductivity (mm/h)
USLE_K	USLE equation soil erodibility (K) factor
HRU	Multiple hydrologic response unit number
SURQ	Surface runoff (mm)
LATQ	Lateral flow contribution to reach (mm)
GWQ	Groundwater discharge into reach (mm)
WYQ	Net water yield to reach (mm)
SYL	Sediment yield (ton/ha)

The results of a simulation based on 30m-DEM combined with a 1:250,000-scaled land use map and 2 different scales of soil maps are summarized in Table 4. As seen in the table, the number of Hydrologic Response Units (HRUs) generated with low and high resolutions are 605 and 1,567, respectively. This would give detailed, high-scaled soil maps to generate approximately 2.6 times more than otherwise. The values of SOL_Z and USLE_K increase with a lower resolution of soil map, while those of SOL_BD, SOL_AWC and SOL_K tend to increase with a higher resolution of soil map. It's general that, in soil structure, larger AWC and SOL_K tend to increase evapotranspiration and lateral runoff, while smaller SOL_Z and SOL_BD tend to reduce them (Kim et al, 2008). Thus, simulations using a higher-scaled soil map will result in an increase in lateral flow, with the ones using a lower-scaled map showing a decrease in evapotranspiration. Higher suspended sediment yields are expected with SB than with SM. This is because a relatively higher USLE_K is expected with the former, as shown in Table 2.

Table 2. Estimated area-weighted soil parameters and HRUs from the two soil data

Scale	SOL_Z mm	SOL_BD g/cm^3	SOL_AWC mm/mm	SOL_K mm/hr	USLE_K	HRU
SB(1:250,000)	590.70	1.38	0.09	36.41	0.17	607
SM(1:50,000)	358.97	1.44	0.10	43.70	0.14	1,567

Tables 3 and 4 shows the percentages of land cover types in 1:50,000-scaled and 1:25,000-scaled maps, respectively. In the former map, the whole area is classified into forestry (79.80 %), farm fields (11.63 %), and rice fields (3.34 %). In the latter map, forestry is sub-divided into 3 different types (i.e. deciduous (14.87%), pine (44.76%), and mixed (20.17%)). And further, the percentage of farm field decreases to 10.1% with a more detailed land cover configuration. When the 1:25,000-scaled land cover map was combined with 30m-DEM and the 1:250,000 –scaled soil map, the number of HRUs increased from 607 to 1,339. A mean of areal CN values computed slightly increases from 69.1 to 73.4 with a detailed land cover configuration. This indicates that a finer land cover configuration would increase surface runoff and sediment yields. The values of USLE_C increased from 0.057 to 0.084, and consequently, would contribute to an increase in suspended sediments.

Table 3. Area percentage of each land cover estimated in 1:50,000-scaled map

Class	Area (%)	Class	Area (%)	Class	Area (%)	Class	Area (%)
Urban	0.88	Wetland	10.1	Forest	0.88	Farm field	10.1
Follow	0.02	Pasture	0.03	Rice	0.02	Water	0.03

Table 4. Area percentage of each land cover estimated in 1:25,000-scaled map

Class	Area (%)	Class	Area (%)	Class	Area (%)
Residence	0.88	Paddy	3.34	Deciduous forest	14.87
Industry	0.02	Farm field	10.1	Evergreen forest	44.76
Commercial	0.05	Vinyl house	0.03	Mixed forest	20.17
Recreation	0.00	Orchard	1.43	Pasture	0.40
Transportation	0.34	Other crops	0.07	Wetland	0.45
Institutional	0.08	Fallow	0.61	Water	2.4

Figure 4 shows the slopes of the Imha watershed based on different DEM resolutions (i.e. 30m, 60m, 90m, 120m and 150m). As seen in the figure, it's evident that a higher resolution gives steeper slopes (as illustrated in a white color), while a lower resolution does gentle slopes (in black), especially, in the southern of the watershed.

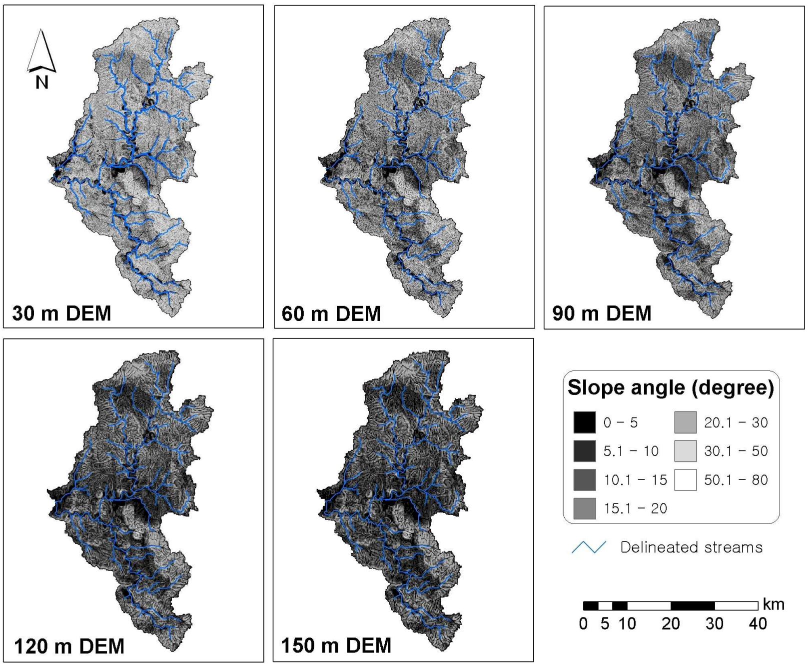


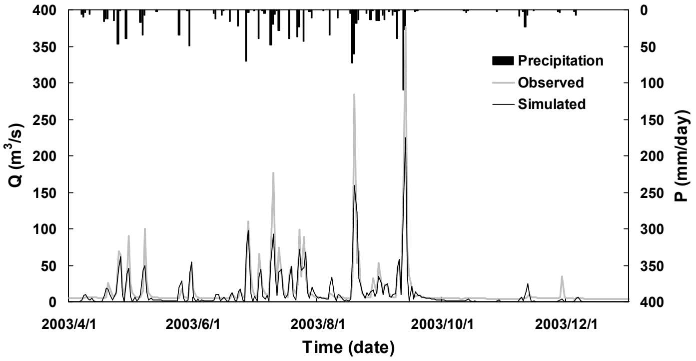
Figure 4. Estimated slope angle variations based on five DEM resolutions in the Imha watershed (a white color shows steeper area)

Effects of Spatial Resolution on the Prediction of Runoff and Suspended Sediment

Each model was calibrated using the same method as the case with automatically-generated spatial input data. CN values were estimated by referring to soil and land cover conditions. In this estimation, the geographic characteristics of Korea and the effects of slope on each HRU were also taken into account (Williams, 1995).

Channel length and sub-basins were determined under the condition of 600ha in threshold area. Figure 5 shows the results of runoff simulations based on the combination of a 1:50,000-scaled land cover map with 1:250,000-scaled soil map. The prediction of suspended sediments was assessed using data measured during the 3 large rainfall events (that occurred in July, 2006), as shown in Figure 6.

(a)



(b)

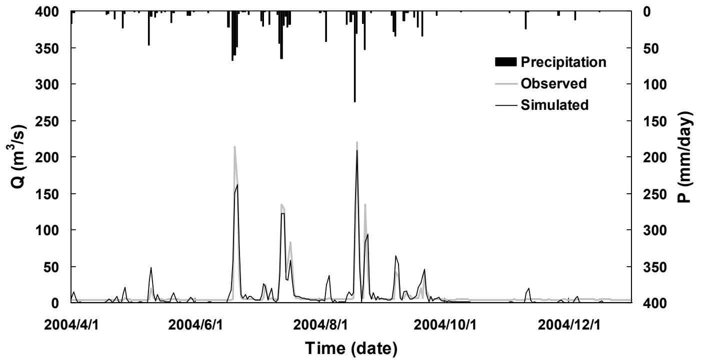


Figure 5. Results of runoff simulations in 2003 (Chongsong) and 2004 (Yongyang) (a) Chongsong Gauging station, (b) Yongyang Gauging station

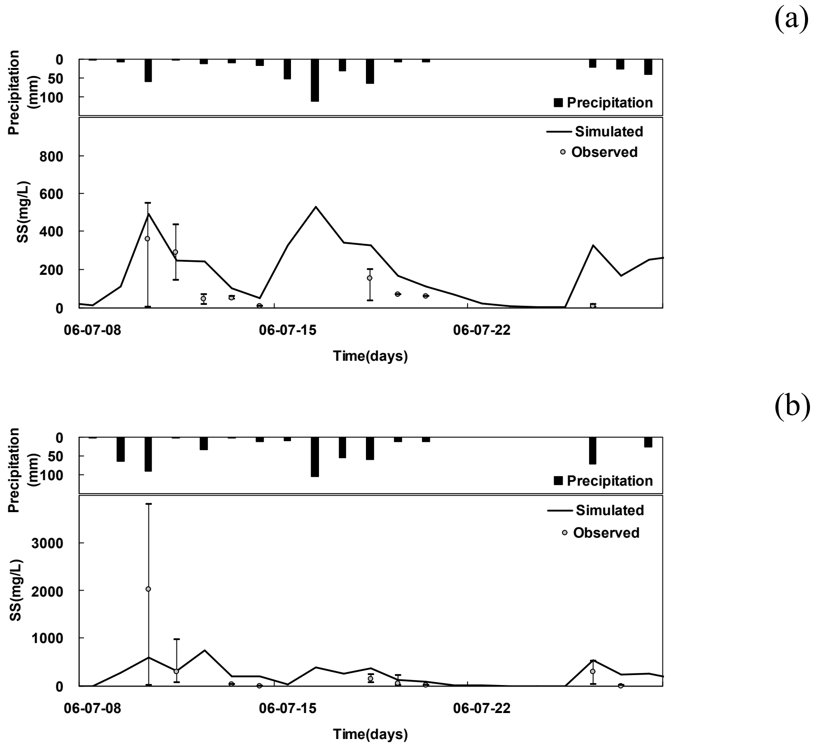


Figure 6. Results of SS simulations (Chongsong and Yongyang) (a) Chongsong Gauging station(b) Yongyang Gauge Staton

To identify the impacts of DEM, Cases 1, 2, 3, and 4 were compared with Cases 5, 6, 7 and 8, respectively. With a finer DEM size, the prediction efficiency of runoff at the Chongsong Gauging station increased by 0.35, 0.4 and 6 percents for R_{eff}, RMSE and R^2, respectively. In the comparison of Case 1 with Case 5, and Case 2 with Case 6. But the comparison of Case 3 with Case 7 revealed that such prediction efficiency decreased, significantly, by 34, 21 and 45 percents for R_{eff}, R^2 and RMSE, respectively. When it comes to the Yongyang Gauging station, it was clear that the application of a finer DEM size increased model efficiency by 20%, 22%, 36% and 80% for R_{eff}, R^2, RMSE and V_E, respectively, in the subsequent comparison of Cases 1 to 4 with Cases to 5 to 8 as shown in Figure 7.

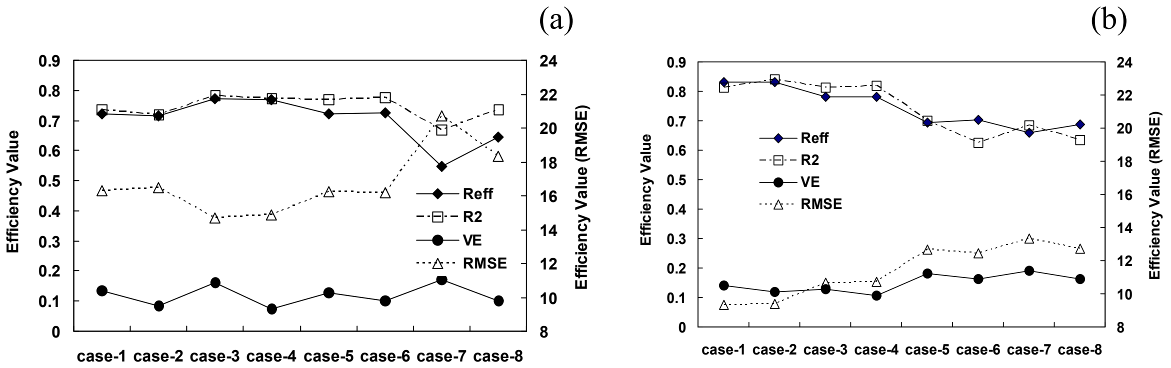


Figure 7. Efficiencies of flow prediction for different cases (a) Chongsong Gauging station(b) Yongyang Gauging station

The impacts of land uses can be identified through the comparison of Case 1 with Case 3; Case 2 with Case 4; Case 5 with Case 7; and Case 6 with Case 8. Model efficiency showed a tendency to statistically decrease by 5 to 19 percents at the Yongyang Gauging station with a coarser scaled land use map. At the Chongsong Gauging station, however, model efficiency increased by 7, 8.4 and 9.2 percents in the comparison of Case 1 with Case 3 and Case 2 with Case 4, while decreased by 21.6, 13 and 24.4 percents for R_{eff}, R^2 and RMSE, respectively.

The impacts of resolution in a soil map can be explained, possibly, by comparing Case 1 with Case 2; Case 3 with Case 4; Case 5 with Case 6; and Case 7 with Case 8. Model efficiency improved by 13 percents on the average, only for V_E, when a coarser scaled soil map was used, while it showed a tendency to neither increase nor decrease for other statistical indexes. Model efficiency has increased by 42 percents only for V_E.

Discussion

This study attempted to assess the impacts of spatial input data (e.g. DEM, land cover, soil map) on runoff and suspended sediment simulation. The results showed that DEM grid size was the most sensitive factor, and that a detailed soil map or land cover map didn't necessarily improve simulation results in terms of statistical implications. The modeling efficiency of R_{eff} was found to be relatively high, even with a minimum of calibration, although it decreased from 0.7~0.8 to 0.6~0.7. This is because the SWAT model enabled the computation of surface runoff using SCS curve number method; in this method, low weights are given to surface storage, interception, infiltration and retention in terms of geomorphology (Chaplot, 2005). The most important reason the efficiency of model simulations decreases with a higher resolution of soil map or land cover map is attributable to a relatively large area of the watershed. This contributes to an increase in uncertainties in parameter estimation, and consequently, a high-scaled map increases errors in the attributes of soil and land cover database.

Similar to the case with runoff, the efficiency of suspended sediment prediction varies depending on different DEM resolutions, and shows an even more significant tendency when compared with that of runoff prediction. This is because sediment runoff shows a higher nonlinearity than rainfall runoff, and SWAT employs MUSLE method that includes slope and slope length for suspended sediment assessment.

Conclusion

Model parameterization using spatial input data is a standard process for specifying and testing a watershed model. In this study, the impacts of different spatial data quality were assessed to enhance the efficiency of a SWAT model that was employed to develop a turbidity management system for the Imha watershed of the Nakdong River basin, South Korea.

Among required geographic information in the model, the impacts of five DEM grid sizes (i.e. 30m, 60m, 90m, 120m and 150 m) on model inputs (e.g. geomorphology) and outputs (e.g. water budgets and sediment yields) were examined in the first place. The values of CV (coefficient of variation) based on five different grid sizes ranged from 0.037 (for channel length) to 1.021 (for slope length in terms of geomorphology), and from 0.058 (for water yields) to 0.613 (for lateral flow in terms of water budgets) or 0.680 (in sediment yields).

A further analysis was conducted using 8 scenarios based on the combination of 30m and 120m DEMs with different scales of land cover maps (1:25,000 and 1:50,000) and soil maps (1:50,000 and 1:250,000). The results of goodness-of-fit (estimated using four methods and data observed at the two field stations) were found to be better in terms of model efficiency (related to the estimation of runoff and sediment yields) when 30m DEM was used. But no significant improvements were found in the combination of all finer scales of land cover and soil data. This indicates that model users should be aware of the sensitivity of DEM resolution, and that more efforts are required in estimating slope length and calibrating subsurface flow and sediment yields.

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B9-2

Calibration of a SWAT Hydrologic Model for the Tamer Watershed in Northern Iran

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SWAT2005 (Soil and Water Assessment Tool) was used to simulate runoff and investigate the effect of various rain-gauge stations on the results of the model in Tamer watershed in northern Iran. The calibrated model will be used to predict the impact of different management operations on the runoff, sediment, and nutrient loads in the 1524 km^2 watershed. SUFI2 version 2.1.5 was used to calibration and performs uncertainty analysis of the model. The watershed studied included two climate and rain gauge stations Tamer and Golidagh. Tamer is located at the very end of the watershed and Golidagh is located at the top of the watershed. The model was run with Golidagh rain gauge station for the years 1999-2005 and with Tamer rain gauge station for the years 1990-1993. The calibration and validation of the model was performed for the years 1990-1993. The results showed that the model had reliably simulated runoff in both of stations. Four factor were considered in judging the model performance of runoff: *P-factor*, *R-factor*, R^2 and *NS*. The respective values of each were, respectively, 0.65, 1.2, 0.55 and 0.55 for calibration and 0.56, 1.2, 0.77 and 0.7, respectively for validation.

KEYWORDS: SWAT, uncertainty analysis, SUFI-2, runoff, rain gauge station, Iran

Introduction

Soil erosion causes economic, social and environmental problems. According to past studies, Asia suffers more than other continents from soil erosion, and Iran is one of the worst affected countries in Asia (Dregne, 1992; FAO, 1994). The mean annual erosion rate in Iran is estimated to be about 2500 t km^{-2}, which is 4.3 times more than the mean erosion rate in the world (Ahmadi et al., 2003). Also, available information shows that 59% of 17 large basins studied in Iran have been severely degraded (Ahmadi et al., 2003).

In recent years, mathematical models of watershed hydrology and transport processes have been employed to address a wide spectrum of environmental and water resources problems. The Soil and Water Assessment Tool, SWAT, (Arnold et al., 1998) was developed to predict the effects of different management practices on water quality, sediment yield and pollution load in watersheds. This is a computationally efficient simulator of hydrology and water quality at various scales. The program has been used in many international applications (Arnold and Allen, 1996; Narasimhan et al., 2005; Gosain et al., 2006; Abbaspour et al., 2007; Yang et al., 2007; Schuol et al., 2008a, b; Faramarzi et al., 2009). Arnold et al. (2000) applied SWAT with the addition of a streamflow filter and recession methods for regional estimation of baseflow and groundwater recharge in the upper Mississippi River basin. The results showed a general tendency for SWAT to under-predict spring peaks and to overestimate autumn streamflow compared to measured monthly data during both calibration and validation periods. Abbaspour et al. (2007) used SWAT to simulate all related processes affecting water quantity, sediment and nutrient loads in the Thur watershed in Switzerland. Their study indicated excellent results for discharge and nitrate, and quite good results for sediment and total phosphorus.

Very little information is available on sediment and river discharge in northen Iran therefore the main goal of this study is to model sediment and river discharge at Tamer watershed. To model sediment yield we intended first to calibrate hydrology while tuning discharge related parameters. Considering the fact that in the Tamer watershed hydrometric station, the sediment data were measured once or twice a month, the model was calibrated mostly using daily discharge data and then sediment parameters were slightly tuned for a better sediment simulation result.

As distributed hydrological modeling is subject to large uncertainties, the definition and quantification of model uncertainty has become the subject of considerable research in recent years. To fulfill this demand, researchers have developed various calibration-uncertainty analysis techniques for watershed models. These include Bayesian inference methods, such as: the Markov chain Monte Carlo (MCMC) method (Kuczera & Parent, 1998; Vrugt et al., 2003; Yang et al., 2007); generalized likelihood uncertainty estimation (GLUE) (Beven & Binley, 1992); parameter solution (ParaSol) (van Griensven & Meixner, 2006); and sequential uncertainty fitting (SUFI-2) (Abbaspour, et al., 2007). We used the program SUFI-2 in the SWAT-CUP package (SWAT Calibration Uncertainty Programs) (Abbaspour, et al., 2010) to calibrate the Tamer model.

Material and Methods

Description of the study area

The Tamer watershed, with an area of about 1524 km^2, is located in the north-east of the Gorganrud basin in Golestan province in Iran (Figure 1). The elevation ranges from 132 m at the outlet of the watershed to 2141 m in the mountainous areas. The mean annual temperature is 17.8°C and the mean annual precipitation is 496.4 mm. approximately 50% of the land is used for agriculture. The major crops are wheat and watermelon. More than 30% of the watershed is covered by forest, and the small part is covered by pasture and orchard.

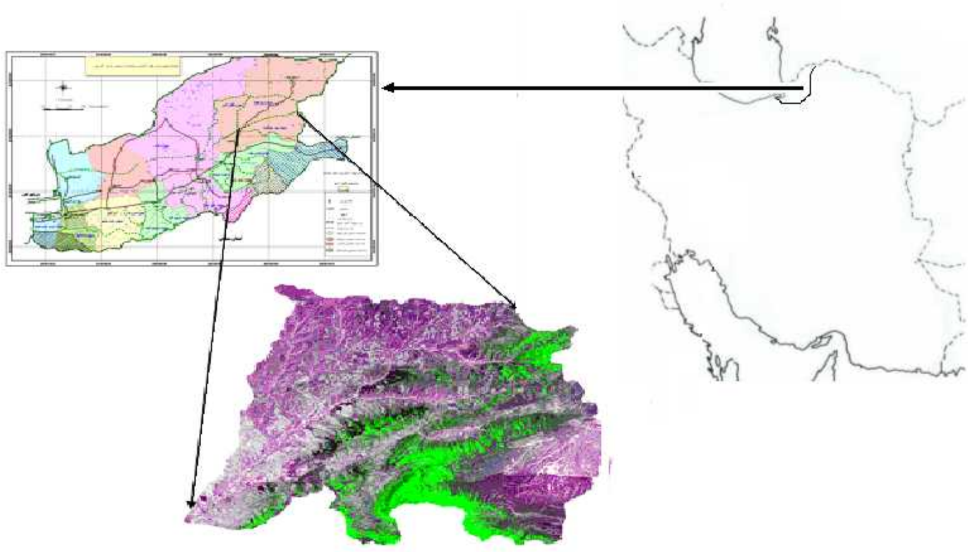

Figure 1 . Location of the Tamer watershed

Description of SWAT

SWAT is a basin-scale, continuous time model that operates on a daily time step and evaluates the impact of management practices on water, sediment and agricultural chemical yields in ungauged basins (Arnold et al., 1998). The model's major components include weather, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing. In SWAT, the watershed is divided into multiple sub-basins, which are then further sub-divided into hydrological response units (HRUs). These units consist of homogeneous landuse, management and soil characteristics. The water balance of each HRU is represented by four storage volumes including: snow, soil profile (0–2 m), shallow aquifer (typically 2–20 m) and deep aquifer (>20 m). The SWAT provides two methods for estimating surface runoff: the SCS curve number and the Green-Ampt infiltration method. In this study, we used the SCS curve number method. The peak runoff is an indicator of the erosive power of a storm and is used to predict sediment loss. The SWAT calculates the peak runoff rate with a modified rational method (Chow et al., 1988). Lateral subsurface flow in the soil profile (0–2 m) is calculated simultaneously with percolation. A kinematic storage routing that is based on the degree of slope, slope length and saturated hydraulic conductivity is used to predict lateral flow in each soil layer. Lateral flow occurs when the storage in any layer exceeds field capacity after percolation. Groundwater flow contribution to total streamflow is simulated by creating shallow aquifer storage (Arnold & Allen, 1996). Percolation from the bottom of the root zone is considered as recharge to the shallow aquifer. In SWAT, there are three methods for estimating potential evapotranspiration: Priestley & Taylor (1972), Penman-Monteith (Monteith, 1965) and Hargreav & Samani (1985). Water flow is routed through the channel network using the variable storage routing method or the Muskingum river routing method. Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by Williams & Berndt (1977).

Description of SUFI-2

In this research, various SWAT parameters related to discharge were estimated using the SUFI-2 algorithm (Abbaspour et al., 2007). In SUFI-2, uncertainty is defined as the discrepancy between measured and simulate variables. To account for this uncertainty, we therefore need to capture the measured data, except the outliers, in the predicted results. Therefore, SUFI-2 combines calibration and uncertainty analysis to find parameter uncertainties that result in prediction uncertainties bracketing most of the measured data, while producing the smallest possible prediction uncertainty band. Hence, these parameter uncertainties reflect all sources of uncertainties, i.e. conceptual model, inputs (e.g. rainfall), and parameter. In SUFI-2, uncertainty of input parameters is depicted as a uniform distribution, while model output uncertainty is quantified at the 95% prediction uncertainty (95PPU). The cumulative distribution of an output variable is obtained through Latin hypercube sampling. The SUFI-2 model starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially fall within the 95PPU, then decreases this uncertainty in steps while monitoring the *P-factor* and the *R-factor*. The *P-factor* is the percentage of data bracketed in the 95% prediction uncertainty (95PPU) calculated at the 2.5% and the 97.5% intervals of the simulated variables. This factor indicates the goodness of the calibration result. The *R-factor*, on the other hand, captures the level of uncertainty of the calibrated model, as a smaller 95PPU band indicates smaller model uncertainty. In each iteration, previous parameter ranges are updated by calculating the sensitivity matrix, and the equivalent of a Hessian matrix (Neudecker & Magnus, 1988), followed by the calculation of a covariance matrix, 95% confidence intervals of the parameters, and a correlation matrix. Parameters are then updated in such a way that the new ranges are always smaller than the previous ranges, and are centered around the best simulation (for more detail see Abbaspour et al., 2007). Because this analytical approach considers a band of model solutions (95PPU) instead of a best fit solution, the goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the above two measures instead of the usual R^2 or Nash-Sutcliffe coefficient NS (Nash & Sutcliffe, 1970), which only compare two signals. An ideal situation would lead to a *P-factor* approaching 100% and an *R-factor* approaching zero. In the current study, we used Arc-SWAT (Olivera *et al*., 2006), where ArcGIS (version 9.2) environment is used for project development. Spatial parameterization of the SWAT model is performed using SUFI-2 for a combined calibration and uncertainty analysis of the SWAT models.

Model parameterization and application

The SWAT-CUP program allows parameter aggregation on the basis of hydrological group, soil texture, land use, sub-basin number, and slope formulated as:

x__<parname>.<ext>__<hydrogrp>__<soltext>__<landuse>__<subbsn>__<slope>

where x__ is a code to indicate the type of change to be applied to the parameter. If replaced by v__ it means the default parameter is replaced by a given value; while a__ means a given quantity should be added to the default value, and r__ means the existing parameter value is multiplied by (1 + a given value); <parname> is the SWAT parameter name; <ext> is the SWAT file extension code for the file containing the parameter; <hydrogrp> is the soil hydrological group (A, B, C or D); <soltext> is the soil texture; <landuse> is the landuse category; <subbsn> is the sub-basin number, and <slope> is the slope delineation. Any combination of the above factors can be used to describe a parameter identifier, thus providing the opportunity for a detailed parameterization of the system. Omitting the identifiers <hydrogrp>, <soltext>, <landuse>, <subbsn>, and <slope> allows global assignment of parameters.

The data used in study are as follows:

i. Digital elevation model (DEM) obtained from the Golestan regional water office with a spatial resolution of 50 m

ii. Digital stream network at the 1:75 000 scale, produced by the Natural Resources Department of the Cartographic Centre of Iran

iii. Soil and landuse maps, at a scale of 1:100 000, produced by the Natural Resources Department of the Cartographic Centre of Iran. The soil map includes 17 types of soil.

iv. Climate data records from 2 rain gauges and 1 air temperature gauges over a period of 16 years (1990–2005); data were obtained from the Golestan regional water office.

The Tamer watershed was subdivided into 23 sub-basins and 94 HRUs. The model was calibrated twice. Once using Golidagh rain gauge station in 1999-2005 period and the second time by using Tamer rain gauge station in 1990-1993 period. Data from the Tamer hydrometric station in the Tamer watershed were used for calibration in 1999-2005 and validation in 1990-1993. In Tamer watersheds, the Hargreaves method was used to estimate evapotranspiration, and the Muskingum routing method was selected to route water through the channel network. The SWAT model was initially calibrated based on the monthly measured discharge data. The objective function was formulated using the *NS* coefficient. Sediment data were based on collected grab samples, which were used to measure suspended solids. Because these grab samples were the only available data for model calibration, the main calibration was performed using discharge data and then by fitting sediment parameters to obtain a better sediment simulation

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Results and discussion

An initial sensitivity analysis resulted in the choice of parameters that were calibrated as listed in Table 1. The results of monthly discharge calibration at Tamer are shown in Figure 2. *R-factor*=1.2, *P-factor* =0.65, *NS*=0.56, and R^2= 0.56, which represent a good calibration result.

An extreme flow event in August 2005 was underestimated but other peaks were satisfactorily captured. Error in the rainfall input data may be one reason for underestimation. The model in March and April overestimates the flow because irrigating extractions from the streams in the watershed were not properly accounted for because of lack of information. Validation results are shown in Figure 3 where the statistics of *P-factor*=0.56, *R-factor*=1.2, R^2=0.77, and *NS*=0.70 indicate adequate validation results.

In the next step we calibrated daily discharge in preparation for sediment calibration. In this attempt the model clearly does not reproduce the extreme events as illustrated in Figure 4. For daily discharge calibration, we obtained *NS*=0.1, R^2=0.1, *R-factor*=0.49, and *P-factor*=0.6. For the validation period in Figure 5, we obtained *NS*=0.3, R^2=0.38, *R-factor*=0.68, and *P-factor*=0.5. The reason of the low coefficient for *NS* is the weakness of the model in simulating the peak runoff. As these were the best daily calibration results, we used this model to simulate sediment. The following statistics were obtained for sediment calibration (Figure 6): *P-factor*=0.5, *R-factor*=0.42, *NS*=0.13, and R^2=0.13, and for validation (Figure 7) we obtained *P-factor*=0.36, *R-factor*=0.03, *NS*=0.07, and R^2=0.82. A reason for the inability of SWAT to model sediment peaks properly is that the flow peaks were not represented well in the model s well as the loess nature of the soil, which erodes quite easily. In the next step we will consider using hourly rainfall to better capture the short duration high intensity rainfall events characteristic of the region.

Table 1. Description of SWAT2005 input parameters selected for runoff and sediment calibration

*Parameter names**	*defenition*	*Initial range*		*Final range*	
		min	max	min	max
r__CN2.mgt	SCS runoff curve number for moisture condition II	-0.3	0.5	-0.87	-0.47
r__CN2.mgt	SCS runoff curve number for moisture condition II	-0.5	0.3	-0.5	-0.3
r__SOL_BD().sol	Soil bulk density (g/cm^3)	0.04	0.3	-0.13	0.26
r__SOL_BD().sol	Soil bulk density (g/cm^3)	-0.1	0.1	-0.19	-0.09
r__SOL_AWC().sol	Soil available water storage capacity (mmH$_2$O/mm Soil)	0.4	1.4	0.15	0.55
r__SOL_AWC().sol	Soil available water storage capacity (mmH$_2$O/mm Soil)	-1.0	-0.7	-0.96	-0.76
r__SOL_K().sol	Soil conductivity (mm/hr)	0.15	1.15	0.62	1.02
r__SOL_K().sol	Soil conductivity (mm/hr)	-1.0	-0.03	-0.65	-0.25
v__ALPHA_BF.gw	Base flow alpha factor (days)	0.0	0.5	0.04	0.12
v__ALPHA_BF.gw	Base flow alpha factor (days)	0.0	0.5	0.26	0.46
v__RCHRG_DP.gw	Deep aquifer percolation factor	0.0	1.0	0.0	0.08
v__RCHRG_DP.gw	Deep aquifer percolation factor	0.0	1.0	0.9	1.0
v__EPCO.hru	Plant uptake compensation factor	0.07	0.7	0.01	0.05
v__ESCO.hru	Soil evaporation compensation factor	0.5	1.0	0.74	0.94
v__OV_N.hru	Manning,s n value for overland flow	0.01	0.7	0.39	0.59
v__CH_N2.rte	Manning,s n value for the main channel	0.09	0.22	0.05	0.13
v__CH_K2.rte	Effective hydraulic conductivity in the main channel (mm/hr)	122.0	216.0	187.0	227.0
v__SPCON.bsn	Channel sediment routing	0.001	0.01	0.006	0.007
v__SPEXP.bsn	Exponent for calculating sediment re-entrained in channel	1.0	1.5	1.17	1.25
v__PRF.bsn	Peak factor for sediment routing channel	0.0	2.0	0.65	0.85
v__APM().bsn	Peak factor for sediment routing sub-basin	0.5	2.0	0.7	1.0
v__CH_EROD.rte	Channel erodibility factor	0.0	0.6	0.25	0.35
v__CH_COV.rte	Channel cover factor	0.0	1.0	0.2	0.3
r__USLE_K().sol	USLE soil erodibility factor	0.0	0.65	0.01	0.3
r__USLE_K().sol	USLE soil erodibility factor	0.0	0.65	0.2	0.4

* v__: means the default parameter is replaced by a given value, and r__: means the existing parameter value is multiplied by (1 + a given value)

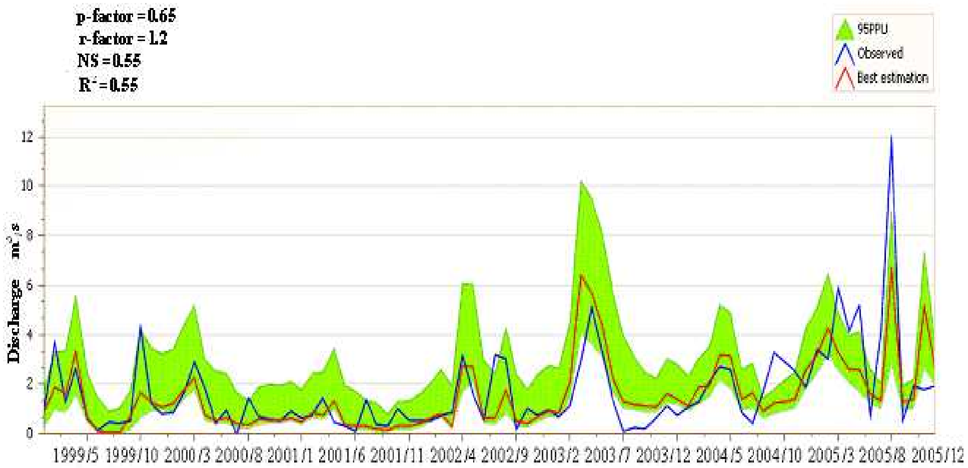

Figure 2. Monthly calibration results

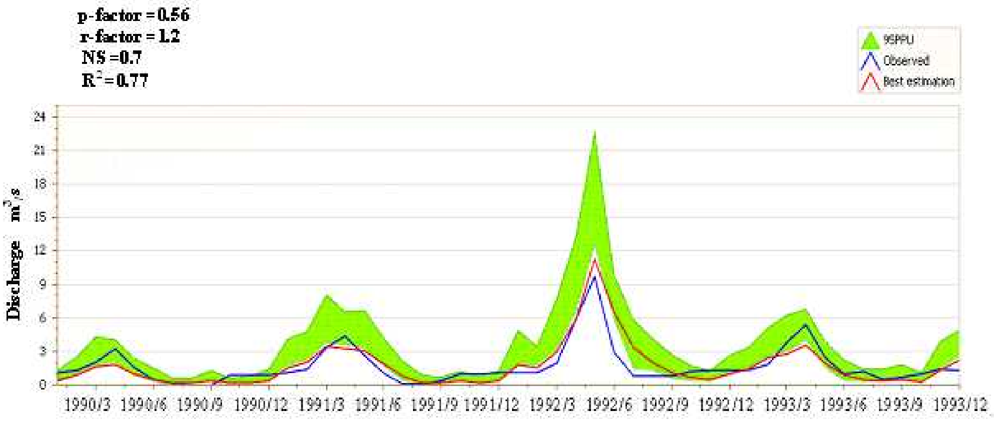

Figure 3. Monthly validation results

Conclusion

The SWAT model was applied to Tamer watersheds in northern Iran to predict runoff and sediment. Monthly calibration and validation of discharge was quite satisfactory. However, daily calibration and validation of discharge produced unsatisfactory accounting of the peak flows. The daily model was further used to simulate sediment. After calibrating for influential sediment parameters, the model results were still not satisfactory. We concluded that the main reason for poor sediment results is the poor capturing of the storm peaks by the flow model, which in turn results from the inadequate description of the rainfall in the region. In further research we will use hourly rainfall data to better capture the extreme frontal rainfall events characteristic of the region.

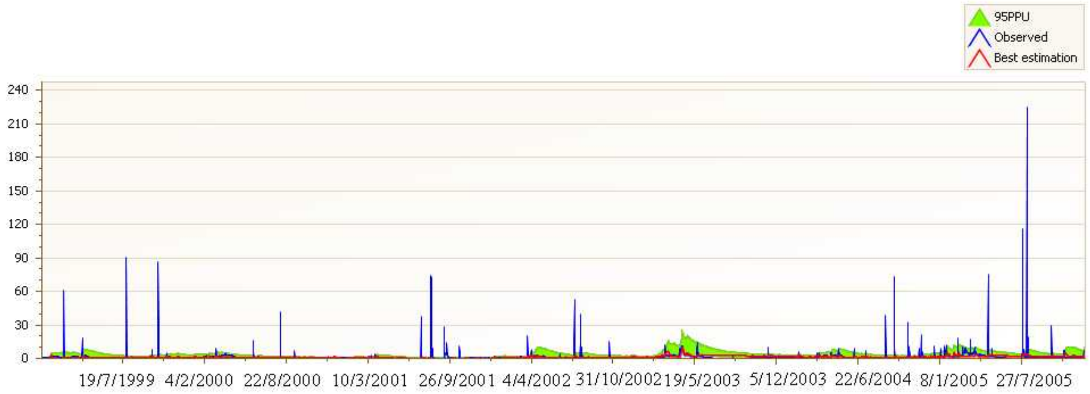

Figure 4. Daily river discharge calibration

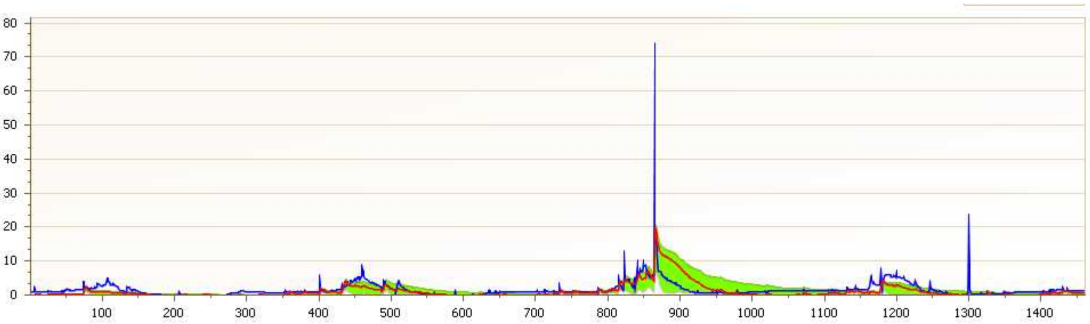

Figure 5. Daily river discharge validation

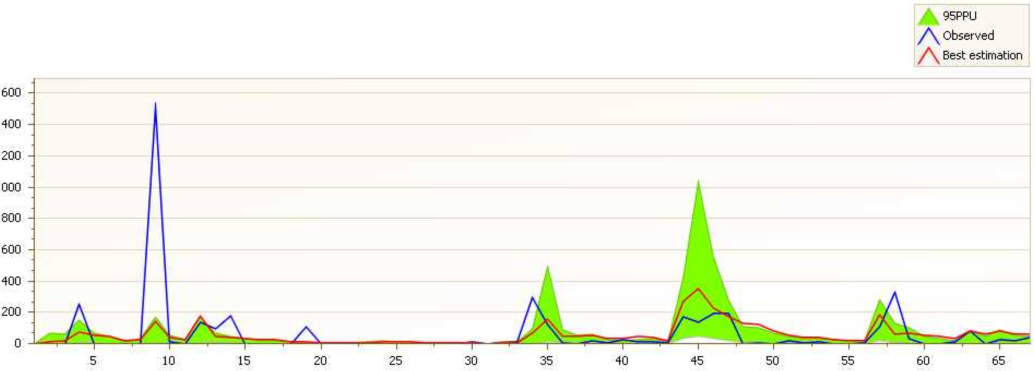

Figure 6. Daily sediment calibration

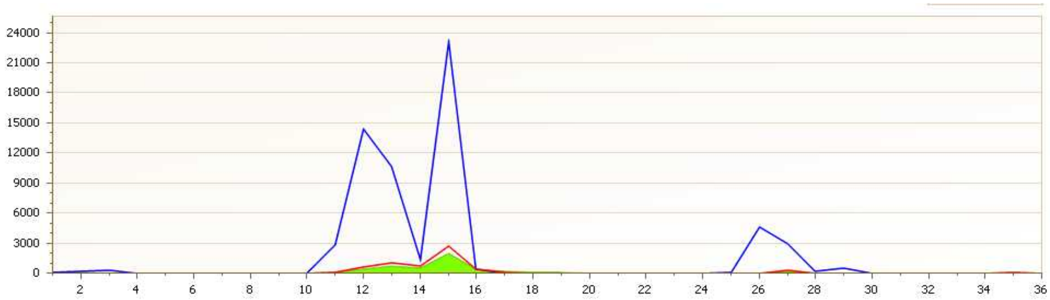

Figure 7. Daily sediment validation

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B9-3

Simulation of Streamflow using SWAT Auto Calibration Tool over the Saemangeum Watershed

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Application of a hydrological component of the Soil and Water Assessment Tool(SWAT) model was attempted to estimate long-term stream flow from the Samangeum watershed.
Hydrologic parameters calibration for basin scale such as Samangeum watershed is quite challenging task since huge variations of hydrologic properties of HRU's. In this study, the sensitivity analysis was conducted initially. The most sensitive parameters were: channel effective hydraulic conductivity(CH_K2), SCS Curve Number II value (CN2), surface runoff lag time(SURLAG), base flow alpha factor (Alpha_Bf), soil evaporation compensation factor(ESCO), and available water capacity (Sol_Awc), respectively. After sensitivity analysis, some important parameters were selected for optimization. Calibration of selected parameters was conducted using SWAT auto calibration tool over the Saemangeum Watershed. The comparison between the observed and simulated stream flow indicated that there is a good agreement between the observed and simulated discharge, which was verified by coefficient of determination (R^2) and Nash Sutcliffe efficiency (NSE) greater than 0.5. We found that auto-calibration tool of SWAT was reliable for the optimization of parameters reflecting Saemangeum Watershed conditions.

KEYWORDS: Autocalibration tool, Parameter, Saemangeum, SWAT

Introduciton

For efficient water quality management of Samangeum reservoir, long-term prediction of stream flow is required. There are several methods of stream flow estimation such as stream flow monitoring, application of regression equation or hydrological model. Stream flow monitoring for the entire Samangeum watershed is not feasible due to cost and labor. Therefore, application of a hydrological model was attempted to estimate long-term stream flow. The Soil and Water Assessment Tool(SWAT) was chosen in this study to estimate stream flow of the watershed. Applicabality of SWAT on stream flow was validated by many researcher. However, hydrologic parameters calibration for basin scale such as Samangeum watershed is quite challenging task since huge variations of hydrologic properties of HRU's. So, autocalibration tool was embedded in SWAT version 2005 for easy calibration. The objective of this study is to evaluate the effectiveness of the SWAT's autocalibration tool at Saemangeum watershed.

Material and Methods

Description site

The Mangeong watershed was selected for this study (Figure 1). The watershed is a subwatershed of Saemangeum watershed. The Mangeong watershed (under Saemangeum) area is 1,741 km^2 and located near Jeonju city, Jeonbuk, Korea. Latitude and longitude range from 35˚55'10''N to 35˚56'23''N and from 126˚51'18''W to 127˚10'46''W, respectively.

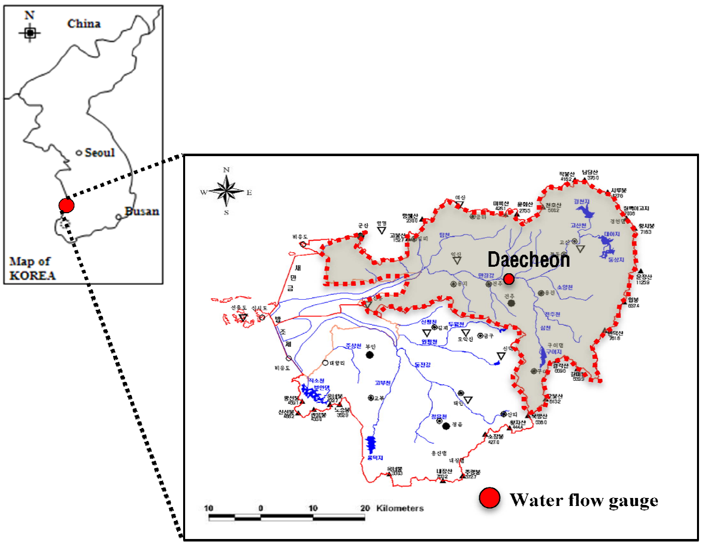

Figure 1. Location and water flow gauges for the Samangeum watershed

SWAT model description

SWAT (Soil and Water Assessment Tool) is a conceptual model developed to quantify the impact of land management practices in large, complex catchments (Arnold et al., 1993; Neitsch et al., 2001a). It operates with a daily time step although sub-daily rainfall can also be used (with the Green and Ampt infiltration method). SWAT incorporates simulation of weather, crop growth, evapotranspiration, surface runoff, percolation, return flow, erosion, nutrient transport, pesticide fate and transport, irrigation, groundwater flow, channel transmission losses, pond and reservoir storage, channel routing, field drainage, plant water use and other supporting processes. SWAT divides sub-catchments into hydrological response units (HRUs), which are unique combinations of soil and land cover. Flow is not routed between HRUs but routing is used for flow in the channel network. A large number (hundreds or thousands) of HRUs can be continuously simulated using SWAT(Kannan et al., 2007).

Construction of input data for SWAT

The SWAT model requires inputs on weather, topography, soils, land use and and stream channels, etc. The DEM of the Saemangeum watershed is shown in Figure 2a. Daily values of precipitation, maximum and minimum temperatures, solar radiation, wind speed, and relative humidity were collected from the weather service data of the KMA (Korea Meteorological Administration). Land use digital data (1:25,000) were used from the National Geographic Information Institute of MLTM (Figure 2b). Six land cover classes are found in this watershed. The detailed soil association map (1:25,000) from NIAST (National Institute of Agricultural Science and Technology)was used for the selection of soil attributes (Figure.3c). Relational soil physical properties such as texture, bulk density, available water capacity, saturated conductivity, soil albedo, etc., were obtained from the Agricultural Soil Information System (http://asis.rda.go.kr) of NIAST (2005).

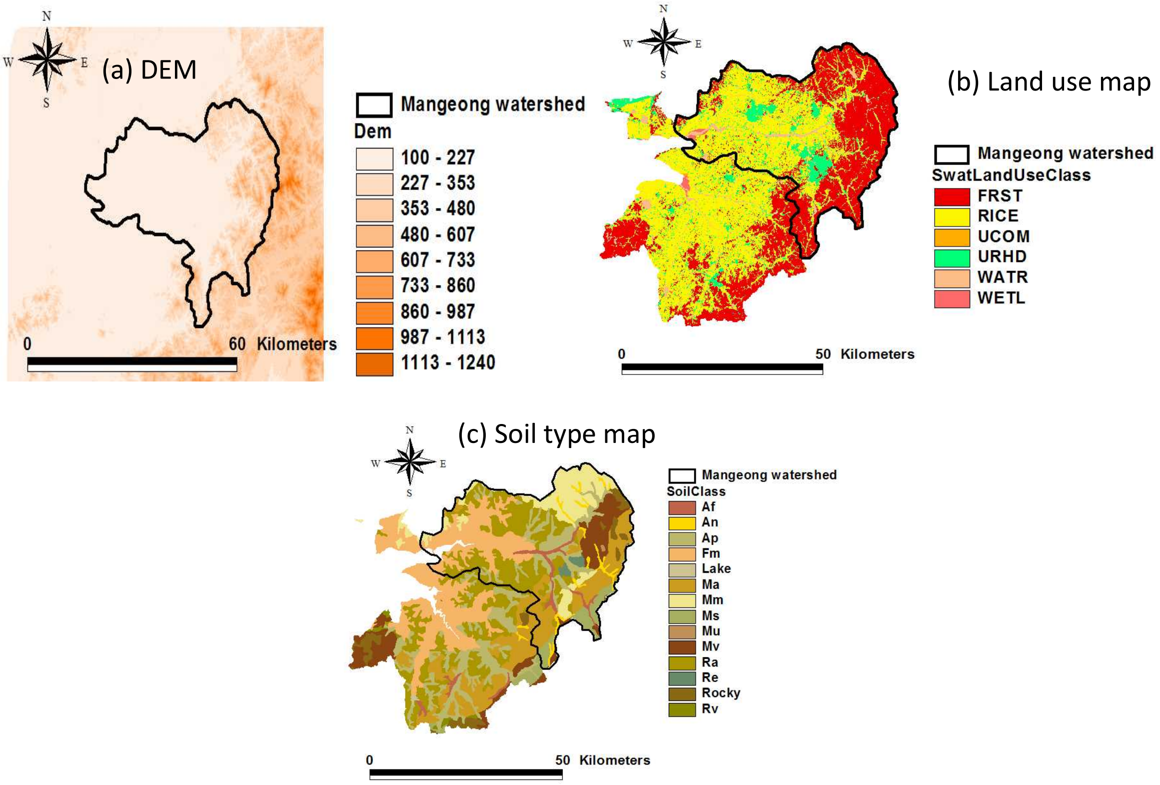

Figure 2. DEM, Land use map and soil type map of the Saemangeum watershed.

Auto-calibration in SWAT2005

SWAT is a complex model with many parameters that can complicate manual model calibration. A parameter sensitivity analysis tool is embedded in SWAT to determine the relative ranking of which parameters most affect the output variance due to input variability (van Griensven et al., 2002). The SWAT model, version 2005 (SWAT2005) has an embedded autocalibration procedure that is used to obtain an optimal fit of process parameters. This procedure is based on a multi-objective calibration and incorporates the Shuffled Complex Evolution Method algorithms.

Model evaluation methods

The performance of SWAT was evaluated using statistical analyses to determine the quality and reliability of the predictions when compared to observed values. The goodness-of-fit measures used were the coefficient of determination (R^2; Eq. (1)) and the Nashe Sutcliffe efficiency (NSE) value (Eq. (2)) (Nash and Sutcliffe, 1970).

$$R^2 = \frac{\left(\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P}) \right)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2 \sum_{i=1}^{n} (P_i - \overline{P})^2} \qquad (1)$$

$$NSE = \frac{\sum_{i=1}^{n} (O_i - \overline{O})^2 - \sum_{i=1}^{n} (P_i - O_i)^2}{\sum (O_i - \overline{O})^2} \qquad (2)$$

where n is the number of observations during the simulated period, O_i and P_i are the observed and predicted values at each comparison point i, and O and P are the arithmetic means of the observed and predicted values. The NSE value was used to compare predicted values to the mean of the average monthly observed values for the subwatershed where a value of 1 indicates a perfect fit. The NSE describes the explained variance for the observed values over time that is accounted for by the SWAT model. The R^2 was used to evaluate how accurately the model tracks the variation of the observed values. The difference between the NSE and the R^2 is that the NSE can interpret model performance in replicating individually observed values while the R^2 does not(Green and Griensven, 2008). For this study, the criteria of NSE > 0.5 and $R^2 > 0.6$ were chosen to assess how well the model performed (Green et al., 2006) with results greater than 0.5 and 0.6 for NSE and R^2, respectively, meaning that the model performed satisfactorily and results below those numbers intending that the model did not perform well. Santhi et al. (2001) and Ramanarayanan et al. (1997) used criteria of $R^2 > 0.6$ and NSE > 0.5 to determine how well the model performed.

Results and discussion

Sensitivity analysis

Parameter sensitivity analysis was conducted using SWAT's sensitivity analysis tool. The most sensitive parameters were: channel effective hydraulic conductivity(CH_K2), SCS Curve Number II value (CN2), surface runoff lag time(SURLAG), base flow alpha factor (Alpha_Bf), soil evaporation compensation factor(ESCO), and available water capacity (Sol_Awc), respectively. After sensitivity analysis, some important parameters were selected for optimization(Table 1). Calibration of selected parameters was conducted using SWAT autocalibration tool over the Saemangeum Watershed.

Hydrologic autocalibration results

The SWAT model was calibrated using autocalibration tool against 2 hydrologic years(2007-2008) of daily measured runoff at the water flow gauge. Figure 3 compares the observed and simulated stream flows using SWAT's autocalibration tool during study period. The statistics of R^2 and NSE were 0.71 and 0.69, respectively. The simulation results showed good agreement with the observed data. It means that auto-calibration tool of SWAT was reliable for the optimization of parameters reflecting Saemangeum Watershed conditions.

Table 1. Parameters for calibration in SWAT model.

Parameter	Description	Optimized value
ESCO	Soil evaporation compensation factor	0.97
CH_K2	Effective hydraulic conductivity in main channel alluvium	148.5
GW_DALAY	Groundwater delay time	47.33
SURLAG	Surface runoff lag coefficient	0.00003
CN2	Curve number	58.72
GW_REVAP	Groundwater revap coefficient	0.17
ALPHA_BF	Baseflow alpha factor	0.96
SOL_AWC	Avaliable soil water capacity	0.21

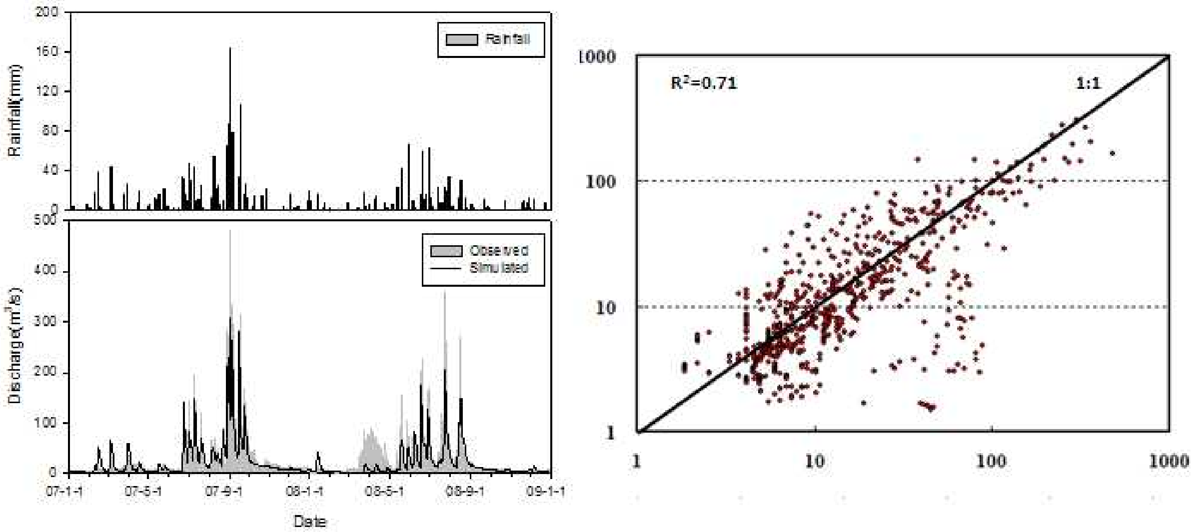

Figure 3. Comparison of the observed and simulated runoff using autocalibration tool

Conclusions

The ability of the SWAT autocalibration tool to simulate runoff from Saemangeum watershed was assessed in this study. The goodness-of-fit measures demonstrated that SWAT simulations using autocalibration tool explained the daily runoff in the observed data well (R^2>0.5, NSE>0.4). Overall, we identified application of SWAT's autocalibration tool as reliable evidenced by statistical measures.

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SESSION PA1

Large Scale Applications

PA1-1

Runoff Simulation using Global Data in the Hwacheon Dam Watershed, Korea

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Hwacheon Dam is a South Korean dam on the Bukhan River, constructed in 1944 for the purpose of electric power generation, flood control and water supply water to the Seoul metropolitan area. However, water inflow to the Han River has decreased by 12 percent since Imnam Dam (storage volume: 27 billion ㎥) was built in 2003 which is located in North Korea. This has caused environmental problems and water shortages in the Seoul metropolitan area. Therefore, it is required to assess the long effects of flow regime alteration resulting from the construction of Imnam Dam. To this end, SWAT-K was applied to Hwcheon Dam upstream area. SWAT-K model is the modified version of SWAT, in which some improved algorithms to better represent characteristics of Korean watersheds are incorporated.

For the model input data of North Korea area, meteorological data of GTS (Global Telecommunication System) and global soil data by FAO/UNESCO were used. Temporal variations of water resources is investigated with comparison of observed and simulated inflows at Hawcheon Dam site. Also, annual, monthly, seasonal decreases in water resources were evaluated using the flow duration curve analysis of simulated streamflow data with or without Imnam dam. The results of this study can be a useful data for the water resources planning and management in the Han River basin, Korea.

Keywords: SWAT, GTS, FAO/UNESCO, Global data, Flow Duration Curve

SESSION PA2

Hydrology

PA2-1

Runoff Potential and Water Storage Capacity of Korean Soil Mapping Units as Affected by Different Topographic Categories

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Abstract

Topography is one of the most important factors of the environmental fate of materials, including soil erosion, runoff, and leaching. Mountainous or hilly landscapes occupy more than 80% of Korea, showing catenary relationships between adjoining soil mapping units (SMUs), soil phase. SMUs were classified into several grades for both of runoff potential, using soil hydrological groups defined by infiltration rate, and water storage capacity, considering soil texture, effective soil depth, and cobble content. Totally, SMUs with high runoff potential, low infiltration rate, occupied the highest portion and decreased in the order of low, moderately low, and moderately high runoff potential groups. SMUs with medium water storage capacity occupied the highest portion and decreased in the order of moderately low, low, moderately high, and high groups. Runoff potential of SMUs, therefore, mainly distributed in extreme ends, whereas water storage capacity was relatively close to normal distribution. SMUs of high land such as mountainous and hilly land had lower runoff potential than those of low land such as fluvial plain, and fluvial-marine plain with compacted layer. Riverside sandy soils without compacted layer, however, had low runoff potential and low water storage capacity. SMUs of fan & valley showed relatively high water storage capacity compared to other topographic categories. More than 60% SMUs in mountain foot-slope, fan & valley, and dilluvial terraces had high runoff potential, whereas SMUs in hilly land showed relatively uniform distribution in runoff potential. This was probably due to human land use such as arable farming, as well as soil forming factors including topography. Soil management practices in SMUs of a middle part of toposequence, including mountain foot-slope and fan & valley, therefore, could have an important role to determine the migration route of water and materials, and need to get more attention for conserving soil and water.

KEYWORDS: Runoff potential, Water storage capacity, Soil mapping units.

Introduction

In Korea, mountainous topographies dominate, occupying 2/3 of the total land area.. The mountain range slopes down toward the south, thus making the southern part of the country fairly level. Not for from the west coast, a somewhat extensive area of rolling land elevated from the present base level is continuous and extends inland along the major rivers, Nagdong, Geum, Han, and Yeongsan. This rolling peneplanes area, including several kinds of land forms, results from the dissection of older peneplanes and valley floors, formed probably during the late pleiocene and Pleistocene times. The low lands include both the coastal plains clayey materials and the continental alluvial plains and valley flood plains of the interior. The rivers are mostly short and swift because of the direction of the mountains and their lateral spurs, as well as the relative narrowness of peninsula. The strongly dissected, intermediate hilly land occupies the transitional levels between the peneplanes and the mountainous lands. It includes areas of sub-mountainous relief and the strongly dissected relics of former intermediate erosion surfaces. Terrace remnants of these levels can be found in some areas.

These topographic features influences on soil formation. To put it the other way, soil characteristics reflects the topographic features in the land. According to NIAST (1992), Korean soils can be broadly divided into 8 topographic categories, including mountainous land (ML), hilly land (HL), mountain foot-slope (MF), fan & valley (FV), dilluvial terraces (DT), alluvial plains (AP), and fluvial-marine plains (FM), and LP (lava plain). LP was excluded from this study because it mainly distributed in Jeju, and Ulleung islands. In this study, we examined the effect of topography on the runoff potential and water storage capacity of SMUs for grasping sketchy information for water flow characteristics of Korean soil.

Materials and Methods

Runoff potential

Runoff potential of soil mapping unit in Korean soil information system can be classified as four grades, low (A), moderately low (B), moderately high (C), and high (D), namely hydrological soil groups (USDA, 1955), defined by infiltration rate. This study used the hydrological soil groups of Korean SMUs proposed by Jung (2006).

Table 1. Hydrologic soil groups defined by USDA (1955)

Hydrologic soil groups	Soil runoff potential	Infiltration rate (cm/hr)
TYPE A	low runoff potential (a high infiltration rate)	0.762-1.143
TYPE B	Moderately low runoff potential a moderate rate of infiltration when thoroughly wet	0.381-0.762
TYPE C	Moderately high runoff potential a slow rate of infiltration rate when thoroughly wet	0.127-0.381
TYPE D	high runoff potential	< 0.127

Water storage capacity

Similarly, water storage of soil profile was classified as five groups, low (I), moderately low (II), medium (III), moderately high (IV), and high (V), defined by soil texture, effective soil depth, and cobble content (Korean soil information system; NIAST, 2000; NIAST(1992)).

Table 2. Average available water contents (AAW)* of textural family groups referred from NIAST (2000)

Sandy	Coarse loamy	Loamy Skeletal	Fine loamy	Coarse silty	Fine silty	Clayey
9.0	20.8	26.9	24.0	32.1	26.5	22.1

*Difference between field capacity (-10kPa of soil water potential) and wilting point (-1.5MPa of soil water potential)

Table 3. Water storage capacity potential grouping referred from Korean soil information system

Groups	Water storage capacity potential	Water storage capacity of soil profile[§] (cm)
I	Low	0-5
II	Moderately low	5-10
III	Medium	10-20
IV	Moderately high	20-30
V	High	>30

[§] Water storage capacity potential of soil profile (cm)
= AAW(%)/100 x Soil volume (%)/100 x Available soil depth (cm)
where, soil volume (%) indicates [100-gravel content (%)].

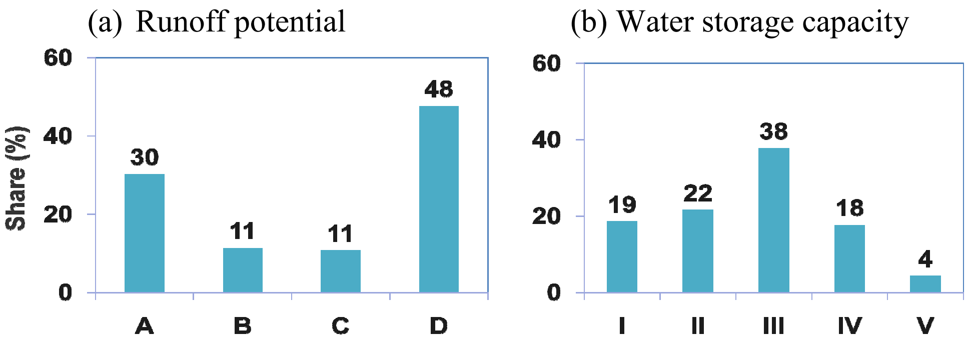

Figure 1. Runoff potential and water storage capacity distribution of SMUs; Runoff potential grades: low (A), moderately low (B), moderately high (C), and high (D); Water storage capacity grades: low (I), moderately low (II), medium (III), moderately high (IV), and high (V).

Results and Discussion

Topographic categories distribution of Korean soils

ML, HL, and FV soils, mainly distributed in slope landscapes, had large portion of Korean soils (Figure 1 & 2). AP soils along rivers occupied great portion in plain landscapes of Korea. The number of soil series, soil classification unit, belonging to each topographic category, however, had highest value in FV. FV commonly located at a merged position of slope landscape, and thereby more various soils can be formed by sequential or mixed effect from the surrounding environment, including soil and water transport. On the other hand, soil mapping units (SMUs), soil phase, had more detailed description of soils including slope, cobble content, and erosion status, compared to soil series. Especially, water flow and physico-chemical characteristics of SMUs are essential input values in GIS-based soil and water modeling including SWAT model. In addition, the topographic distribution percentages and the number of SMUs had a positive linear relationship with those of area in general, unlike the number of soil series. This was probably due to higher number of SMUs belonging to slope landscapes such as ML, HL, FM, and FV with their higher variability in slope, cobble content, and erosion status. In this study, we examined the effect of topography on the runoff potential and water storage capacity of SMUs for grasping sketchy information for water flow characteristics of Korean soil.

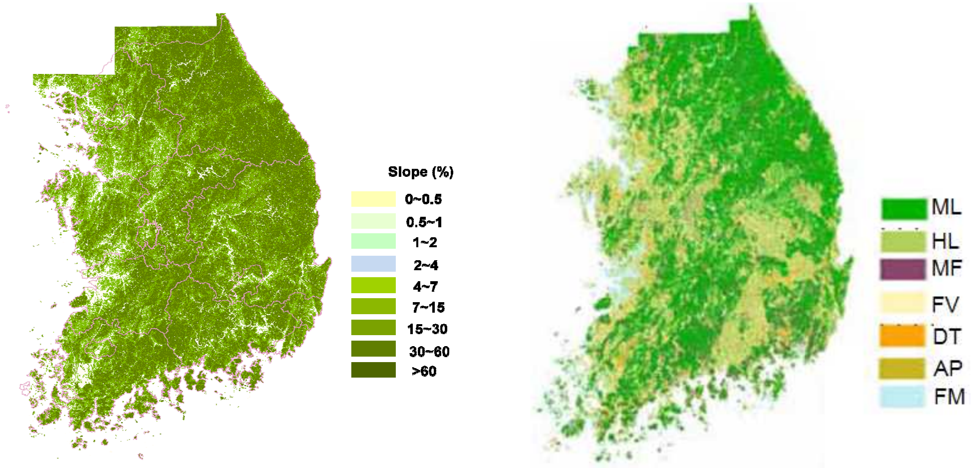

Figure 2. Slope (a) and topographic distribution (b) in Korean soils

(a) Area

(b) No. of soil series

(c) No. of SMUs

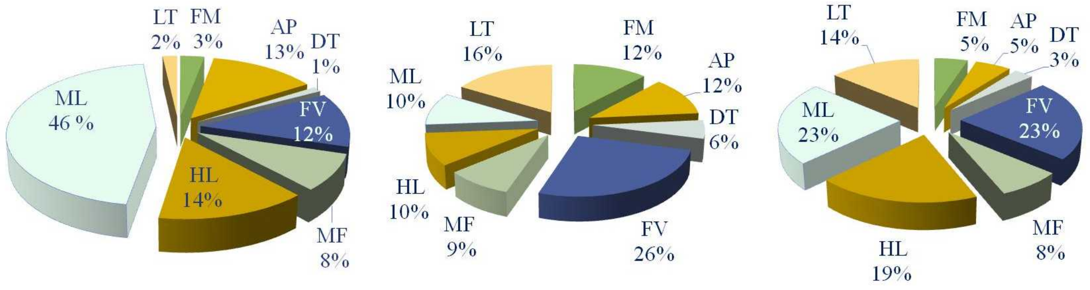

Figure 3. Topographic distribution in Korean soils: (a) area, (b) & (c) the number of soil series and SMUs belonging to each topograpic category, respectively; ML: mountainous land, HL: hilly land, MF: mountain foot-slope, FV: fan & valley, DT: dilluvial terraces, AP: alluvial plains, FM: fluvial-marine plains, LP: lava plain.

Runoff potential and water storage capacity distribution of SMUs with different topographic categories

Totally, high runoff potential (D), in other words, low infiltration rate, occupied the highest portion and decreased in the order of A, B, and C groups (Figure 3). SMUs with medium group (III) in water storage capacity occupied the highest portion and decreased in the order of II, I, IV, and V groups. Runoff potential of SMUs, therefore, mainly distributed in extreme ends, whereas water storage capacity was relatively close to normal distribution.

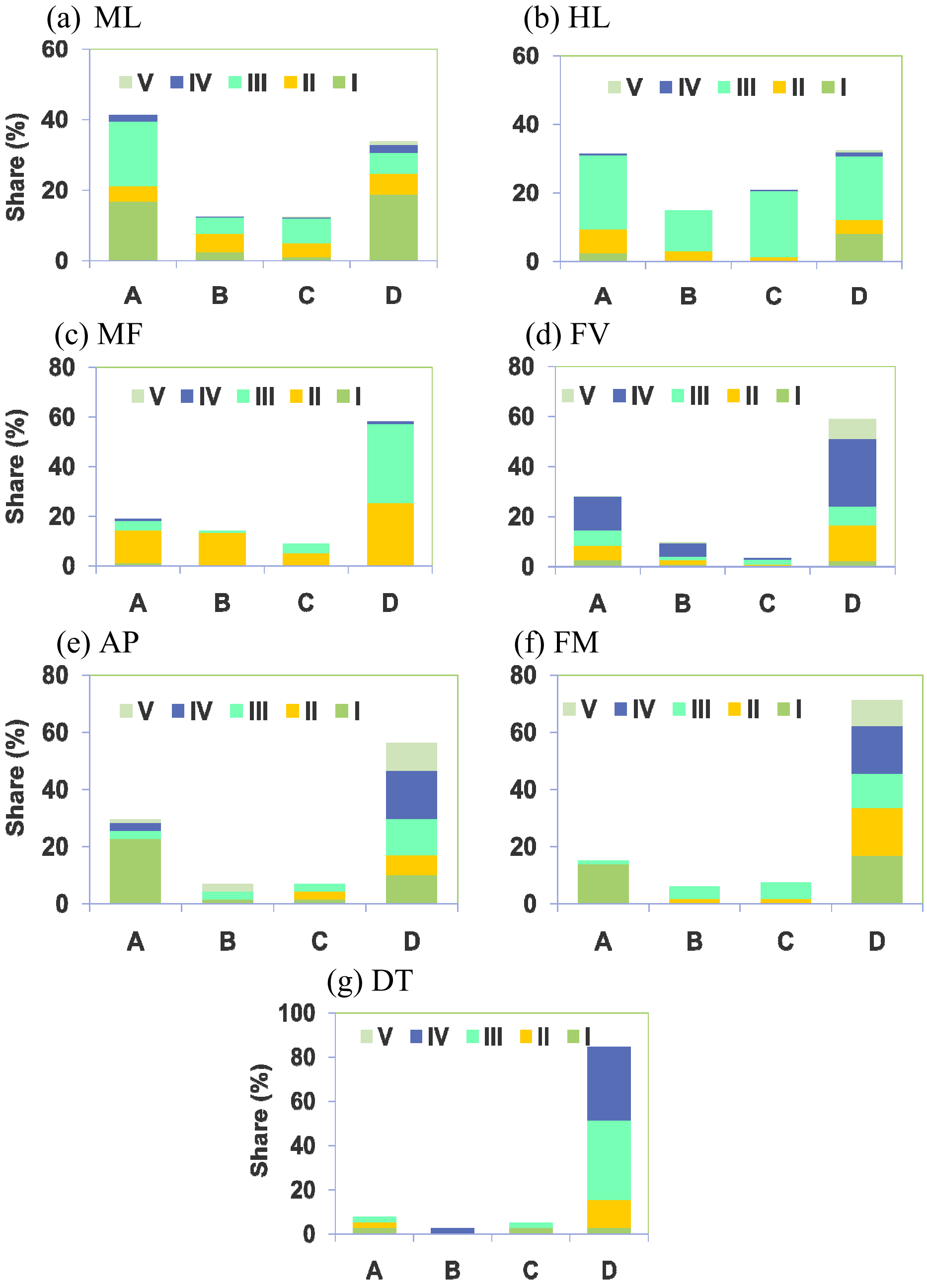

Figure 4. Runoff potential and water storage capacity distribution of SMUs with different topographic categories; ML : mountainous land, HL: hilly land, MF: mountain foot-slope, FV: fan & valley, DT: dilluvial terraces, AP: fluvial plains, FM: fluvial-marine plains ; Runoff potential grades: low (A), moderately low (B), moderately high (C), and high (D); Water storage capacity grades: low (I), moderately low (II), medium (III), moderately high (IV), and high (V).

SMUs of High land such as ML and HL had lower runoff potential than those of low land such as AP, and FM topographic categories with compacted layers. Riverside sandy soils without compacted layer in AP, however, had low runoff potential and low water storage capacity. More than 50% SMUs of fan & valley showed relatively high water storage capacity of IV, or V group, which was higher than other topographic categories. More than 80% SMUs of DT had high runoff potential, presumably due to their fine-texture. Besides, more than 60% SMUs in FM, and FV had high runoff potential, whereas SMUs in HL showed relatively uniform distribution in runoff potential. This was probably due to human land use such as arable farming, as well as soil forming factors including topography.

Conclusions

Relatively higher runoff potential and higher water capacity in lower land is probably due to finer texture and larger disturbance by human-being with lower land in general. On the other hand, high land could also have high runoff potential due to steep slope, although it has high infiltration rate. Soil management practices in SMUs of a middle part of toposequence, including mountain foot-slope and fan & valley, therefore, could have an important role to determine the migration route of water and materials, and need to get more attention for conserving soil and water.

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PA2-2

Analysis of Impact of Land Use Change on Runoff through Several Streams in Jeju Island, Korea

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Abstract

Jeju Island, the highest level of rainfall region in Korea, is formed by vesicular volcanic rocks and ashes causing a half of the total rainfall permeates underground which leads the Island to have the rich groundwater resources, although most of streams are dried. The expansion of agricultural land, massive establishment of tourist development and road construction in the upper area of the streams are increasing the damage rapidly nearby the lower area of the streams. For importance of integration of Jeju Island's water resources, there are needs of a stable water supply along with preserving and managing of the groundwater, which is the only water source in Island, and grasping the changes in stream flow amount due to prolonged land-cover map and its use for rational development and utilization. The streams in Jeju Island is developed in north and south area from the Halla Mountain where it is located in the middle of Island, and their total number of 143 streams are distributed including district and small streams. Among the streams in the Island, Chunmi stream, which is located in southern east of Jeju Island, and Oaedo stream, Ongpo steram, Yeanoae stream, which are typical examples with frequent runoff, were selected as a study watershed and applied SWAT model. For applying the SWAT model to Island's four stream watersheds, data of weather and rainfall observation in each stream watershed from Jeju meteorological observatory were collected and analyzed dividing present and past 30 years data. The study watershed's DEM was processed and applied using arc-info with 30m ×30m resolution DEM provided by Ministry of Environment, and the soil map data was used as an applied model data diving by 1: 25,000 precise soil map to soil series building 100m x 100m latticed size through Agricultural Soil Information System(ASIS) which offered by National Institute of Agricultural science and Technology. Landuse map was used as a model applying data by building 100m × 100m latticed size using year 1975 and 2000 landsat satellite image provided by Ministry of Environment and Arcview program. A few methods were applied to each part, such as, surface flow using a method of CN, Channel Routing using a method of Muskingum, Potential evapotranspiration using a method of Penman-Monteith. The results of the research that comparing change of direct flow in major streams, such as, Chunmi stream, Oaedo stream, Ongpo Stream, and Yeanoae stream in the past and the present, due to the development of watershed and the changes of land use pattern aroused by land use change through applying SWAT model, which is the semi-distributed runoff and rainfall, are summarized as follows.Although the change of land-coverage in four major streams between the past and the present were slight, the areas of impermeable land in the lower area of the streams generally extended approximately two times higher than in the past. Therefore, it proved that amount of the direct runoff has a major impact on flood disaster increased by at least 1%~6%.Particularly, in the case of Oaedo stream where shows most frequent land use change, the result that we divided the sub-basin into two according to the land use change and applied it into the model is as follows: in the upper part of the stream was there little land use change, while in the lower part did land use change occur a lot with highly increased direct flow percent compared to other basins. Through the continuous extension of observing hydrological measures and discharge sites to collect advanced data for comparing and analyzing change of watershed runoff in streams as the land use change progress, it should be quantitatively identifiable the change of hydrological patterns caused by land use change.

KEYWORDS: Jeju Island, SWAT, Land use change, Stream runoff

Introduction

The poor development of surface water in Jeju Island where entirely depends water resources on surface water and the tendency recently to be much in demand of water due to development of various industries as well as increase in population and land cultivation1). For preserving water resources to fulfill the needs, Jeju is in desperate need to develop Jeju Island surface water. Recently, there is a huge change of the environment run off in streams due to the cityward tendency of the population and increase in land use rate.

Especially, the change on surface water flow and polluted ground water caused by urbanization of increase in impermeable and load construction rate making a serious issue to the society to demand the effective solution to it. Also, the streams located in downtown, where undercurrent capability decrease for rainfall and increase in runoff discharge as well as the amount of peak flow due to the urbanization, bring a urban disaster to low-lying area and lower watersheds.

It is necessary to have hydrological monitoring and mathematical hydrological model in order to have evaluation of influence on change of land use and devise a proper measure. The analysis on urbanization or change of land use using hydrological model makes a tendency to prefer applying physical based in distributed or semi-distributed runoff model for the conspiration of temporal and spatial changes in most watersheds. For the research on land use change, more detailed and a powerful model for verification is required.

Ji Dong Sik et. al. surveyed that it has showed the big change of land due to land development and urbanization. To use the data, the group conducted a study on the effect of urbanization and abnormal climate changes on the flood discharge.

Lee Seong Jong et. al, researchers who studied for changes of land use with the urbanization process analyzed the sample of runoff characteristics is related to increase in impermeable layers by simulating the land use between past and present in Dorim stream using the WEP model.

Park Min Ji et. al, who tested the simulation of applying HSPF model for land use changes, proved that increasing runoff volume was closely connected with expansion of urban areas and decline in forest zone with analysis of runoff characteristics as precipitation conditions and land use changes, especially in the season when the highest rain intensity was showed that the rate of peak flow was at the highest. Likewise, it is a top priority of hydrological monitoring for preparing effective measures following evaluate of urbanization impacts.

However, the observation would not be enough to fulfill understanding and establishing direct relation in complicated hydrological phenomena and land use changes, but with mathematical hydrological model would be suitable to understand the relation of hydrological phenomena and land use changes.

Some studies on ground water were partly being progressed by researchers who have studied water resources in Jeju Island, and there are some basis studies of estimating runoff in major streams, but there is hardly any study which estimates runoff applying water flow observation and hydrological model on the streams in Jeju. Only some researcher who simulated their runoff for a long term has been published1.

The study focused on how the land changes by the urbanization, like development of tourist complex, cultivation of land, development of residential properties, and construction of impermeable layer roads, have any effect on amount of direct flow between past and present using SWAT model, which is the continuous rainfall-runoff model, near Oaedo stream watershed.

A Study Methods and Watersheds

A study methods

The streams in Jeju Island are developed in north and south area as center of boundary line between Jeju and Segwipo, and their total number of 143 streams are distributed including district and small streams. It is important to establish the data connected with GIS to raise up the efficiency of model which reflects physical characteristic in watershed.

There are five kinds (DEM, land cover map, soil type map, boundaries of watershed, stream shapes) of GIS input data required for SWAT model.

The boundaries of watershed and stream shapes simulate inside of SWAT model, thus data of DEM, land-cover map, soil type map were established. The resources of SWAT model input data, such as, hydrological and meteorological data(precipitation, solar radiation, wind speed, climate and humidity), 100m grid-scale geographical data, land cover map, and soil type map were categorized into the past 30years and current data. Also, for any model of calibration and verification, the data surveyed the watershed region in Oaedo stream were organized systematically.

The data set up with the standard runoff characteristic in Jeju streams through dividing into direct flow, total runoff, and conducted a study of sensitivity analysis of parameter. There are two type of the sensitivity parameters, one is to bring sensitive impact on direct flow, another is affected total runoff, extracting each sample and calibrating current runoff using the method of Jung Woo Yeol and Yang Seong Ki.

As a result of calibration of current runoff, it was able to calculate sensitivity parameter and apply them into the past runoff simulation and made data in the past. It was useful to analyze and compare the runoff in past and present.

Research of watershed

Most streams in Jeju Island are dry streams and consist of small scale surface water along the V -shape valley from north and south as the center of Baek-Rok-Dam at top of Halla Mt. formed by erosion. These streams show very different characteristics depending on the conditions of topography and rainfall, stiff slope in south and north direction, and they are considered curvy, direct type stream.

This research was selected the samples of watershed as Chunmi stream in East, Oaedo stream in North, Ongpo stream in West, Yeonoae stream in South among the 143 streams in Jeju(Figure 1).

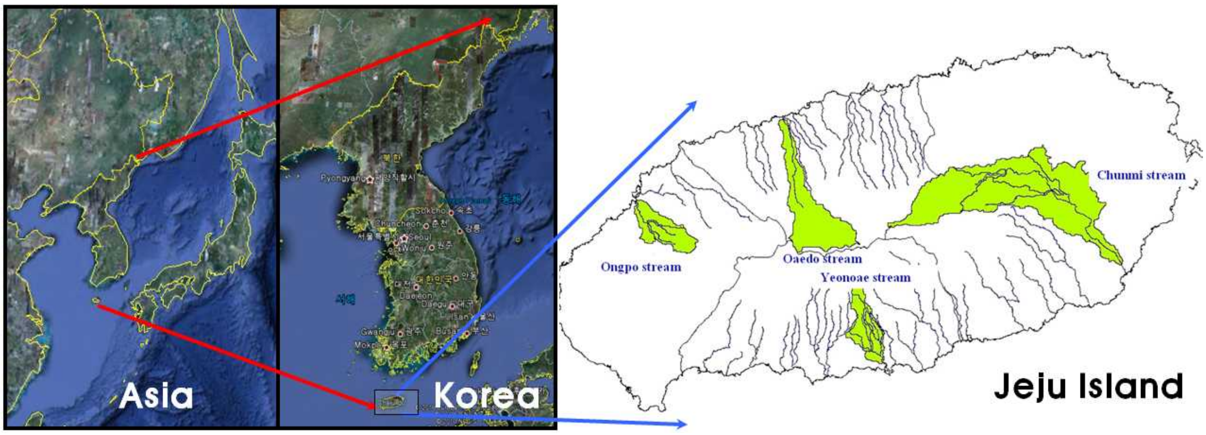

Figure 1. Basin for the study

Chunmi stream, which is located in the East, is the longest stream in Jeju, and the distance of stream is 25km in length. Oaedo stream in North is 18.3km, Ongpo stream in West is 9.6km, and Yeonoae stream is 9km.

Moreover, the watershed area of Chunmi stream is 127.64km^2, the area in Oaedo stream is 44.54km^2, the area in Ongpo stream is 20.09km^2, and the area in Yeonoae stream is 19.61km^2.

Analysis and Establishment of Input Data on SWAT Model

Establishment hydrological and meterological data in the watersheds

Hydrological and meterological data used to estimate runoff on SWAT model are basically high and low temperature, radiant quantities, wind velocity, and humidity etc. Besides, input data showed clearly which positions to observe and observation runoff as well as the level of reservoir are required as the case may be.

There are four branches (Jeju, Seogwipo, Sungsan, Kosan) , monitoring weather under meterological agency control, and 19 branches of meterological agencies and 48 branches belong to the national emergency management agency in Jeju are monitoring rainfall. The term of applying four major watersheds model was divided past and present. The status of appying period and rainfall data for each stream are shown in Table 1.

Table 1. The status of rainfall station at the basins

Watershed	period		Rainfall observatory
	Past	Present	
Chunmi	1988. 1. 1~ 1997. 12. 31	2000. 1. 1~ 2009. 12. 31	Sungsan, Pyoson, Gyorae, Songdang
Oaedo	1975. 1. 1~ 1984. 12. 31	2000. 1. 1~ 2009. 12. 31	Jeju, Hangpa, Chunback, Aewol
Ongpo	1988. 1. 1~ 1997. 12. 31	2000. 1. 1~ 2009. 12. 31	Gosan, hanrim, Aewol
Yeonoae	1975. 1. 1~ 1984. 12. 31	2000. 1. 1~ 2009. 12. 31	Seogwipo, Songsandong, Doneko

It has been possible to apply past data of rainfall since 1975 to the watersheds in Oaedo stream and Yeonoae stream. For Chumi stream and Ongpo stream, the record in 1975 were not found, thus those streams used a data from 1988 to 1997 on the model for each.

GIS input data

The attribute information in hydrological model system contains slope analysis, slope direction analysis, land use, land cover, etc., which are provide to basic data of DEM. DEM (Digital Elevation Model), which system expresses the attitude values as a grid-scale unit per 1second (30m) using sample contour in altitude map, is the data to surveys all over the world from USGS(United States Geological Survey). DEM(30m × 30m) which provides in Ministry of Environment calibrated with method of arc-info and made a new model of DEM to apply on study watershed.

The result of DEM, Jeju had 0-1950 altitude, the standard altitudes of watersheds were 283.69m, the standard slopes in streams discovered 9.04%.(Figure 2).

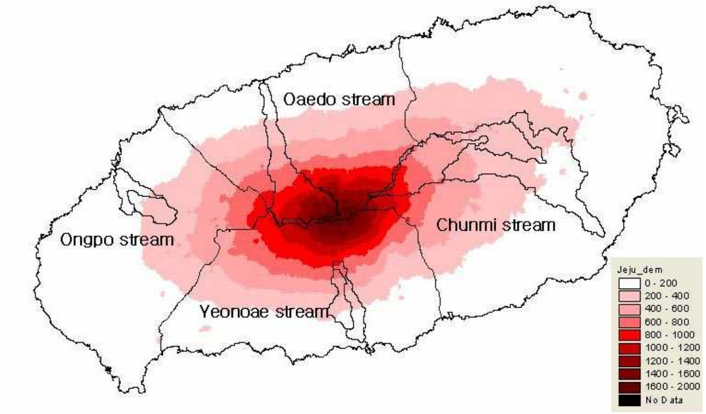

Figure 2. DEM

The watershed in Chunmi stream had 394m standard altitudes, 7,11% standard slopes. Oaedo stream had 468m,17,12% Yeonoae stream had 313,5m, 11,07%and Ongpo stream had 188m,4,86%, standard slopes in Ongpo stream were more less than the standard slope of others, that means Ongpo streams had gentle slopes.

The landuse map data offered by synthetic information system (http://www.wamis.go.kr) in national water resources security was utilized as an applied model of land cover map. These data were classified Landsat satellite image in 2000 by land cover types, transformed into GRID file on arcinfo and arcview GIS 3.3.

It was collected land use data applying Arcview program and classified the data by the study watersheds on each stream, and then the data used input data of model by setting up 100×100m(Figure 3).

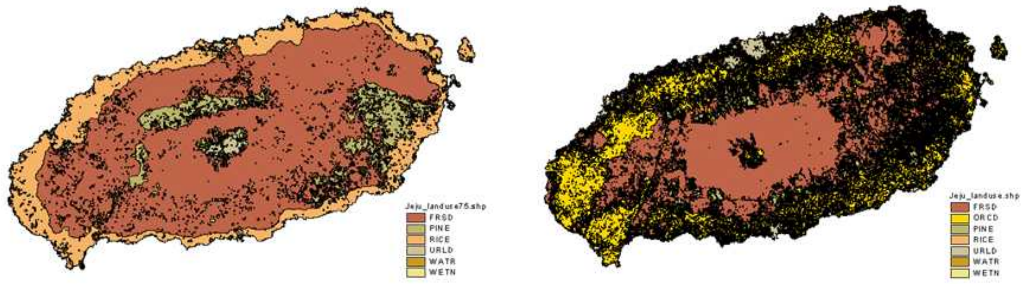

Figure 3. Jeju Landuse Map(1975 & 2000)

In 1975, the percentages of forest regions were 39,3% that consists the highest rate, followed by grassland and farm land. In 2000, the conditions of land use were changed that forest regions, farm land, and urban area were in order by higher percentage(Table2).

Table 2. Jeju Landuse

	Past(1975)		Present(2000)	
	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)
Paddy field	317.4	17.2	282.4	15.3
Grassland	407.8	22.1	432	23.4
field	148.8	8.06	1.9	0.1
Forest	725.3	39.3	745.6	40.4
City	236.4	12.8	376.5	20.4

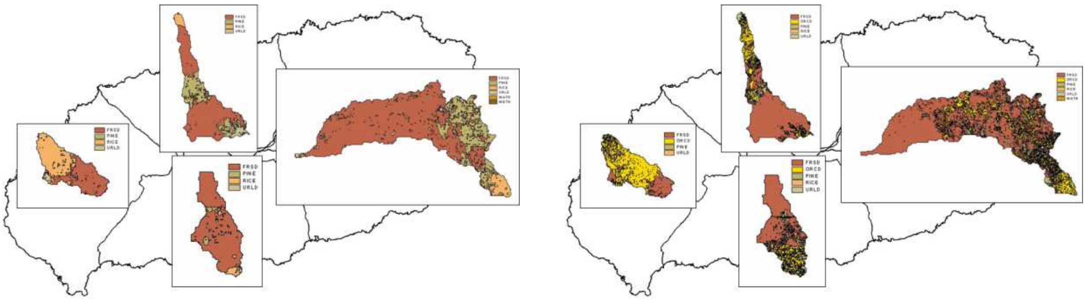

Figure 4. Study area Landuse map(1975 & 2000)

Table 3. Ground coverage state at the Watershed to be studied(Past)

	Chunmi stream		Oaedo stream		Ongpo stream		Younoae stream	
	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)
Paddy field	0.03	0.02	1.4	2.98	-	-	-	-
Grassland	28.4	21.62	10.3	22.99	0.1	0.52	0.8	3.83
field	6.2	4.68	1.9	4.15	8.3	45.55	0.2	0.63
Forest	95.7	72.88	30.4	68.24	9.2	50.74	17.6	90.09
City	1.1	0.8	0.7	1.64	0.5	3.18	0.2	0.63

Table 4. Ground coverage state at the Watershed to be studied(Present)

	Chunmi stream		Oaedo stream		Ongpo stream		Younoae stream	
	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)	Area(km^2)	Ratio(%)
Paddy field	0.01	0.01	0.07	0.16	-	-	3.68	0.14
Grassland	11.14	8.73	4.71	10.58	0.30	1.48	2.22	11.32
field	25.4	19.9	7.31	16.42	13.84	68.87	1.35	18.78
Forest	86.86	68.05	31.52	70.77	4.56	22.70	12.37	6.91
City	4.24	3.32	0.92	2.07	1.40	6.95	0.03	6.86

Soil Data Base classified physical information by soil characteristic should be established, since soil-type map on SWAT model has only the numeric data about spatial distribution according to soil characteristic. Soil type map data were designed as input data as 31 pieces of soil series which arranged 1:25000 detail soil type map offered from Agricultural Soil Information in National Academy of Agriculture science. The soil type map also was transformed as shape file and arranged attributed values as the same land use map.

In this way of searching a land use data, it was collected by applying Arcview program and classified the data by studying watersheds in each stream, and then the data used to input data on the model by setting up 100×100m(Figure 5).

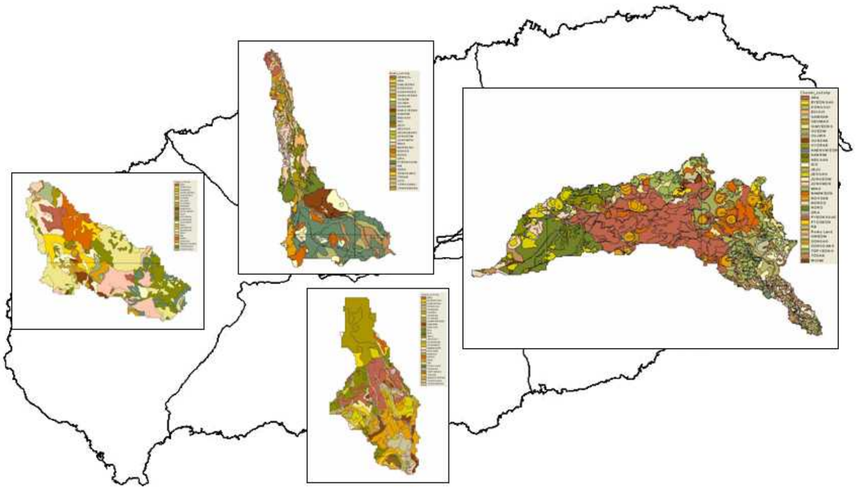

Figure 5. Study area Soiltype map

Application of SWAT Model

Sensitivity Analysis of parameters

The study watersheds were applied in sensitivity analysis of parameters, there were 2-type of parameters, one was influenced by direct flow, another was influenced by total runoff. so, the selected samples of each parameter were calibrated and verified the current runoff in the way of Jung Woo Yeol, Yang Seong Ki. The seven parameters was set up the standard values and tested changes of sensitivity analysis by ±25% in phase. There were divided dry watersheds and wet watersheds as focus on characteristic of Jeju streams. The sensitivity analysis was carried out for the 2-type of watershed and the output of parameters in the dry streams had closely effects on direct flow as standard direct flow. Moreover, the information was discovered how each parameter impact on the direct flow, total runoff by progressing on the sensitivity analysis. The result showed that the CN2 parameter was the highest impact on direct flow, there were CN2, SOL_AWC, ESCO parameters influencing the total runoff.

The effect and verification of model to use the current data

It is necessary to gather hydrological data for calibrate the result of model in Chunmi stream. Hydrological data in Chumi stream existed only that data on July and August in 2002 and on June and July in 2006. One of data when surveyed on June and July in 2006 calibrated the model and got the direct flow data of 30,27% in Chunmi stream (Figure 6).

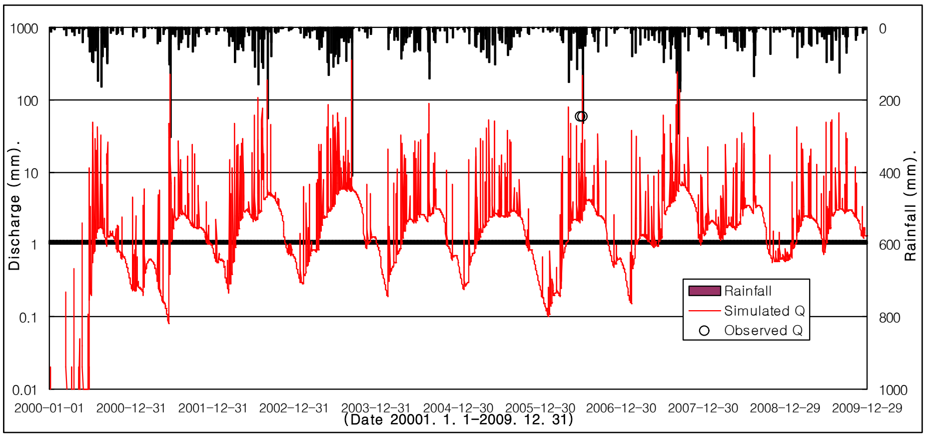

Figure 6. Result of the present runoff simulation of the basin of Chunmi watershed

It was collected the runoff data for the purpose calibrating and verifying in Oaedo stream. There were total 5 times (on March and July 2times, on August 1time in 2007) to calibrate the runoff data, because the run off data was searched only using current's rainfall as measurement of the speed of current. With the result that the data of direct flow showed 22,10% in Oaedo stream (Figure 7).

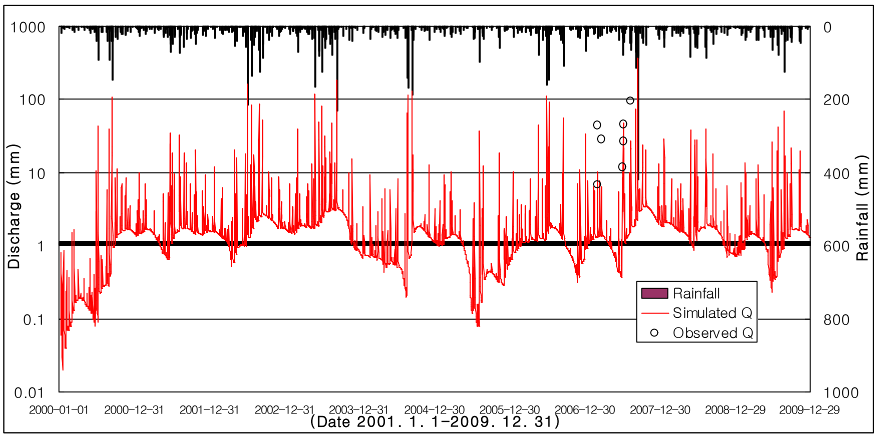

Figure 7. Result of the present runoff simulation of the basin of Oaedo watershed

The data of runoff (Moon, 2004) in Ongpo stream that was surveyed between 2002 and 2003 calibrated. Observed values consisted of elements of base runoff was higher than simulated value. Simulated values of output were modified since CN2 parameter showed to reduce -7 values, SOL_AWC parameter also reduced -0, 05, but REVAPMN, ESCO showed to increase values each +250, +0,95 in Ongpo stream. The outcome of modification, mean square error was 0,62 of REVAPMN, 0,86 of R^2, simulated efficient coefficient ME estimated 0,56, rates of direct flow discharge were 25,6% (Figure 8).

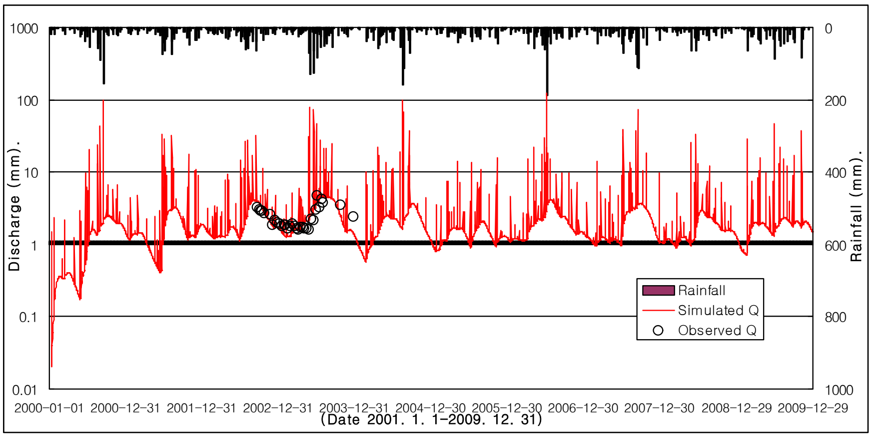

Figure 8. Result of the present runoff simulation of the basin of Ongpo watershed

The Model that was utilized the study of runoff discharge in 2003 (Moon, 2004) and the study of hydrologic and geological survey as well as synthetic groundwater survey in Jeju. And estimated outcome of the model applying to Yeonoae stream was calibrated and verified.

Firstly, total amount of runoff discharge at exit area of the watershed was modified. Secondly, all the small watersheds of CN2 values were adjusted to be lower and fixed them. and then, SOL_AWC values were adjusted to be lower -0,05, REVAPMN were adjusted to be higher +450, ESCO was upward +1, GW_REVAP adjusted the lowest limit values. After calibrated, the rate of direct flow discharge was 27,8% in Yeonoae stream (Figure 9).

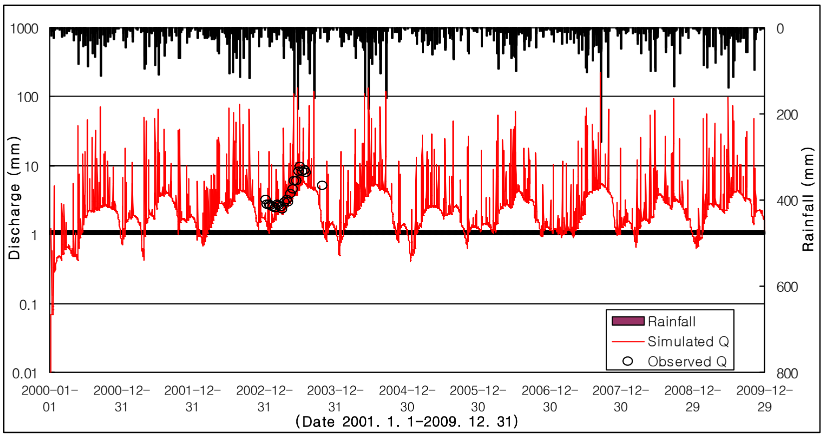

Figure 9. Result of the present runoff simulation of the basin of Yeonoae watershed

The past and the present comparison of direct runoff

Land cover data of the input data of SWAT model were classified into past (the land cover of Landset satellite images, 1975) and present (the land cover of Landset satellite images) and the data were applied to the model.

To estimate the amount of direct flow discharge according to land cover of the past, the model based on actual observation data should have calibrated. There was no measurement of depth of runoff during applying to the model in four major watersheds.

Thus, the amount runoff in the past was estimated through the parameters used to calibrate the amount of current runoff discharge instead of past data in order to compare direct flow discharge changes as the land cover.

Chunmi stream is the highest level of rainfall region in4 major streams. As comparing the amount of direct flow discharge between past and current, it shows that the amount of direct flow in current increases about 1% as against the past amount. The result of calculation is listed below Table.5.

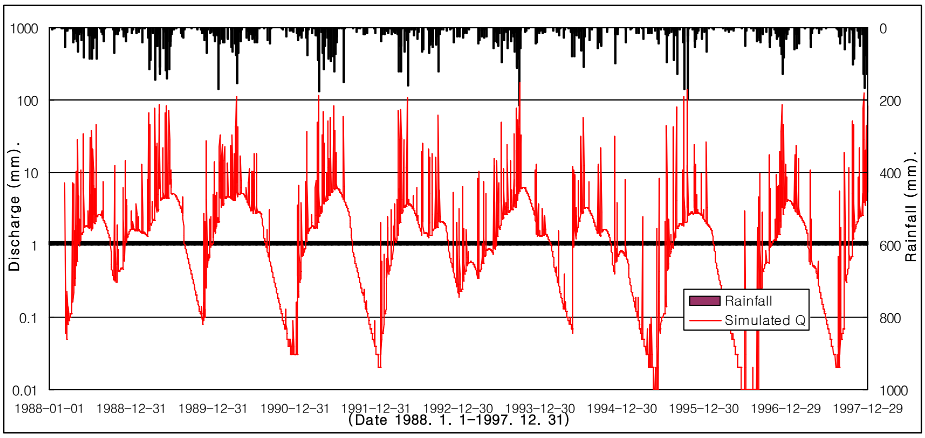

Figure 10. Result of the past runoff simulation of the basin of Chunmi watershed

Table 5. The past and the present comparison of direct runoff(Chunmi watershed)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1988	1450	288.08	19.87	2000	1854.5	378.12	20.39
1989	2223	737.72	33.19	2001	1584.4	462.81	29.21
1990	1922.9	538.77	28.02	2002	2291.5	829	36.18
1991	2202.4	742.12	33.70	2003	2729.5	1054.65	38.64
1992	1844.5	523.16	28.36	2004	1730.5	483.11	27.92
1993	2043.8	682.99	33.42	2005	1617	409.06	25.30
1994	1222.7	262.86	21.5	2006	1889.9	644.71	34.11
1995	1458	487.92	33.47	2007	2632.1	1061.59	40.33
1996	1161.6	287.3	24.73	2008	1558.2	374.84	24.06
1997	1704.3	576.34	33.82	2009	1753.5	466.51	26.60
Average	1723.3	512.726	29.01	Average	1964.1	616.44	30.27

As discovering the results that obtained to use land cover data between past and present in Oaedo stream, it showed 16% standardized rates of direct flow for 10years beyond past(1975~1984) and 22% for 10years in the present.

The factor tied up with increase the rate of direct flow discharge was impermeable land. As impermeable land increased, the amount of direct flow discharge became growth highly. Oaedo was the most enormous changes of land use in four major streams went up about 6% as compared with the amount of direct flow between past and present.

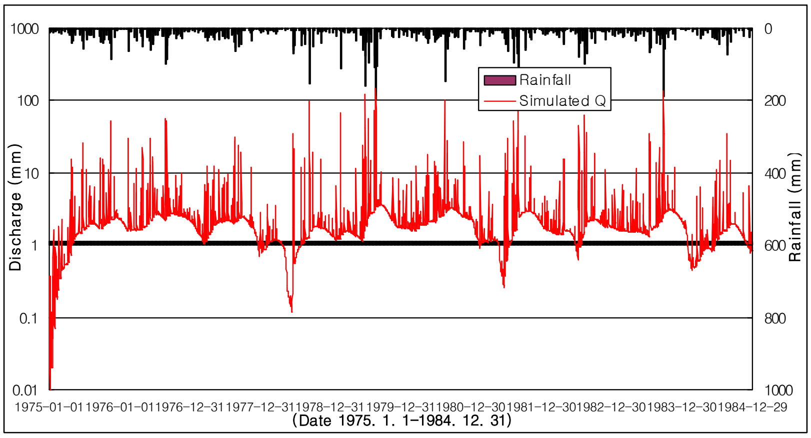

Figure 11. Result of the past runoff simulation of the basin of Oaedo watershed

Table 6. The past and the present comparison of direct runoff(Oaedo watershed)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1975	1279.5	128.4	10.04	2000	1195	244.9	20.50
1976	1452.5	180.34	12.42	2001	1400	199.6	14.26
1977	1180.8	112.42	9.52	2002	1723	483.4	28.05
1978	1079.8	164.14	15.20	2003	2028	614.5	30.30
1979	1838	471.82	25.67	2004	1356	350	25.79
1980	1545.6	185.52	12.00	2005	900	87.3	9.70
1981	1612.4	431.06	26.73	2006	1555	341.5	21.96
1982	1248	161.29	12.92	2007	2164	770.8	35.62
1983	1373.6	322.2	23.46	2008	1336	227.7	17.04
1984	878.5	136.98	15.59	2009	1328	247.4	18.63
Average	1348.87	229.42	16.36	Average	1498.5	356.7	22.18

Ongpo watershed which was lightest rainfall in four major streams was shortage of the meteorological data in the past. That's why it was used the data from 1988 to 1997 and analyzed the past runoff data as the same other watersheds.

The data of land use changes didn't show much difference among the streams and the comparative results of direct flow increased about 1%.

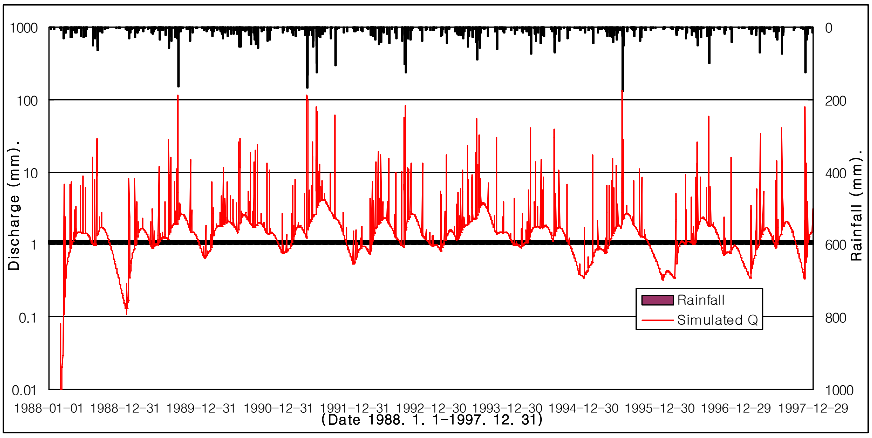

Figure 12. Result of the past runoff simulation of the basin of Ongpo watershed

Table 7. The past and the present comparison of direct runoff(Ongpo watershed)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1988	735.5	132.37	18.00	2000	1018	273.32	26.85
1989	1081.5	257.87	23.84	2001	1124	265.09	23.58
1990	1162.3	232.38	19.99	2002	1252	287.81	22.99
1991	1504	555.35	36.92	2003	1531	450.77	29.44
1992	1107.6	292.77	26.43	2004	1288	397.88	30.89
1993	1151.4	271.71	23.60	2005	848	151.76	17.90
1994	834.3	187.95	22.53	2006	1372	377.52	27.52
1995	1003	280.13	27.93	2007	1320	404.67	30.66
1996	837.4	173.93	20.77	2008	991	193.15	19.49
1997	875.1	223.86	25.58	2009	1149	306.48	26.67
Average	1029.21	264.94	24.45	Average	1189.3	310.84	25.60

As discovering the results that obtained to use land cover data between past and present in Yeanoae stream, it showed 25.54% standardized rates of direct flow for 10years beyond past(1975~1984) and 27.80% for 10years in the present.

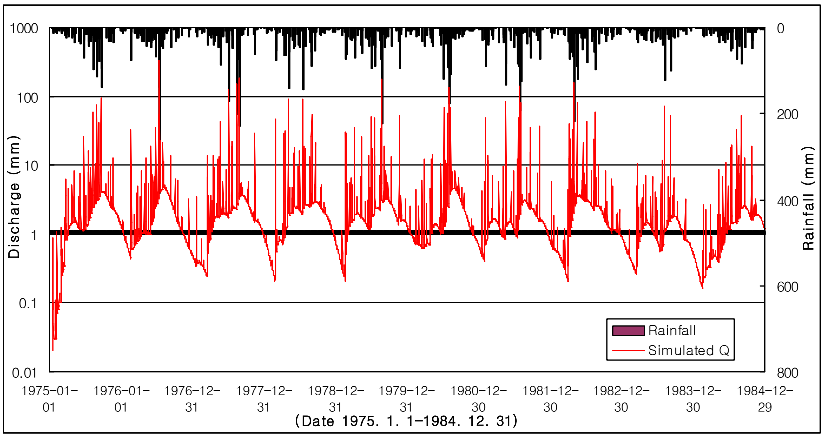

Figure 13. Result of the past runoff simulation of the basin of Yeanoae watershed

Table 8. The past and the present comparison of direct runoff(Yeanoae watershed)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1975	1833.6	410.23	22.37	2000	1379	309.2	22.42
1976	1987.9	636.61	32.02	2001	1794	471.7	26.29
1977	2009.9	647.8	32.23	2002	1899	515.4	27.14
1978	1827.3	461.3	25.24	2003	2309	747.8	32.38
1979	1899.3	530.5	27.93	2004	2309	740.1	32.05
1980	1699.9	448.9	26.40	2005	1413	321.0	22.72
1981	1833.5	573.6	31.28	2006	1781	432.4	24.28
1982	1887.6	519.1	27.50	2007	2195	728.4	33.18
1983	1149.0	171.0	14.88	2008	1693	464.9	27.46
1984	1232.6	191.4	15.53	2009	2035	612.4	30.09
Average	1736.1	459.0	25.54	Average	1880.7	534.3	27.80

Comparison direct flow discharge depending on land use change in Oaedo stream

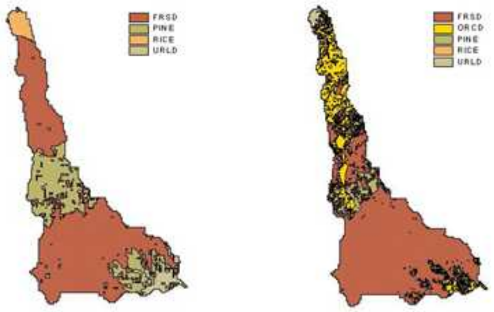

Figure 14. Land-cover map of study watershed(Oaedo 1975 & 2000)

Land-cover changes were extreme in Oaedo of the 4 major streams and the Oaedo watershed was analyzed to compare the direct flow data related in land use changes, as follows figure 14. showed that land use changes rarely appeared in upper watershed and changed the data only in lower watershed.

To understand correct direct flow data, it was needed to compare upper and lower watershed of direct flow data.

Oaedo stream divided by upper and lower watershed was applied the model, there were little different rate of runoff compared the past and present in upper watershed where was hardly changed land use(Table 9~10).

Table 9. The past and the present comparison of direct runoff(Oaedo upper stream)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1975	1279.5	209.3	15.36	2000	1195	201.7	19.64
1976	1452.5	288.6	18.87	2001	1400	152.6	14.68
1977	1180.8	180.1	14.25	2002	1723	370.3	25.64
1978	1079.8	255.8	22.84	2003	2028	457.3	24.56
1979	1838	647.9	32.50	2004	1356	296.0	24.53
1980	1545.6	288.4	16.44	2005	900	87.3	11.25
1981	1612.4	567.2	28.64	2006	1555	281.1	22.65
1982	1248	248.8	19.85	2007	2164	601.4	29.54
1983	1373.6	311.2	20.65	2008	1336	177.5	17.59
1984	878.5	118.2	13.45	2009	1328	191.4	17.32
Average	1348.9	311.5	20.29	Average	1498.5	281.7	20.74

Table 10. The past and the present comparison of direct runoff(Oaedo down stream)

Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)	Year	Rainfall (mm)	Direct runoff (mm)	Direct runoff percent (%)
1975	1279.5	252.1	19.70	2000	1195	366.5	30.67
1976	1452.5	337.3	23.22	2001	1400	330.6	23.61
1977	1180.8	218.4	18.50	2002	1723	657.9	38.19
1978	1079.8	305.2	28.26	2003	2028	800.5	39.47
1979	1838	733.3	39.90	2004	1356	494.6	36.48
1980	1545.6	335.0	21.67	2005	900	186.7	20.75
1981	1612.4	643.3	39.90	2006	1555	509.2	32.75

1982	**1248**	**294.8**	**23.62**	**2007**	**2164**	**974.1**	**45.01**
1983	**1373.6**	**361.0**	**26.28**	**2008**	**1336**	**364.9**	**27.31**
1984	**878.5**	**152.5**	**17.36**	**2009**	**1328**	**384.8**	**28.98**
Average	**1348.9**	**363.3**	**25.84**	**Average**	**1498.5**	**507.0**	**32.32**

There was a 6% direct flow increase when Oaedo stream was not divided into upper and down subwater shed but one water shed to run the model. However for better precise finding of direct flow, subwater sheds direct flow analysis were also tried. The result came out that the down stream of Oaedo increased 6% making 25.84% as it shown in table 4.15 figure 26. comparing with the past upper stream, and 12% increase making 32.32% comparing with the current upper stream.

For the result, CN2 has the most effect parameter on direct flow, and CN2, SLO_AWC, ESCO are common parameters to have a effect on total flow. Model correction too placed applying these sampling parameters.

Result

Jeju Island has different hydrological characteristic from other provinces with hydrological and geologic system. Even though the Island is the highest level of rainfall region in Korea, should depend on groundwater entirely due to the peculiar features about hydrological and geologic data.

The resources of groundwater don't last, but there happens seriously problems, such as excessive demand of water and careless of danger development.

That's why suffer the stream regions from many disaster.

Therefore, it is strongly essential for Jeju to develop surface water in order to prevent lack of water and secure the water resource.

In order to calculate the data of runoff in the watersheds as land use changes, it should be primary to study hydrological model that evaluates the runoff data between land use changes of the past and present.

SWAT model, which is the semi-distributed runoff model for calculation runoff data watershed, was carried out each runoff data of the past and present for four major streams in Jeju.

The watersheds of Chumi that had dry stream and weren't conducted a survey serial high of runoff. The data based on twice measurements of direct flow in 2006 were calibrated and showed similarities between twice high of runoff, but it was hard to calibrate and verify accurately parameters caused by shortage actual data of high of runoff. The watershed of Oaedo was stream, but there was no serial runoff data so far.

The data based on 5 times measurement as rainfall in 2007 were calibrated, the output showed similarities between actual data and calibrated result.

However, these results are not quitely sure to evaluate the actual data.

It is supposed that serial runoff data were calibrated and verified correctly, can be deduced from the result data.

It was used that the data of runoff in Ongpo stream were studied from 2002 to 2003 and the watershed of Yeonoae stream in 2003, both watersheds showed great results by calibration and verification of model.

Since there was no actual data in the past, the calibrated parameters of current were applied and the data of direct flow in the past were obtained. The rate of direct flow were 16~29% (standard values 22%).

As a result of estimating direct run off of past and present as the change of landcover in four major streams, the areas of impermeable land generally extended approximately two times higher than in the past, also show that the direct runoff increased by 1 ~ 6%.

It supposes to survey runoff and collect data of SWAT model in streams, it will make sure that the estimate of daily runoff discharge for a long term and generally management of watersheds utilize.

Therefore, it is imperative to survey runoff for the purpose of collecting the data of SWAT model in streams, Jeju. Through the continuous extension of observing hydrological measures and discharge sites to collect advanced data for comparing and analyzing change of basin runoff in streams as the urbanization progress, it should be quantitatively identifiable the change of hydrological patterns caused by urbanization.

This type of study can be significantly useful to not only for securing Jeju Island's surface water resource, but also establish flood disaster prevention measures in order to reduce damage and defend against flood disaster in nearby city basins.

Acknowledgements

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PA2-3

The Impact of Soil Hydraulic Conductivity Variations on the Simulated Responses of SWAT Model

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The soil hydraulic conductivity is one of the important input variables for simulating SWAT model. However, the soil hydraulic conductivity values at the modeling scale are very limited and often unavailable in Korea. In order to simulate SWAT model the soil hydraulic conductivity values need to be estimated indirectly. One of the indirect methods of estimating soil hydraulic properties is to use pedo-transfer function (PTF) which provides soil hydraulic conductivity values using easily measurable soil information such as soil texture and organic matter.

In this study five different PTFs for the soil hydraulic conductivity were applied to investigate the impact of the soil hydraulic conductivity variation on the simulated responses of SWAT model at Bocheong-cheon and Ansung-cheon watersheds in Korea. The SWAT model was calibrated based on daily stream flow data using the shuffled complex evolution global optimization method. The simulated result of SWAT model shows that daily stream flow at outlet of watershed is independent of spatially averaged hydraulic conductivity of watershed. The relation between groundwater recharge and spatially averaged hydraulic conductivity of watershed exhibited the inverse relationship such that the monthly recharge decreased with an increase of spatially averaged hydraulic conductivity of watershed. The response of subsurface lateral flow revealed that the lateral flow increased with an increase of spatially averaged hydraulic conductivity of watershed showing positive relation. The simulated responses of SWAT model indicates that the proper identification of spatially consistent soil hydraulic conductivity has an important implication for modeling groundwater recharge and subsurface lateral flow at the watershed scale.

PA2-4

Estimation of Reasonable CAPPI Mesh Size Using SWAT Model

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Abstract

The objective of this study is to determine the reasonable mesh interval with the comparison of effects of runoff rate from rainfall, which was simulated by ANN (Artificial Neural Network) according to CAPPI (Constant Altitude Plan Position Indicator) mesh size. There are no absolute selection criteria for the mesh size. But mesh size for generating precipitation from radar data is generally selected 4km×4km considering only wind effects. That selection method with just effects of wind speed has some limitations of applying to hydrologic processes.

The target basin of present study is the Soyangangdam watershed located in the east central area of Korea. Three rainfall observatories in Soyanggangdam basin have been operated. Hourly rainfall from observatories was used as target values for ANN model. Reflectivity (CAPPI), which is input values for ANN model, is obtained from Gwangdeok Mt. weather radar observatory located in the west of Soyanggangdam basin. The period of study is 2007 flood season (6/21~9/20) of Korea. ANN was considered for generating hourly rainfall at the grid point by mesh interval. Then, input of daily precipitation for SWAT was obtained by 24-hour accumulation of the simulated hourly rainfall. Virtual observatory, with MAP (Mean Area Precipitation) that is obtained as average of grid point in basin, is established in the centroid of each basin.

From comparison on runoff of SWAT according to mesh sizes, the low RMSE (Root Mean Square Error) between simulated and measured runoff at the Soyanggangdam outlet was displayed by 4km and 8km.

Keywords: SWAT, CAPPI, Artificial Neural Network

Introduction

This study was to determine the reasonable CAPPI mesh interval with the comparison on effects of runoff rate by using the SWAT model. High rainfall observatory density is required for examining rainfall characteristics due to spatial-temporal variability of rainfall. A large percentage of mountain terrain in Korea leads to higher spatial and temporal variability of precipitation. More rainfall observatories need to be constructed. However, observatory density is practically lower in mountain area. To estimate the rainfall through high-resolution radar data is expected to become a realistic alternative to low observatory density in the mountain area. Doppler radar can measure many hydrologic factors (Hudlow, 1988; Hudlow et al., 1991). Radar-based short-term rainfall prediction and flash flood forecasting were conducted by many researchers (Georgakakos and Hudlow 1984; Georgakakos, 1986a, b; Seo and Smith, 1992). Chiang (2007) used the Dynamic ANN for precipitation estimation and forecasting from radar observations.

Process

Collection of hydrologic data

Soyanggangdam watershed is selected as a study area. Figure 1 shows the location of Soyanggangdam basin. The SWAT model among rainfall-runoff models is applied to compare the effect of runoff according to the simulated rainfall from reflectivity. A semi-distributed SWAT is a physically based hydrologic model. Therefore, physiographic parameters for SWAT are derived from a DEM (Digital Elevation Model) with a resolution of 30x30 m^2. The digital land-use map with scale of 1:25000 and the digital detailed soil map are used for HRU (Hydrological Response Unit). The hourly and daily precipitations of hydrologic data (01/01/2006 ~ 12/31/2008) are obtained from Inje, Bupyeong and Myeonggae observatories, which have been operated in Soyanggangdam basin (Figure 2). And the weather data among hydrologic data (01/01/2006 ~ 12/31/2008) are obtained from Inje observatory. Radar reflectivity (CAPPI) of 2007 flood season (06/21~09/20), which is input values for ANN model, is obtained from Gwangdeok Mt. weather radar observatory located in the west of Soyanggangdam basin.

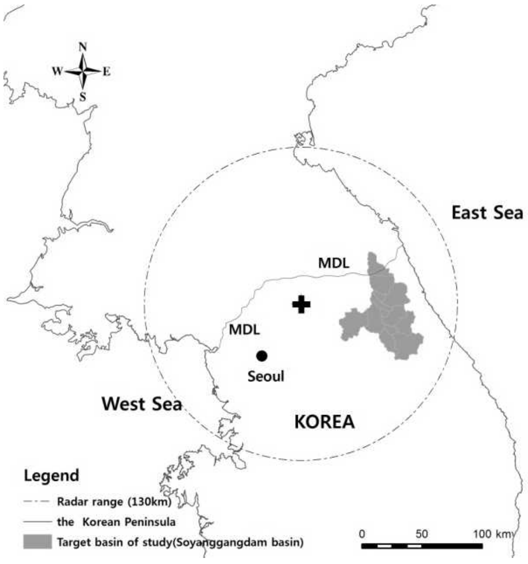


Figure 1. Location of study basin.

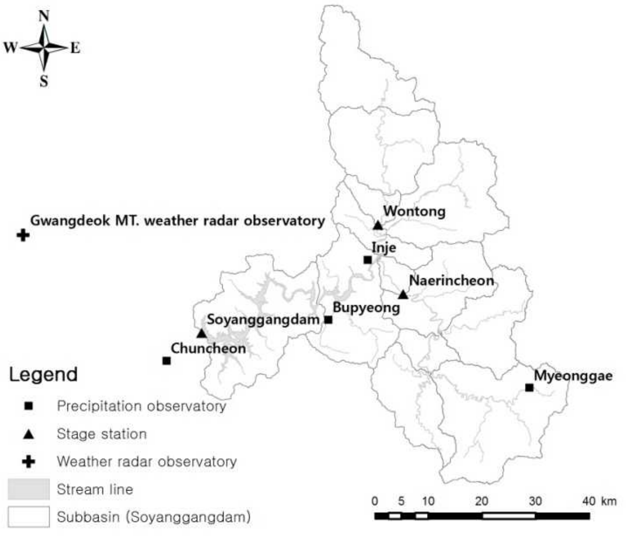
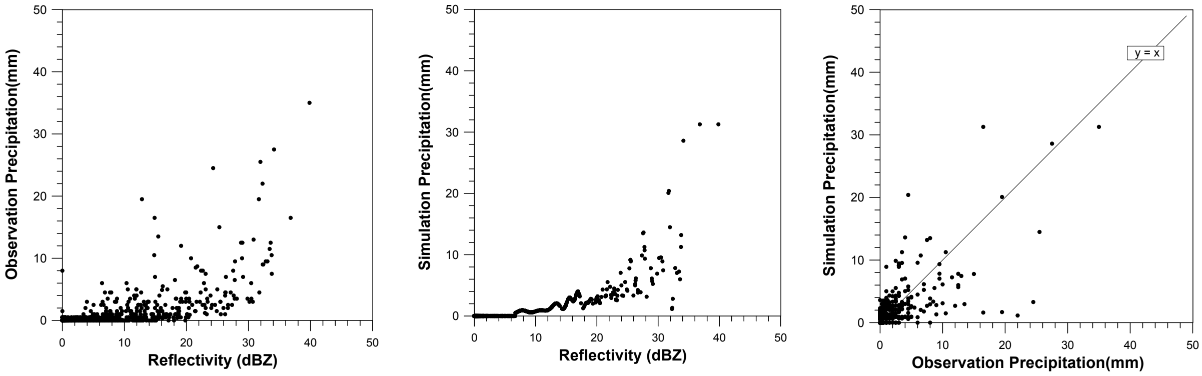


Figure 2. Location of hydrologic stations

Simulation of rainfall using ANN model

Input of daily precipitation for SWAT was obtained by 24-hour accumulation of the hourly rainfall which is simulated by ANN according to CAPPI mesh size. ANN model is made up of three layers: one input layer, one hidden layer and one output layer. Hourly rainfall from Inje, Bupyeong and Myeonggae observatories apply to target for training. And the reflectivity in the observatory location is used as input for training. Hourly precipitation from Chuncheon observatory is used for validating for ANN model. Figure 3 shows the result of validation for ANNs such as relationships between reflectivity and measured rainfall, reflectivity and simulated rainfall and measured and simulated rainfall, respectively.



(a) Relationship of reflectivity and observation rainfall

(b) Relationship of reflectivity and simulation rainfall

(b) Relationship of simulation and observation rainfall

Figure 3. The results of generating the rainfall for ANN model

Also, Figure 4 shows the comparison on relationship between measured and simulated daily rainfall. And Figure 5 shows the spatial distribution of precipitation in 08/27/2007.

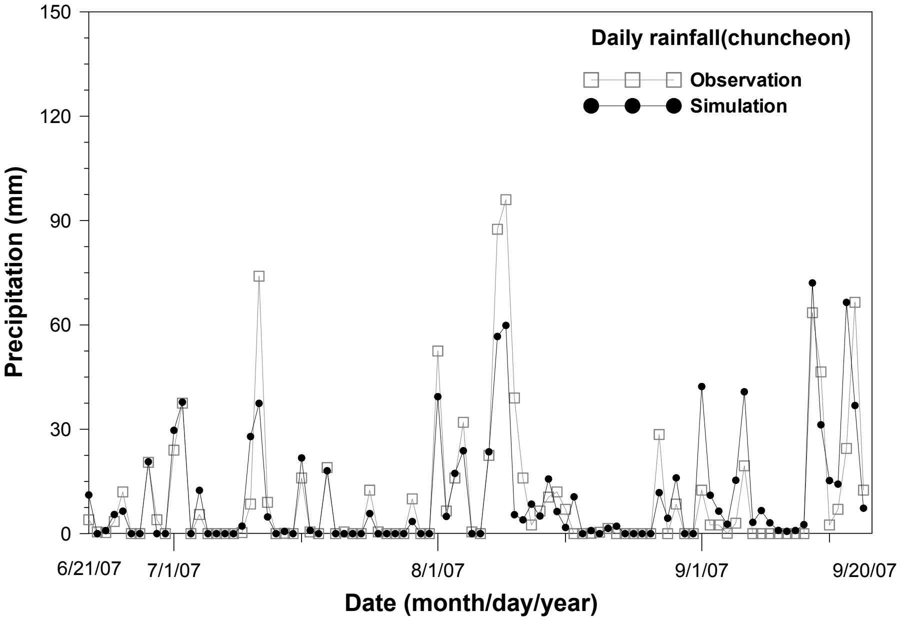


Figure 4. Simulated and observed daily rainfall

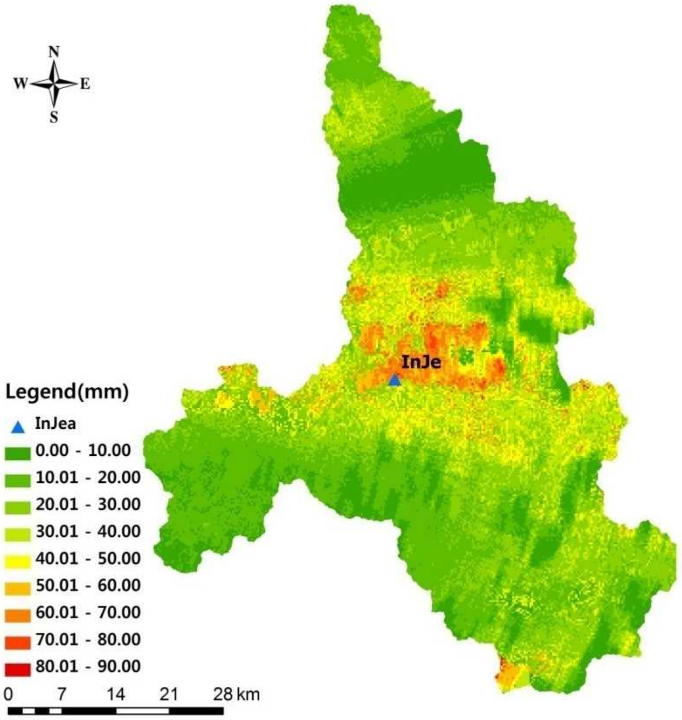


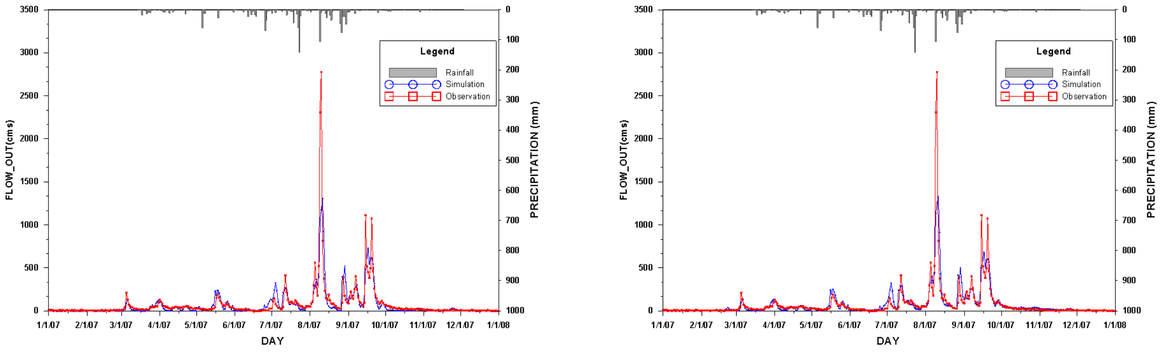
Figure 5. Spatial distribution of simulated daily rainfall in the Soyanggangdam basin (08/27/2007)

Set-up of SWAT model and calibration

The Soyanggangdam stage station with good quality of discharges data is selected for the verification of runoff rate at the watershed outlet. The period of three years 2006 to 2008 is applied to determine the parameters of SWAT model: The period of 2006 year is used as set-up for SWAT model, the period of 2007 year as calibration of parameters in SWAT model, the period of 2008 year as validation for SWAT model. And then, the final parameter is determined about the Soyanggangdam basin. Due to limitation of collection of radar data, the application of daily rainfall from radar data in SWAT consists of 2 steps: The first step is to warm-up SWAT by inputting the measured rainfall at site into model for 01/01/2006 ~ 06/20/2007. The second step is to apply the simulated daily rainfall from ANN according to mesh interval in SWAT model for 06/21/2007 ~ 09/20/2007. And basin of Soyanggangdam is divided into 13 subbasins. The accuracy of drainage basin is evaluated by comparison between basin area that is obtained from WAMIS (WAter Managerment Information System) and basin area that is divided by SWAT model. Table 1 shows the area of basin division. And Figure 6(a) shows the flood hydrograph before calibration in 2007 while Figure 6(b) shows the flood hydrograph after calibration in 2007.

Table 1. Basin areas between SWAT and WAMIS.

class	total area from SWAT(km^2)	total area from WAMIS(km^2)	difference (km^2)
Soynaggangdam outlet	2,691.0	2,703.0	12.0
Inbokcheon outlet	929.6	931	4.4



(a) Before calibration (b) After calibration

Figure 6. Calibration results at the Soyanggangdam outlet.

Runoff rates according to mesh size

Daily rainfall (MAP) of virtual observatory is calculated by increasing mesh size from 1km to 16km grid; 1km×1km, 2km×2km, 4km×4km, 8km×8km and 16km×16km. ANN was considered for generating hourly rainfall at the grid point by mesh interval. Then, input of daily precipitation for SWAT was obtained by 24-hour accumulation of the simulated hourly rainfall. Virtual observatory, with MAP that is obtained as average of grid point in basin, is established in the centroid of each basin. Figure 7 shows the comparison on results between measured and simulated runoff according to mesh size.

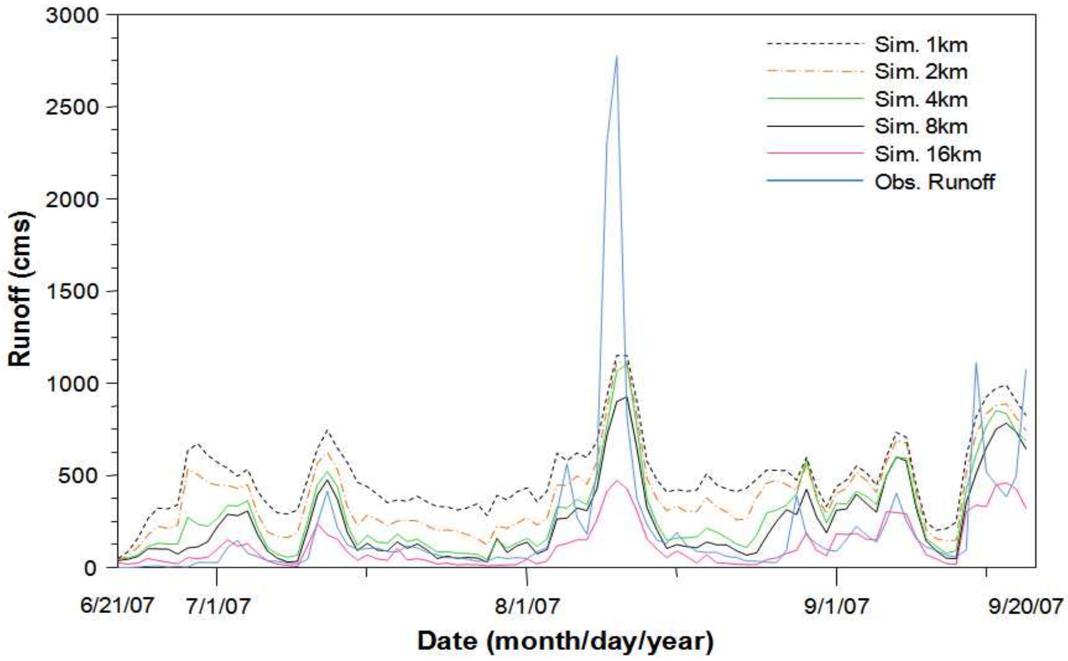


Figure 7. The comparison on result between measured and simulated runoff according to mesh size.

The low RMSE between simulated and measured runoff at the Soyanggangdam outlet was displayed by 4km×4km and 8km×8km. Table 2 shows RMSE between measured and simulated runoff at the final outlet according to mesh sizes.

Table 2. RMSE according to mesh sizes.

Class	RMSE				
	1km	2km	4km	8km	16km
Soyanggangdam outlet	393.44	337.31	300.25	301.56	353.87

CONCLUSION

General pattern between measured rainfall at site and simulated rainfall using the ANN from reflectivity is displayed similarly. However, irregular pattern with relationship between high rainfall at site and low reflectivity is underestimated. Also, Soyanggangdam watershed is classified as a large basin in runoff. Spatial and temporal variability of precipitation is higher in large basin. To estimate rainfall through high-resolution radar data is expected to become a realistic alternative for forecasting a flash flood by localized heavy rainfall. From comparison on runoff of SWAT according to mesh sizes, the low RMSE between simulated and measured runoff at the Soyanggangdam outlet was displayed by 4km×4km and 8km×8km. First of all, study will be conducted to define relationship between reflectivity and minimum effective rainfall through large collection of the long-term remote-control data according to precipitation event.

Acknowledgements

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PA2-5

Analysis of Hydrologic Components and Water Resource Increase for the Watershed Management and Groundwater Dam Construction in Oshipcheon, Korea

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Abstract

The Oshipcheon watershed, a major water source, Yeongdeok-gun, Gyeongsangbuk-do province, has suffered from a continuous drought due to irregularity in precipitation. The construction of surface water dam for securing water resources may cause many problems such as changes in ecosystem and climate, along with water contamination. Accordingly, the groundwater dam is suggested as an alternative for the surface water dam in order to secure water resources. However, analysis and evaluation on various changes in environments such as interconnection of surface water, groundwater and flow change, and drawdown of groundwater level have not been performed, possibly due to technical problems in Korea. In this study, the change in groundwater level due to the construction of groundwater dam was evaluated using a SWAT-K model that integrates surface water and groundwater. In addition, the feasibility of the construction of groundwater dam was also assessed by analyzing the water level duration curve. We calculated the quantity of water resources using the area of watersheds and changes in groundwater level.

KEYWORDS: Oshipcheon watershed, groundwater dam, SWAT-K, water resources

Introduction

The importance of water resources around the world has been emphasized because the persistence of drought increases possibly due to rapid changes in earth environments. Hence there is a need for solution method on how optimal water resources that can afford to meet the demand for the present and the future should be secured. That is one of the important notions in water resources management. The water resources is regarded as renewable but may bring about several problems depending on recovery degree.

Especially because the water resources of Korea have undergone significant imbalance of rainfall with respect to time and space, conditions related to development and management of water resources are greatly poor. Moreover, further development of surface water dam that have been used for most water resources in Korea has been confronted with several problems: the difficulty in the dam site selection due to narrow space in land use, destruction of ecosystem of the dam area to be submerged, and regional self-centeredness. Hence, there have been severe difficulties in ensuring water resources to meet the water demand that constantly increases in recent (Kim, 2009).

To solve those problems encountered in securing of water resources, the construction of groundwater dam has been highly suggested as an alternative method. In Korea six groundwater dams have been operated, but the detailed evaluation of its effectiveness and the state of operation have not been made so far because they were constructed during 1980s.

The basic concept and theory of the groundwater dam were systematically established by Hanson and Nillson (1986). In Korea the groundwater dam was firstly constructed in 1983. It is considered that the groundwater dam has little effect on ecosystem and it also has nothing to do with environmental destruction. Moreover, the land use of surface is possible even after groundwater dam is constructed because there is no land submerged by its construction. Also there is little possibility of dam collapse. Its most advantage is that the installation and utilization for water extraction are freely available. However, the groundwater dam has suffered from some problems which include the scarcity of storage capacity due to an inappropriate method of barrier construction, the reduction of water extraction capacity by exposure to contamination at the upstream area, and indifference to the role of the groundwater dam for securing water resources (Kim et al., 2005; Park et al., 2005; Kim et al., 2009; Kim et al., 2010).

For such reasons, together with recognition of the importance of groundwater dam, several methods have been tried to analyze the effect of groundwater dam. However, most of then use MODFLOW, an analysis model for groundwater flow.

Lim (2002) and Park et al. (2006) investigated the groundwater flow after construction of groundwater dam using the index development for management of groundwater dam and MODFLOW model. Kim (2007) studied hydrologic component analysis of the groundwater dam by SWAT model, commonly used as a surface area model. Since MODFLOW and SWAT models are in reality for groundwater and surface water, respectively, these are evaluated to be insufficient for the analysis model of groundwater dam for which an integrated analysis of groundwater and surface water is required. To this end, Kim et al. (2004) developed SWAT-K model as a perfect interlock per daily unit, which integrates SWAT model and MODFLOW model.

In this study, the effect of the groundwater dam, as an optimum method for securing water resources of the Oshipcheon river basin located in Yeongdeok-gun, Gyeongsangbuk-do province, southern part of Korea, was evaluated. The change in groundwater level was analyzed by SWAT-K model and validity analysis of its construction was presented on the basis of the evaluation result.

Outlines of the Study Area

Topography and geology

The study area, Yeongdeok-up, Yeongdeok-gun, Gyeongsangbuk-do province, is located at the eastern slope of Taebaek Mountains, and it is characterized by topography with hilly section in west and gradually lowering land in east. The geology of the area consists of plutonic rocks such as granite and granodiorite, and acidic to intermediate porphyrytic rocks, and volcanic rocks with pyroclastic rocks, which typify highland. Afterwards, sediments, volcanic clasts and ashes were deposited in the structural basin that formed during Tertiary. With the advent of Quaternary, consistent repetition of a rise and drop of sea level resulted in the sedimentary formation composed of sand and conglomerate which develops parallel to the coast line, forming the uppermost layer in geochronology. The study area is assumed as an optimum site for the construction of groundwater dam because it is located at the coast and has abundant groundwater in alluvium.

Precipitation analysis

Precipitation is certainly necessary for the analysis of groundwater dam because it has great effect on the water level and the recharge rate of groundwater. For this study, annual data recorded by the Yeongdeok atmospheric observatory were used (Table 1). Annual precipitation during the last decade averages 1224.34 mm with an irregular record of 729.30 mm in 2008. For this reason, the drought has been continued to the present. Therefore there is a need for securing water resources by construction of groundwater dam and for analysis related to a possible rise in water level by groundwater dam.

Table 1. Annual precipitation during the last decade.

month year	1	2	3	4	5	6	7	8	9	10	11	12	Precipitation
1999	6.3	16.0	65.8	134.5	134.0	158.3	133.8	351.5	302.0	47.8	13.5	0.2	1363.7
2000	83.5	0.0	28.5	39.5	49.3	104.5	87.0	265.0	281.0	16.0	63.0	0.0	1017.3
2001	35.0	42.5	6.5	13.0	20.5	182.5	74.5	51.5	368.0	170.5	11.0	27.0	1002.5
2002	131.0	0.0	48.5	113.5	100.0	9.5	224.5	533.5	84.5	72.0	0.0	63.0	1380.0
2003	30.6	40.5	52.1	156.5	197.0	228.5	341.5	310.0	245.0	19.5	210.0	9.0	1840.2
2004	34.1	12.8	9.0	92.5	82.0	210.5	191.0	374.0	196.5	8.0	42.0	20.5	1272.9
2005	41.3	35.5	83.1	41.0	35.5	95.5	226.0	248.5	289.5	105.0	3.0	0.1	1204.0
2006	60.0	29.4	17.5	133.0	103.0	30.5	586.5	95.0	70.5	28.0	62.0	21.0	1236.4
2007	8.0	39.0	108.5	20.0	103.5	153.5	151.0	190.0	310.0	42.5	55.5	16.0	1197.5
2008	64.6	2.5	59.0	59.6	48.7	104.0	124.9	124.7	63.0	47.6	18.0	12.7	729.3
Decade average	49.44	21.82	47.85	80.31	87.35	127.73	214.07	254.37	221.00	55.69	47.8	16.95	1224.34

SWAT-K Model

SWAT (Soil and Water Assessment Tool) model, initially developed in USA for a watershed model, has been used in order to predict effects of methods of land management on the behaviors of water analogues and agricultural chemicals as a function of various types of soil, land use, and the state of land management over a long period in regional complex watersheds.

Since its invention in 1994, SWAT model has been continuously improved and to date the model interface was developed by connection with Windows environment and GIS. In Korea it has been widely used in various areas of research such as institute and academic.

Watershed discharge models including SWAT have been mainly applied to the management of surface water, therefore, there is still difficulty in interpreting the groundwater field.

Especially, SWAT model has problems in analysis of groundwater characterized by relatively slow flow rate. On the other hand, since MODFLOW model has no other analysis methods about components of the water cycle except groundwater flow, there is difficulty in determination of recharge quantity of groundwater as main input data. Therefore if making up for the weak points of the two models while keeping merits of both, we can quantify each component of the water cycle. SWAT-K model that integrates SWAT model and MODFLOW model needs hydrologic components such as precipitation, evaporation, infiltration, recharge, stream level, discharge of groundwater, and so on (KICT, 2007), as illustrated in Figure 1.

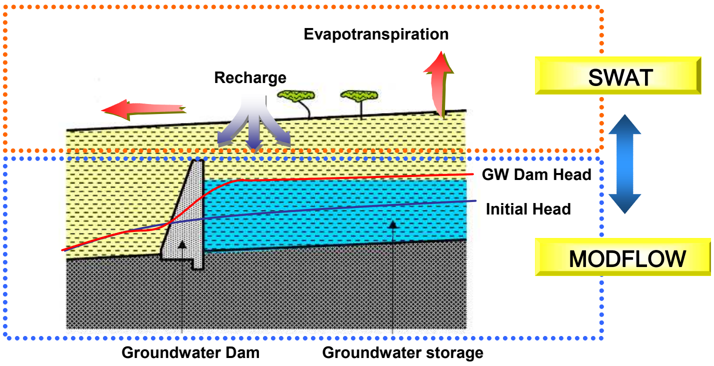

Figure 1. Integrated model of SWAT and MODFLOW.

SWAT-K Model Interpretation

Input data

The study area is a candidate site for groundwater dam where the drought continues. We analyzed an increase of water level at the site where groundwater dam was constructed. Input data including atmospheric data during 1999~2008 (Table 1) and DEM 100 m, soil map, land use map by a numerical map (1 : 25,000) were used for simulation of discharge over a long period using SWAT-K (Figure 2～Figure 4).

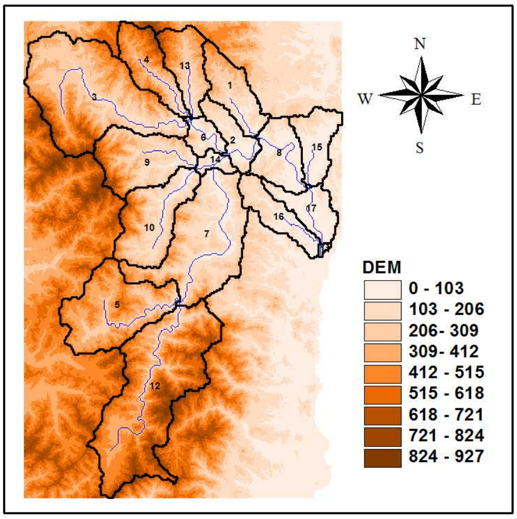

Figure 2. DEM data of the study area.

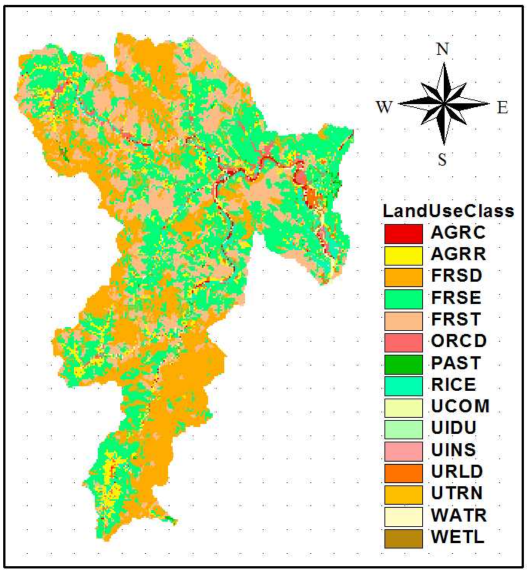

Figure 3. Land use map of the study area.

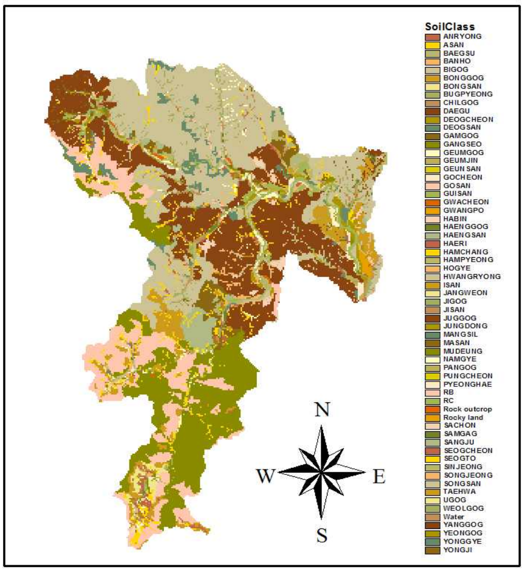

Figure 4. Soil map of the study area.

The area of the watershed is 370.00 km^2 and its total length is 115.26 km. According to the aquifer test, permeability coefficients are 115.26 km for alluvial aquifer, 8.60×10^{-3} m/d for rock aquifer, and 1.0×10^{-8} m/d for groundwater dam, respectively (Table 2). Figure 5 shows the study site, drainage, and subbasin. We analyzed the watershed after subdivision into 17 subbasin.

Table 2. Hydrological data in the study area.

	watershed area (km^2)	stream length (km)	permeability coefficient (m/d)		permeability coefficient of groundwater dam(m/d)
			alluvial aquifer	rock aquifer	
study area	370.00	115.26	29.38	8.60 × 10^{-3}	1.00 × 10^{-8}

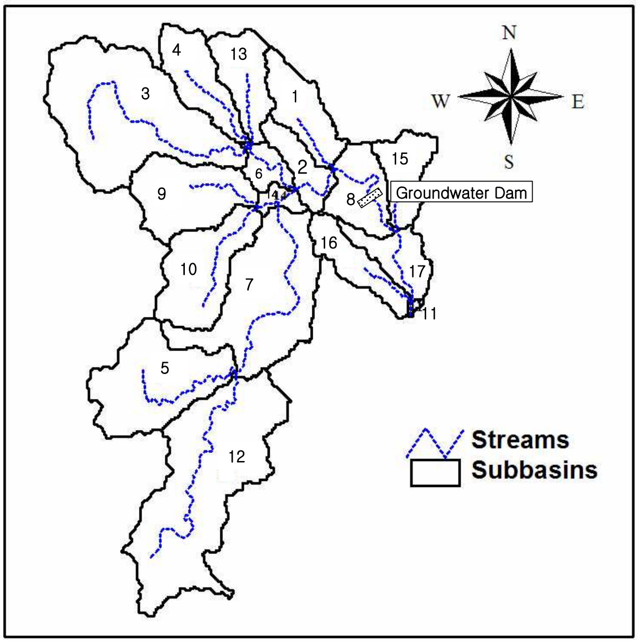

Figure 5. Study site and subbasins.

Comparison of water level before and after construction of groundwater dam

We performed the model analysis to identify the increase effect of groundwater level due to the construction of groundwater dam. In this study, changes in groundwater level at the upstream region and downstream region of the dam constructed were analyzed, respectively. Figure 6 illustrates comparison of groundwater levels at the upstream region of the groundwater dam before and after its construction (2000~2008), showing groundwater level with an increase of about 0.5m after dam construction.

Figure 7 shows comparison of groundwater level at the downstream region of groundwater dam before and after its construction. It was expected that there would be a decrease of groundwater level at the downstream region due to the decrease of inflow from the upstream region. But no decrease of groundwater level was found in the region. This result confirms that there is no problem in groundwater level at the downstream region due to the construction of groundwater dam. Therefore, it is evident that the groundwater dam plays an important role in securing water resources.

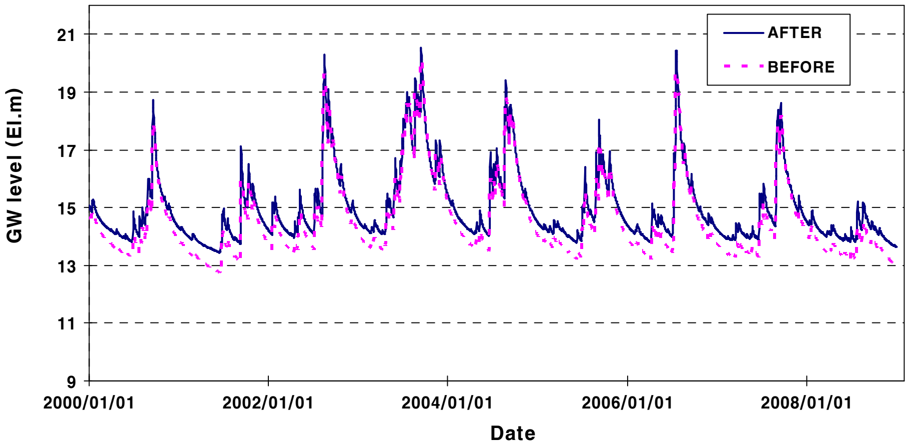

Figure 6. Changes in groundwater level before and after the construction of groundwater dam(the upstream region).

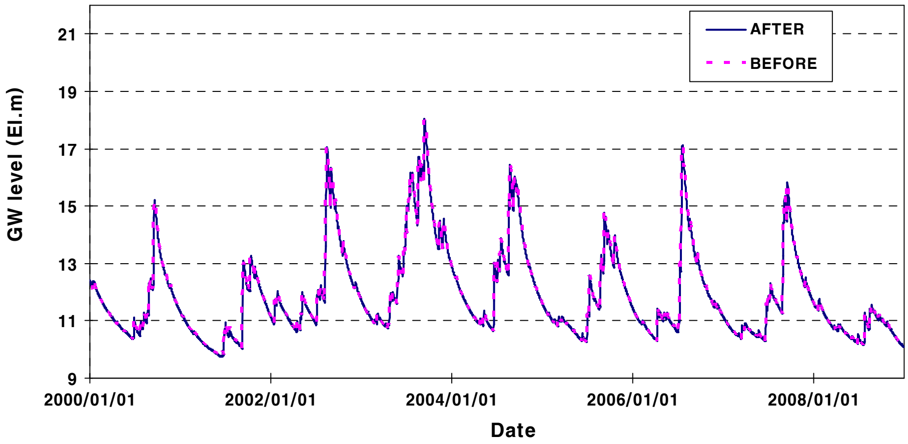

Figure 7. Changes in groundwater level before and after the construction of groundwater dam(the downstream region).

Comparison of groundwater levels before and after construction of groundwater dam with water pumping

Oshipcheon, a major water source of the study area, has suffered from a decrease in water quantity due to the drought. Water shortage in this area results not only from an increase in water supply due to rapid local development but also from the area expansion for the water supply. It is estimated that at least water quantity of 10,000 m^3/d is required for the sufficient supply of water (Yeongdeok-gun, 2009). Accordingly, we predicted changes in the groundwater level using SWAT-K model in order to analyze the effect to surrounding groundwater system if the required quantity 10,000 m^3/d is pumped after the construction of groundwater dam.

Figure 8 shows changes in groundwater level at the upstream region before and after the construction of groundwater dam if water is pumped at 10,000 m^3/d. Figure 9 shows comparison of groundwater level at the downstream region before and after the construction of groundwater dam if groundwater is pumped. After pumping, groundwater levels are similar to those before pumping, which means that groundwater dam has little effect on groundwater level even if the required quantity is pumped.

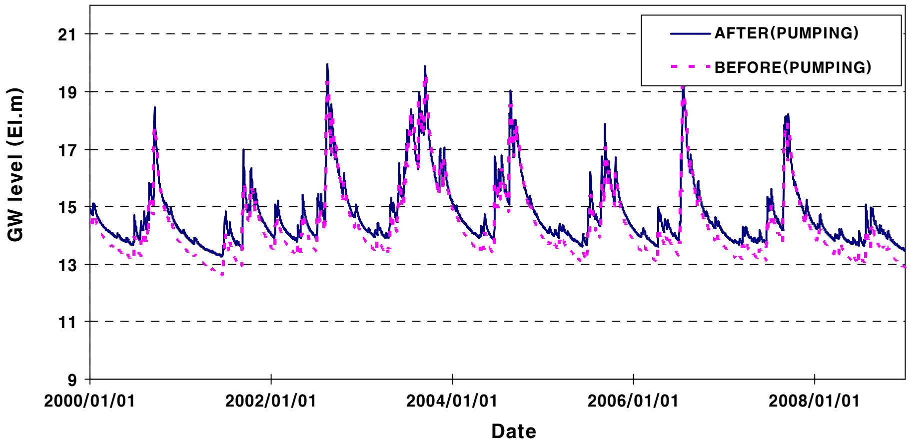

Figure 8. Changes in groundwater level before and after the construction of groundwater dam if water is pumped (the upstream region).

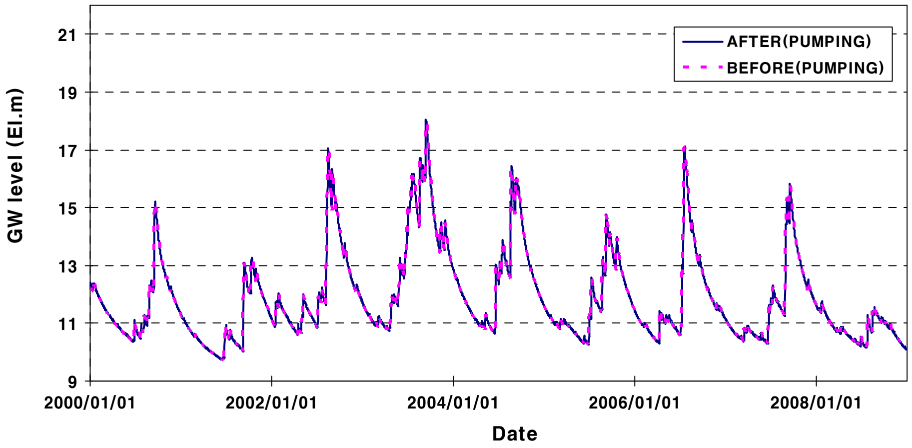

Figure 9. Changes in groundwater level before and after the construction of groundwater dam if water is pumped (the downstream region).

Conclusions

Although utilization of groundwater may cause problems due to a drawdown of groundwater level, such problems can be solved by interconnected management of surface water and groundwater. Especially the flow of groundwater is interactive for alluvial aquifer where surface water and groundwater are interconnected to each other. Therefore, surface water inflows to groundwater system if water level of surface water is high, whereas groundwater discharges to surface water if its level is high. Hence, overall interconnection of surface water and groundwater may minimize the problems attributed to groundwater utilization. In this study, the change in groundwater level resulted from the construction of groundwater dam was evaluated using a SWAT-K model that integrates surface water and groundwater. In addition, the feasibility of the construction of groundwater dam was also assessed by analyzing the water level duration curve. Based on the analysis, there is little change in groundwater level and discharge quantity at the downstream region due to the construction of groundwater dam. It is evident that the construction of groundwater dam plays an important role in securing water resources.

Acknowledgments

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PA2-6

Evaluation of Runoff Prediction at Upper Watershed of Daecheong Reservoir using SWAT-K Model

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Abstract

There have been growing concerns of algal growth at Daecheong reservoir due to eutrophication with excess nutrient inflow. Rainfall-driven runoff and pollutant from watershed are responsible for eutrophication of the Daecheong reservoir. In this study, upper watershed of the Daecheong reservoir was selected and runoff characteristics were analyzed. The SWAT and SWAT-K model were used for evaluation of runoff. The R^2 and the EI value for runoff were 0.87 and -0.86 using the SWAT model, and the R^2 and the EI value were 0.93 and 0.46 using the SWAT-K model. As a result, SWAT-K model has been proven to predict runoff better, compared to SWAT model.

KEYWORDS: SWAT model, SWAT-K model, Runoff

Introduction

Daecheong reservoir which serves as an important source of water supply to Daejeon city and Chuncheong province. In the Daecheong reservoir, since algae alert system was implemented in 1997, except for one year (1999), algae alert was announced in every year including 4 years (2000, 2001, 2003 and 2006) with warning level of the alert system. Dispersion, changes in influent flow, water quality, phytoplankton propagation and plankton community structure are influenced greatly by influent and their qualities which in turn are determined by the intensity and amount of rainfall, land usage, soil ingredients and plantation at the upper watershed of tributaries (NIER, 2009). Therefore, Long-term monitoring would be an ideal method at upper watershed to improve water quality at Daecheong reservoir. However, computer models have been utilized due to limitations in cost and labor in performing long-term monitoring at the watersheds. The Soil and Water Assessment Tool (SWAT) has been widely used for hydrology and water quality researches worldwide over the last a couple of decades. To apply the SWAT to watersheds in Korea, where rainfall-runoff characteristics are not in the similar condition in USA, several medications should be made. Thus the SWAT-K (Kim et al., 2007) was developed by the researchers in Korea. SWAT model uses the variable storage routing method and the Muskingum routing method. These methods are under restriction setting parameter as performing daily runoff simulation.

In this study, one upper watershed of the Daecheong reservoir was selected and runoff characteristics were analyzed using the variable routing method of SWAT2000 (Arnold et al., 1993) and nonlinear routing method of SWAT-K model (Kim et al., 2007) to evaluate model performance of each model.

Methodology

Study Area

Embayment area located at Annae-myun Okchun-goon was selected as the study watershed; rainfall-runoffs were monitored and used to evaluate model performance. The area of the watershed is about 16.5 km^2, and forest area is the dominant land use at watershed (69.4%). Figure 1 is Annae watershed within Daecheong reservoir.

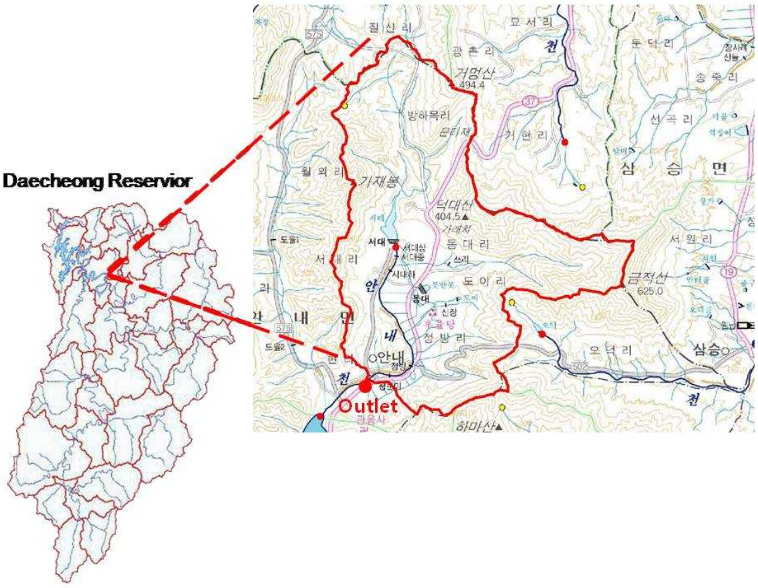

Figure 1. Annae watershed and Daecheong reservoir watershed

Observed runoff data

In this study, to evaluate runoff estimated from SWAT and SWAT-K model, observed runoff data was used (NIER, 2009). Table 1 is observed rainfall, rainfall intensity, and runoff volume. It was observed that rainfall was 5.0 ~ 84.0 mm, rainfall intensity was 0.57 ~ 5.75 mm/hr and runoff volume was 686.16 ~ 536,907.58 m^3. Table 1 data from January to October 2009 were constructed.

Table 1. Rainfall, rainfall intensity, runoff volume at Annae watershed for 2009 (NIER, 2009)

Date	Rainfall (mm)	Rainfall intensity (mm/hr)	Runoff volume (m^3)

09.03.11~12	8.0	0.57	791.00
09.04.20~21	26.0	2.17	724.68
09.05.15~17	47.0	1.34	3,582.36
09.06.03	17.0	5.67	686.16
09.06.09~10	10.5	0.7	2,789.27
09.06.20~21	33.0	2.54	3,838.96
09.07.02~03	5.0	1.67	42,330.20
09.07.07~08	57.0	2.48	376,381.89
09.07.09~11	84.0	1.71	536,907.58
09.07.12~13	63.5	3.18	259,247.08
09.07.17~18	34.5	5.75	152,876.19
09.07.19	8.0	1.6	88,193.28
09.07.21~22	68.0	4.25	316,565.55
09.08.12~13	60.0	1.94	85,000.10
09.08.27~28	15.0	2.14	14,817.73
09.10.17	9.5	4.75	5,071.75

SWAT-K Model parameters

In the SWAT-K model, input data structure of SWAT was maintained to be compatible with other SWAT application. In this study, a pluviometer was installed at the study basin. For the verification, the data were compared with those at Okchun and Boeun sites from KMA (Korea Meteorological Administration).

In this study, 1:25000 scale map provided by National Geographic Information Institute) was used to construct Digital Elevation Model (Figure 2). Soil map was quoted from the detailed soil map (1:25000) of National Academy of Agricultural Science (Figure 3). For the land use data, 1:25000 scale soil surface map provided by the Environmental Geographic Information System (EGIS) of the ministry of environment was used (Figure 4) (NIER, 2009).

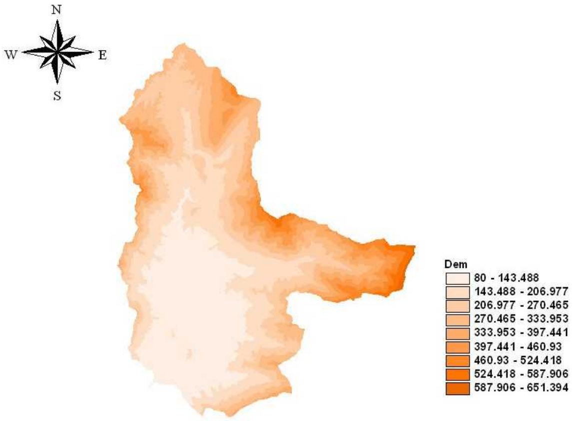

Figure 2. DEM of study watershed

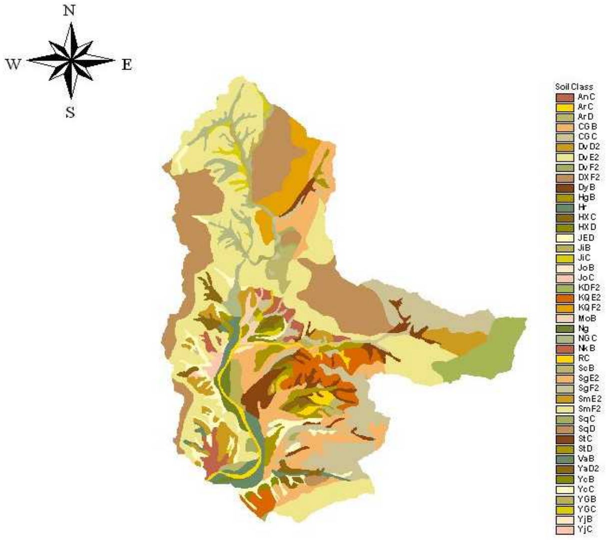

Figure 3. Soil map of study watershed

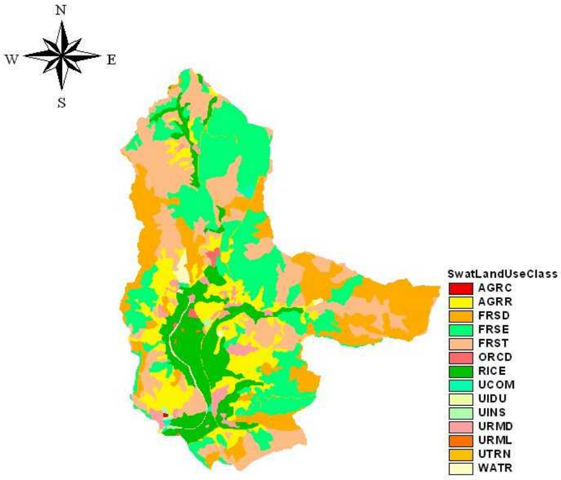

Figure 4. Land use map of study watershed

In this study, the variable storage method of SWAT and the nonlinear storage method of SWAT-K was simulated and compared with observed runoff to evaluate hydrology prediction accuracy.

Results and Discussion

SWAT 2000 model simulation

In this study, SWAT 2000 was calibrated with changes in SWAT input parameters, such as CN2, GW_REVAP. With calibration, The R^2 and the EI for runoff comparisons were 0.87 and -0.86, respectively (Figure 5).

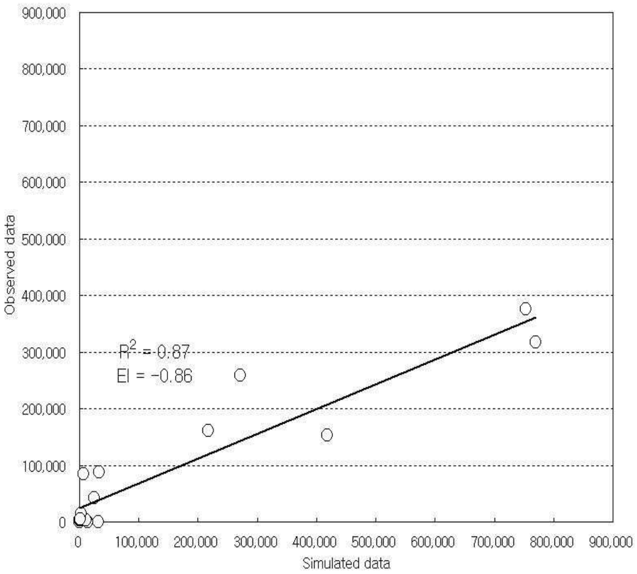

Figure 5. R^2 and EI of runoff estimation after calibration using the SWAT2000 model.

SWAT-K model simulation

The SWAT-K was calibrated with the same procedures. To run the SWAT-K, the SWAT engine was first used to setup SWAT input dataset, and then SWAT-K engine was run. The R^2 and the EI for runoff comparisons were 0.93 and 0.42 after calibration (Figure 6).

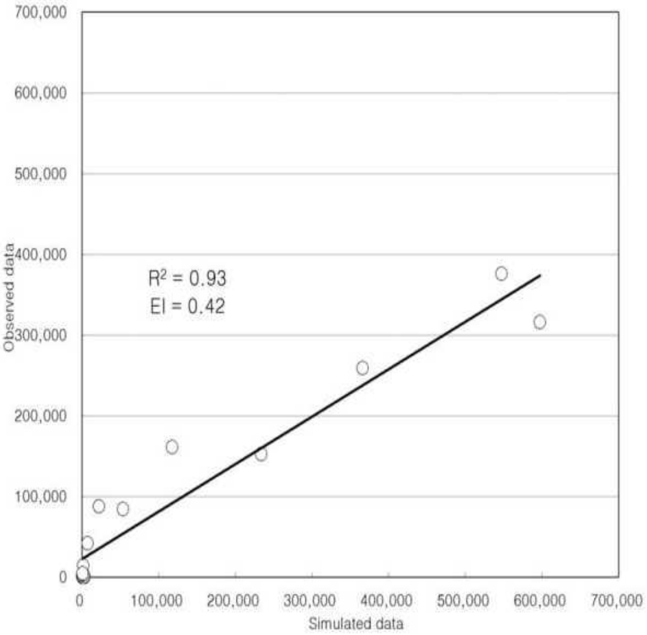

Figure 6. R^2 and EI of runoff estimation after calibration using the SWAT-K model.

Conclusion

There have been growing concerns of algal growth at Daecheong reservoir due to eutrophication with excess nutrient inflow. To predict inflow into Daecheong reservoir with higher accuracy, accuracy of stream flow estimation at upper watershed should be secured. In this study, SWAT and SWAT-K model were evaluated at upper watershed in Daecheong reservoir.

In this study, the SWAT and SWAT-K models were run for the study watershed using the same input parameter values. It was found the SWAT-K estimated values matched the observed flow data with reasonable accuracy. It was found that the SWAT-K with channel flow routing method using nonlinear storage equation was proven to be efficient for runoff estimation at upper watershed in Daecheong reservoir.

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PA2-7

Multi-site Landuse Based Calibration of SWAT Simulated Hydrologic Components

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This project aims at assessing the impacts of several land use change and climate change scenarios on streamflow and water quality to support EPA's Global Climate Research Program's national-scale water quality assessment. The Appalachian-Chattahoochee-Flint (ACF) basin was one of the pilot watersheds simulated in the project. The SWAT model was applied to simulate hydrologic response of ACF River basin, which lies in parts of Georgia, Alabama, and Florida and covers an area of 50,764 km^2. The ACF basin empties into the Gulf of Mexico at Apalachicola Bay.

Within the ACF basin, one HUC 8 was chosen as calibration focus area where intensive model calibration was conducted. A multi-site landuse based calibration was attempted in order to obtain a better spatial calibration and yet have a single parameter set for the entire basin. The basin was calibrated and validated for flow, sediment, and nutrients. The entire ACF basin was divided into 101 sub-basins. The calibration focus area within ACF consisted of 21 subbasins and 1,342 HRUs. The model parameters were adjusted within the practical range to obtain reasonable fit between the simulated and measured flows and water quality. Two other locations: one predominantly forest and the other, predominantly urban were chosen to set the parameters for forest and urban areas, respectively, which were then applied across the entire watershed. There is essentially one set of parameters for a land use type for the entire basin. This approach resulted in very good model performance for the calibration focus area as well as at several other locations within the ACF basin.

Keywords: SWAT, Calibration, Hydrology, Sediment, Nutrients

PA2-8

Assessment of Hydropower Potential using the SWAT Model for Southern Mizoran, India

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In the present study, the Soil and Water Assessment Tool (SWAT) model has been applied to assess the water availability in the Mat River basin of Southern Mizoram, India. The results of the SWAT model along with satellite data have been utilized in the GIS framework to identify potential hydropower generation sites in the Mat River basin. Thirty three potential hydropower sites have been identified within the Mat river basin covering 147.325 km^2 area. A total of 3039.47 KW, 1127.16 KW and 804.98 KW power can be harnessed at 50 %, 75 % and 90% dependability respectively. The results reveal that hydropower potential sites can be efficiently evaluated by use of the SWAT model.

Keywords: Hydrological modeling, SWAT model, GIS, satellite data, hydropower.

SESSION PA3

Climate Change Applicatoins

PA3-1

Water Supply Reliability Assessment Considering Climate Changes

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This research was performed to examine changes in the timing of the growth of crops along with changes in temperatures due to climate changes and to analyze the change of water-supply-reliability by adding an analysis of the change of agricultural water supply patterns in the basin area of Miryang dam in Korea. Had-CM3 model from U.K. was the tool adopted for the GCM model, a stochastic, daily-meteorology-generation-model called LARS-WG was also used for downscaling and for the climate change scenario (A1B) which represents Korea's circumstances best. First of all, to calculate changes in the timing of the growth of crops during this period, the theory of GDD was applied. Except for the period of transplanting and irrigation, there was no choice but to find the proper accumulated temperature by comparing actual temperature data and the supply pattern of agricultural use due to limited temperature data. As a result, proper temperatures were found for each period. 400? for the preparation period of a nursery bed, 704? for a nursery bed's period, 1,295? for the rice-transplanting period, 1,744? for starting irrigation, and 3,972? for finishing irrigation. To analyze future agricultural supply patter changes, the A1B scenario of Had-CM3 model was adopted, and then Downscaling was conducted adopting LARS-WG. To conduct a stochastical analysis of LARS-WG, climate scenarios were generated for the periods 2011~2030, 2046~2065, 2080~2099 using the data of precipitation and Max/Min temperatures collected from the Miryang gauging station. Upon reviewing the result of the analysis of accumulated temperatures from 2011~2030, the supply of agricultural water was 10 days earlier, and in the next periods-2046~2065, 2080~2099 it also was 10 days earlier. With these results, it is assumed that the supply of agricultural water should be about 1 month ahead of the existing schedule to meet the proper growth conditions of crops. At first, water-supply-reliability was analyzed in case the total design discharge is supplied as a form of Firm Supply and considering agricultural water supply pattern change. In 2011~2030, it is not possible to supply water 2,156 out of 7,305 days, which makes water-supply-reliability 70.5%. In 2046~2065 and 2080~2099, it is not possible to supply water 460 and 643 out of 7,305 days, which makes water-supply-reliability 93.7% and 91.2%. Next, it is not considering agricultural water supply pattern change. The results show that it is not possible to supply water 2,197 out of 7,305, which makes water-supply-reliability 69.9. In 2046~2065 and 2080~2099, it is not possible to supply water 484 and 721 out of 7,305 days, which makes water-supply-reliability 93.4% and 90.2%.

From the results of the research, agricultural water supply patterns should be altered. And considering agricultural water supply patterns change, the reliability of water supply becomes more favorable too. Furthermore, since the unique characteristics of precipitation in Korea, which has high precipitation in the summer, water-supply-reliability has a pattern that the precipitation in September could significantly affect the chances of drought the following winter and spring. It could be presumed that better dam-maintenance could be done if the pattern of supply change of agricultural water use could be known in advance and the supply in the end of September is reduced.

However, it could be more risky to make changes to the constant supply pattern under these conditions due to the high uncertainty of future precipitation. Although, several researches have been conducted concerning climate changes, in the field of water-industry, those researches have been solely dependent on precipitation. Even so, with the high uncertainty of precipitation, it is difficult for it to be reflected in government policy. Therefore, research in the field of water-supply-patterns or evapotranspiration according to the temperature or other diverse effects, which has higher reliability on anticipation, could obtain more reliable results in the future and that could result in water-resource maintenance to be safer and a more advantageous environment.

PA3-2

Assessment of the Impact of Climate Change on Watershed Phosphorus Load and Reservoir Eutrophication

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Massive industrialization and the extended use of fossil fuels have caused global climate dynamics and have changed land atmosphere interactions at unprecedented scales. Watershed phosphorus loads are the main cause of reservoir and lake eutrophication which is one of the main problems in water quality management. In this study, a triple model of climate change and watershed with a reservoir phosphorus models are used to evaluate the impact of climate change on watershed phosphorus yield and reservoir eutrophication. The climate change scenarios of a GCM (General Circulation Model) are utilized by a Statistical Downscaling Model (SDSM). The SWAT model is used to estimate the phosphorus load of the watershed based on specified soil and land use and the management practices. The SWAT model is calibrated and validated for a three year period of available observed data. Then 50 years of predicted data of precipitation and temperature are used in the SWAT model to evaluate the climate change impact. The model is applied to the Aharchai River watershed upstream of the Satarkhan reservoir in the northwestern part of Iran. The results show that the model can be considered as an efficient tool in planning the long term management of reservoir eutrophication and watershed phosphorus loads.

Keywords: Phosphorus Load, Climate Change, Statistical Downscaling, SWAT model.

PA3-3

Climate Change Impact Assessment on Soil Water Availability and Crop Yield in Blue Nile Basin (Case Study Anjeni Watershed), Ethiopia

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General Circulation Models (GCMs), currently the most advanced tools for estimating future climate change scenarios, operate at coarse (typically 0.5^o) resolutions. Downscaling of GCM output is necessary to assess the impact of climate change on local water management activities. This study was conducted to quantify changes in water availability and crop production under different climate change scenarios in the Anjeni watershed. This watershed (113.4 ha) is located in Northern Ethiopia at 37°31'E / 10°40'N. Within the watershed terracing is a common soil and water conservation practice. In order to estimate possible climate change impacts on water availability and crop production within the watershed, climate change scenarios of precipitation and temperature were developed for the South Gojam sub basin of area 16,762km^2, in which the watershed is located. The outputs of HadCM3 coupled atmosphere-ocean GCM model for the SRES A2 and SRES B2 emission scenarios were used to produce scenarios for the period 2011 to 2070. These outputs were downscaled to the watershed through the application of the Statistical Downscaling Model (SDSM). Results indicate that for both scenarios there is an increasing trend in annual temperature with A2 scenarios showing greater change than the B2 scenario. Significant variation of monthly and seasonal precipitation (i.e. a decrease in average Kiremt precipitation by about 9 and 7% in 2020 and 6 and 5% in 2050 for both A2 and B2 scenarios) was simulated. These changes in rainfall and temperature were used with the Soil Water Assessment Tool (SWAT) hydrological model to simulate future water availability and crop production. SWAT was calibrated with five years of monthly flow data (1986-1990) and then the model was re-run using the scenario data as input. The results indicate that for both scenarios there is an increasing trend in potential evapotranspiration as well as a reduction in the soil water content in the watershed. The study indicated that due to the combined effect of projected variation in seasonal rainfall, increases in temperature and consequent reduction in soil water, there is likely to be an overall decrease in crop production in the watershed.

Keywords: Anjeni watershed, Climate change, SDSM, Soil water availability, Crop yield and SWAT

SESSION PA5

Sediment, Nutrients and Carbon

PA5-1

Effects of Landuse on Nonpoint Sources Pollutant Loadings at Small Watersheds

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NPS pollutans are closely related to the watershed charateristics, as well as land use within the watershed. Forest watershed has a slower response time for initiation runoff, a lower peak discharge, and a smaller amount of runoff than the agricultural watershed. However, hydrologic and water quality processes in an agricultural watershed in Korea are characterized by typical cutivation system, paddy rice fields. This study was conducted to examine the effects of land-use on NPS pollutants from small watersheds in Korea. Rainfall, stream discharge, and associated sediment and nutrient loadings were periodically monitored at the outlets of forest and agricultural watersheds. The SWAT model was introduced in this study to generate the trends of water quantity and quality on the watershed outlets. A statistical evaluation was performed by comparing the simulated and measured values in terms of runoff, sediment, and nutrient loadings.

Keywords: SWAT, Landuse, Runoff, Sediment, Nutrient

PA5-2

Estimation of Runoff Unit Area Loads for Nutrients from Sloping Cropland and Forest using SWAT model

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Abstract

Runoff unit area loads estimation of nonpoint source pollution for landuse have been customarily calculated based on observed runoff discharge and water quality for a certain specific year due to great expense for getting data, however, it is necessary to consider seriously in Korea which is the region with significant changes of runoff discharge for each year in river channel. In order to estimate runoff unit area loads of representative Nonpoint source pollutants such as T-N, T-P, it can be more reasonable to calculate unit area load based on estimating pollution runoff discharge for many years by using SWAT model.

In this study, Flowrate, T-N and T-P were measured for the SWAT calibration and verification from 2005 to 2006 in Bonggok watershed which located at Banpo-Myeon, Gongju City, Chungcheongnam-DO of the Republic of Korea as a representative forest area including reclamated sloping cropland. and then unit area load of T-N and T-P was estimated from sloping cropland and forest

As the result of implementing calibration and verification of SWAT model by using daily runoff discharge data which were actually measured during 2005~2006, Nash-Sutcliffe coefficient(NTD) for flowrate was 0.70~0.76 and Coefficient of Detemination(R^2) showed values of 0.80~83 and Nash-Sutcliffe coefficient(NTD) for T-N and T-P load was 0.54~0.72 and Coefficient of Detemination(R^2) showed values of 0.62~0.86. And then SWAT simulation was performed from 1997 to 2006 with optimal parameters determined through calibration process so as to estimate long-term unit area load from sloping cropland and forest in experimental watershed

As the result of calculating unit area load for T-N and T-P for the past 10 years with SWAT model, T-N unit area load from forest was 3.29kg/㎢?day and T-P unit area load was 0.15kg/㎢?day and T-N unit area load from sloping cropland was 11.15kg/㎢?day and T-P unit area load was 0.70kg/㎢?day. It showed that a little bigger than the unit area load suggested by calculation based on short-term measured data, it was judged that we can manage more efficiently nonpoint pollution sources in Target watershed by using average annual discharge load which was estimated with long-term simulation data of SWAT model .

Keywords: SWAT Model, T-N, T-P, Uunit area load, Sloping cropland, Forest, Nonpoint pollution source.

Introduction

Nonpoint source pollutants discharged in forest areas or fields are closely related to precipitation-discharge. Therefore, about 80% of nonpoint source pollutants are discharged between May to September, and 20% in dry season from October to April. As this shows, since nonpoint source pollutants are discharged when it rains, there are big changes in daily, and seasonal discharged amount, and because they change depending on regional characteristics such as climate, geography, land use and land slope, and river basin's shape, for quantification of pollutants, there is a need for observed data about accurate water flow and water quality during precipitation. However, for collecting observed data about nonpoint source pollutants during precipitation, water flow and water quality should be measured. There are few in-depth observed data, because large budget and many workforces are required.

This study precisely measured yearly discharge and water quality when it rains and when it is clear in fields and forest areas and calculated discharge unit area, and for quantification in other areas, SWAT model, which is widely used in korea and abroad, was used for standardization. SWAT model, quasi distribution type of discharge model, was applied to rural areas' forest areas and fields in Bonggok-Ri, Banpo-Myeon, Gongju City, and simulated generation about discharged amount of nonpoint source pollutants from forest areas and fields and nutrients was conducted, which is expected to be used as a basic data for management measure of nonpoint source pollutants and nutrient unit area load calculation would be provided using modeling.

Literature Review

Nonpoint source pollutants are pollution sources that are distributed as surface, and most of them are discharged during precipitation. In Korea, for the first time in 1994, research on land use regarding nonpoint source pollutants and nation-wide pollution contribution degree were conducted. Lee et al.(1998) examined soil loss amount and used it as a basic data for comprehensive conservation and management for soil and water resources. Jung et al.(1976) examined soil and nutrients loss amount in sloping area and conducted a research on soil loss prediction and classifying nutrient loss conditions. In addition, Yoon et al(2001) analyzed discharge characteristics of nonpoint source pollutants by characteristics of land use. Damages from soil loss included productivity reduction from cropland area loss(Jung, 1998; Lee et al., 1998 ; Shin et al., 2003),burying of reservoir or river due to accumulation of carried soil (Kim et al., 2003 ; Lee et al., ; Oh et al., 1977), and river pollution from cropland's nutrients loss(Ann et al., 1996 ; Jung et al., 1998 ; Jung et al., 2000 ; Kim et al., 1997).

It has not been long since people recognized the importance of nonpoint source pollutants in Korea, because policies were implemented centering on point source pollutants. Accordingly, compared with various efforts for water quality improvement, the effect of water quality improvement is not that significant. Fortunately, in "Nationwide nonpoint source pollutants research project "conducted by Ministry of Environment in 1995, established unit of nonpoint source pollutants in areas such as city, paddy field, field, forest area and pasture, and estimated generated amount of nonpoint source pollutants. Based on them, contribution degree of nationwide nonpoint source pollutants was examined, which led to introduction of various measures for nonpoint source pollutants in 'Water management comprehensive measure' in 1997 and 'Special comprehensive measure for water quality improvement of Paldang waterworks such as Han river' in 1998.

In addition, in 2000, through “Paldang watershed nonpoint source pollutants optimal management project validity research and basic plan establishment(2000.6)”, optimal management technologies by land use characteristics were provided, and based on them, in major nonpoint source pollutants inflow areas, nonpoint source pollutants reduction facility establishment projects such as undercurrent area, swampy land purification facility, nitrogen and phosphorus elimination facility using natural purification method are planned to be implemented for improving the water quality of Paldang lake to the first grade by eliminating nonpoint source pollutants in Paldang watershed. In addition, in other watersheds such as Nakdong river, Geum river and Youngsan river, based on research on nonpoint source pollutants, it is planned to focus on preventing water pollution in river and lake by establishing nonpoint source pollutants management measures suitable for characteristics of watershed and by minimizing water pollution factors from nonpoint source pollutants, and basic ‘nonpoint source pollutants management guidance’ for managing nonpoint source pollutants in a desirable way was made and distributed for nonpoint management use by local autonomous government, project practitioners, stock raising farmhouse and general public.

Robillard et al.(1982) reported that among activities regarding stock raising, nonpoint source pollutants affecting commonly water quality reduced dissolved oxygen. And it was also reported that discharge of nonpoint source pollutant from various land activities caused nitrogen richness, and ammonia nitrogen was related the most with stock raising activity and problems and measures were offered regarding soil loss and farming management methods.

In the U.S. and Europe, land use and land cover were defined differently, in environment fields, use of land cover map is being emphasized. Land cover map was greatly different from land use current situation considering production purpose and characteristics of used data. Therefore, for making total pollution load management system proper, current unit system should be changed to land cover item, and utilization method for right use of land cover map and academic research on new unit system establishment should be conducted. And in the U.S. where nonpoint source pollutants management was first conducted, from 1970s related model has been developed and currently it is composed of GIS and nonpoint source pollutants.

As the fact that nonpoint source pollutants significantly affect water quality was accepted, some nations showed great interest in this management, and IAWQ(International Association on Water Quality) organized research group of experts in the field of nonpoint source pollutants and active research activities are being made.

Pollutants Discharge Unit Interpretation

To briefly define unit discharge load, it is the pollutants amount discharged from unit land area per hour, and the unit is either nonpoint pollutants load (kg or tons)/area(ha or ㎢/time(yr or day). Although many problems are being raised regarding unit discharge amount by land use of nonpoint source pollutants, due to simplicity of use and easiness of existing data application, it is being widely used, and in nonpoint source pollutants model, formulas of unit discharge amount by landuse along with land use, land characteristics and irrigation hydrology matters. Unit discharge load amount calculation methods currently being used include calculation using empirical formula and actual survey which calculates by observing flow amount and pollution load amount in watershed.

Calculation method

Calculation is done by dividing permeable area and impermeable areas of watershed land. For permeable land, USLE(Universal Soil Loss Equation) formula is used to predict yearly average of soil loss from long term rainfall event. And rainfall event depending on region, the region's land shape, slope and land cover are also important factors. The calculation method using USLE calculates loss amount for unit area through the formula below and specific nonpoint pollutants loss amount and content amount relations are used for unit calculation.

$$Y(s) = R \times K \times LS \times Cv \times P$$

Y(s) = soil loss amount(㎥/ha/year)

R = Rainfall erosivity factor

K = Soil erodivility factor

LS = Slope length and steephess factor

Cv = Cropping management factor

P = Conservation practices factors

Actual survey method

There are largely three kinds of unit discharge load calculation according to research method. First, on the soil surface, total amount of pollutants is measured and accumulation rate and disintegration rate are applied, and it is mainly used in urban areas for calculating unit discharge load of nonpoint source pollutants. Second method is to measure density by directly collecting discharge matters during precipitation by land use. Third one is to compare water quality of river upstream and downstream that pass through certain areas during rainfall and calculate nonpoint source pollutants unit discharge load in the watershed in question by converting difference of water quality, which is the most reliable method in unit calculation. This method is also used in examining correlations by using regression formula and using observed flow amount, precipitation, and amount of pollutants discharge as well as in calculating single rainfall event, and monthly, seasonal and yearly unit calculation of pollutants by calculating pollution load.

The method used in calculating unit discharge load in major nations is determined depending on basic data accumulation, In the case of the U.S. that has sufficient data, regarding pollutants about which unit discharge load, years of continuous measurement water quality data and flow amount date are used for calculating unit discharge load. In other words, sample automatic collector and flow amount automatic measuring instrument are used for remote transmission, and among water quality items, temperature and dissolved oxygen are measured in local area directly and the date is transmitted, and pH, turbidity and Alkalinity are tested immediately after sample collecting. In addition, SS, various nitrogen (NH_3-N, dissolved organic nitrogen, nitrogen attached to sediment and so on), and phosphorus (dissolved phosphorus, phosphorus attached to sediment) are refrigerated and transmitted to laboratory after sample collecting for analysis, and thorough this method, density is measured and flow amount and density data are combined to calculated unit discharge load by single rainfall event, and year. As this shows, the U.S. uses years of data using automatic measure facilities and calculate unit discharge load, and the calculation method is like the following.

$$\text{Nonpoint source pollutants unit discharge load(kg/ha/yr)} = \sum CiQi/A$$

Ci : density in order of i(mg/l) Qi : flow amount in order of i (ton/year), A : watershed area(ha)

In the case of Japan, rather than long term continuous data is used, rainfall-discharge-pollution measurement data for numerous times are used and they are connected with yearly rainfall or flow amount for calculating nonpoint source pollutants discharge load and the method is like the following.

Nonpoint source pollutants unit discharge load (kg/ha/yr) = $k\sum CiQiTi * 365\sum t$

Ci : density in order of i (mg/l)

Qi : flow amount in order of i (ton/year)

Ti : time interval regarding sample[(former sample collecting time-present time sample collecting time)/2+(present sample collecting time – next sample collecting time)/2]

k: conversion coefficient, $365\sum t$: yearly unit conversion coefficient

This method cannot conduct actual survey of nonpoint source pollutants for a year continuously, therefore calculated values about sample collecting time are converted and used. The methods to convert unit discharge load yearly include rainfall time application method, rainfall weighting density method, and discharge amount weighing method. Table 1 shows the methods used for converting short term nonpoint source pollutants load into yearly unit.

Table 1. Methods used for converting short term nonpoint source pollutants load into yearly unit

Applied method	Calculation formula	Calculation details
Direct rainfall frequency application method	L=N . Ia	Yearly load=yearly discharge frequency×average load per discharge frequency
Valid rainfall method	L=Ia(Pa/pa)	Yearly load = average load per discharge frequency ×(yearly average valid flow amount/average valid flow amount per frequency)
Discharge rate method	L=Im(Qm/qm)	Yearly load=actual survey flow amount weighing average density×(yearly discharge/actual survey discharge)
Discharge-weighing density method	L=N(Ia(Qa/qa)	Yearly load=yearly discharge frequency×(average load per frequency×(average load per discharge in population group /average load per discharge in sample)

Examination of existing unit

(1) Farmland

Important nonpoint source pollutants related to farmland, in the case of field, include eroded matter and nutrients (nitrogen and phosphorus) and in the case of paddy field, eroded matters and dissolved nutrient that absorbed agricultural chemicals and nutrient.

Since the discharge characteristics of field and paddy field are different, Korea and Japan divide into field and paddy field for offering unit, but the U.S. offers unit by unifying into cropland.

In Korea's field, except for special cases, there is no such case that conducts irrigation affecting material balance. Therefore, as for inflow and outflow channels related to nonpoint source pollutants discharge are composed of inflow and soil surface runoff by fertilizer, rail fall and falling dust and discharge through underground penetration.

Among them, soil surface discharge is very small, and it is true that underground penetration amount is related to fertilization, but it becomes larger with more rainfall. In particular, nitrogen is closely related to underground penetration amount and fertilization amount, and according to a survey in Japan, nitrogen fertilizers underground penetration rate is above 32%. In the fields of oxidation condition, nitrogen rapidly oxidizes into nitrate nitrogen and eluviates in land, therefore there is a clear correlation in counter measuring fertilization amount. In the meantime, phosphorus is strongly fixed to land, it does not have significant correlation with underground penetration and it is discharged mainly through land surface runoff.

Table 2. Nonpoint source pollutants unit in field (unit: kg/ha/yr)

Classification	reference	BOD	COD	SS	T-N	T-P
field	Whipple et al.(1976)	-	-	-	6.50 (0.10~13.0)	1.5 (0.07~2.88)
	Cemola et al.(1979)	17.9 (4.0~31.0)	-	2241 (285~4205)	25.9 (15.0~36.9)	1.06 (0.18~1.61)
	Jennings, M/E.(1980)	-	48.2	286.2	1.28	0.3
	Sonzogni et al.(1980)	-	-	1460 (200~4800)	9.12 (0.37~17.9)	2.56 (0.37~17.9)
	BongSoo Rim(1984)	23	91	23	-	-
	DongKyun Kim, et al.(1987)	25.9	-	-	-	0.62
	YoonSoo Seo(1987)	6.57	32.9	350.4	12	3.98
	Woodward-Clyde(1989)	17.9	-	450	25.9	1.06
	EuiSo Choi, et al.(1991)	8.4	-	-	-	1.93
	SangChul Shin et al.(1992)	23.7	-	-	-	2.77
	Water quality information comprehensive management system development (1995. 12)	4.62	-	416.45	3.44(TKN)	0.53

cropland	Paldang watershed nonpoint source pollutants optimal management project (2000.6)	19.3	34.5	355.9	6.8	0.5

Table 3. Nonpoint source pollutants in fields(4 major rivers) (unit : kg/ha/yr)

Classification		BOD	COD	SS	T-N	T-P	비고
Field	Han river	2.9	12.2	722.6	58.60	0.87	
	Nakdong river	3.5	7.4	233.0	39.83	0.83	
	Geum river	9.8	27.6	195.0	19.35	1.49	
	Youngsan river	7.1	18.9	23.0	20.03	0.31	
	National average	5.8	16.5	293.4	34.45	0.88	

data) Ministry of Environment, Report on nonpoint source pollutant survey research(1995. 11)

In the case of Korea, Table 2 and Table 3 show nonpoint source pollutants in field of 5.8~25.9kg/ha/yr of BOD, and in the case of the U.S., it shows 5.5~31.0kg/ha/yr, which is similar to that of Korea.

(2) Mountainous area

When rainfall flows through forest and into valley, it meets with land and in this course physically and chemically it is changed. Generally, materials that have positive(+) material balance include ammonia, total nitrogen and total phosphorus and materials that have negative(-) material balance include K, and Na. Nitrogen and carbon abound in mountainous area, most of them are accumulated in land, and nitrogen in forest land is several tons per hectare, but the mount absorbed by tree for a year barely exceeds 200kg/ha.

Nitrogen in land exists as organism in most cases and it is slow to be changed into inorganic matters. In temperate zones, generally, the speed to become inorganic is 20~400kg/ha/yr, almost identical with the absorbed amount per year by forest, therefore, discharged nitrogen as discharged water from mountainous area is not above10kg/ha, recirculation to accumulated amount is 10%, discharged amount is 1%, which means a very slow speed of circulation. In addition, since in mountainous area, most other pollutants strike a balance when it comes to inflow and outflow, as far as ecosystem is disturbed artificially, nonpoint pollution load in mountainous area is very small compared with other areas.

Table 4 and Table 5 show nonpoint source pollution unit of 4 major rivers and unit of exiting mountainous areas.

Table 4. Nonpoint source pollution in mountainous areas (4 major rivers)(unit : kg/ha/yr)

classification		BOD	COD	SS	T-N	T-P	비고
Mountainous area	Han river	5.0	9.3	1143.5	24.34	1.84	
	Nakdong river	1.4	4.2	22.5	4.15	0.05	
	Geum river	4.2	15.0	84.0	1.10	0.12	
	Youngsan river	3.2	8.8	8.9	2.48	0.05	
	National average	3.5	9.3	314.7	8.02	0.52	

Table 5. Nonpoint source pollution unit in mountainous area (existing research) (unit: kg/ha/yr)

classification		BOD	COD	SS	T-N	T-P
mountainous areas	Whipple et al.(1976)	-	-	4.75 (0.69~8.80)	8.0 (3.0~13.0)	0.47 (0.029~0.91)
	Cemola et al.(1979)	5.11 (3.6~6.94)	-	97.8 (44.9~132.1)	3.10 (2.41~5.11)	0.10 (0.011~0.073)
	Jennings, M/E.(1980)	-	13.43	4.02	0.95	0.11
	BongSoo Rim(1984)	3.65	9.86	4.75	-	-
	Kuk Gong(1986)	-	13.9	-	3.58	0.11
	YoonSoo Seo et al.(1989)	3.56	-	-	-	0.036
	Woodward-Clyde(1989)	5.11	-	85.1	2.92	0.11
	SangChun Shin el al.(1992)	2.56	-	-	-	0.073
	Kuk Gong (1992)	-	-	-	2.56~6.94	0.15~0.18
	Water quality information comprehensive management system development (1995. 12)	3.51	-	329.94	2.29(TKN)	0.33
	Paldang waterworks nonpoint source pollutants optimal management project (2000.6)	3.4	7.2	333.4	1.3	0.1

Study Area and Data Survey

Watershed

In this study, watershed of Bonggok-Ri, areas with characteristics of farmland's continuous pollutants discharge were selected (Figure 1). As for selection criteria, in the case of mountainous area, in the range of continuous water utilization movement, areas were selected, and areas of 3°~ 5°variation of vegetation and slope on the same line were selected. In the case of cropland (field), areas where flow water from forest area are transmitted directly and areas that are not affected by flow water were selected as controlled group and in the case of crop land (field), out of non-affected area from forest area, two regions were selected respectively.

Figure 1. Experimental watershed map

Water flow and water quality Survey

(1) Survey period

When it rains and when it is clear, measuring water flow amount and water quality were conducted on the same point from 2005 to 2006, and researches were conducted in two point (②, ④ points) within watershed where measurement is easy. In addition, at the end of point 4, pressure type flow amount instrument (Flowtote-2) was used to calculated flow amount and point 2 was calculated with specific-flowrate method.

SWAT Model's Application and Result Analysis

GIS basic input data establishment

For application watershed basic map, 1:25,000 NGIS (National Geographic Information System) figure map and Rural Development Administration's 1:25,000 precise soil map were used, and for land cover map, Environmental Geographic Information System (EGIS) 1:25,000 land cover middle classification was used. Theme map established Digital Elevation Model (DEM), and from 1:25,000 precise land map, hydrologic land group map, land properties, land erosion factor, penetration coefficient, and measurement density data was established. In addition, EGIS's 1:25,000 land cover map was used to calculate research area's cover map.

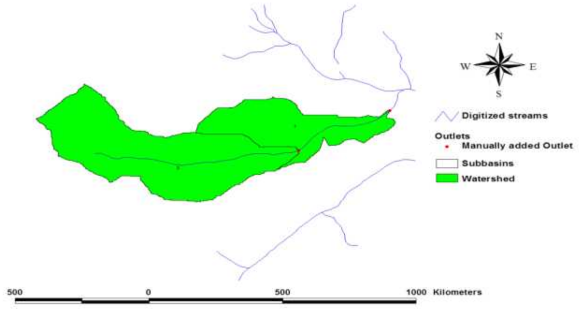

Figure 2. Water system map of applied watershed

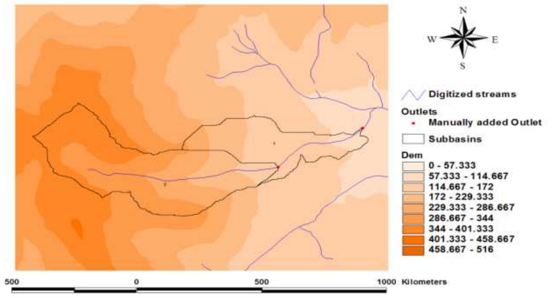

Figure 3. DEM of applied watershed

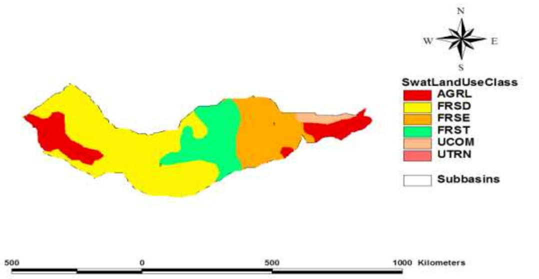

Figure 4. Land cover map of applied watershed (middle classification)

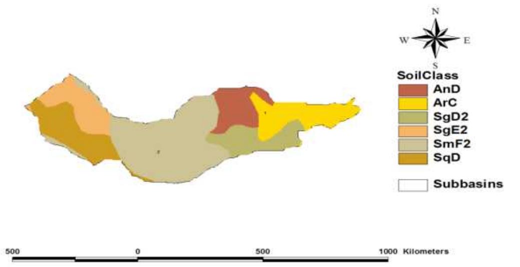

Figure 5. Precise land map of applied watershed (1:25,000)

DJDS.dbf, DJOP.dbf, DJRH.dbf, DJTP.dbf, and DJWS.dbf, files of insolation, rainfall, relative humidity, highest/lowest temperature, wind speed were established, in the 5 files, location information of two weather station (Daejeon, Banpo) and data file's names such as solkeumbk.dbf, pcpbk.dbf, humkeumbk.dbf, tmpkeumbk.dbf, winkeumbk.dbf for each station respectively.

Evaluation method of model implementation result

Evaluation index method is mainly used for hydrologic model's evaluation and COE defined like the following.

$$COE = 1 - \frac{\sum_{i=1}^{n} (\beta_{mi} - \beta_{ci})^2}{\sum_{i=1}^{n} (\beta_{mi} - \overline{\beta}_{m})^2}$$

.

COE means evaluation index of discharge amount, n means comparison days, , β_{mi} means observed discharge amount, β_{ci} means presumed discharge amount, and $\overline{\beta}_{m}$ means average discharge amount through the whole period.

COE has the value from -∞ to 1, in ideal case it is 1, and this means in the relationship between presumed value and observed value there is a identical relationship of 1:1.

As a complement method for evaluation index, coefficient of determination (R^2) value was additionally offered, evaluation of total pollution load during corrected period was evaluated using relative error.

Calibration of model

(1) Runoff calibration

(a) Parameter calibration

In this study, simple and widely used simple trial and error method was used even though it takes time. The calibration of model was calibrated using runoff amount measured at the final outlet point of applied watershed in 2005. As for criteria for model's calibration, it was calculated with observed values and coefficient of determination through simulated regression analysis and evaluation index method.

(b) Runoff amount calibration

For calibration of runoff discharge, this research calibrated by selecting parameters using calibration tool provided by SWAT model itself. As a result, CN_2 increased 8 compared with standard value of model.

Table 5. Discharge amount parameter and calibrated values

Input file	Parameter	Calibrated value
*.mgt	CN_2(Curve number)	△ 8

Table 6. Evaluation index and coefficient of determination of runoff amount by point

Classification	Point 2	Point 4
Nash-Sutcliffe coefficient(NTD)	0.70	0.76
Coefficient of Determination(R^2)	0.80	0.83

Figure 6 and Figure 7 show changes in observed and simulated values according to 2005 rainfall, the correction period, and as the Figures show, calibration values relatively well reflect observed value.

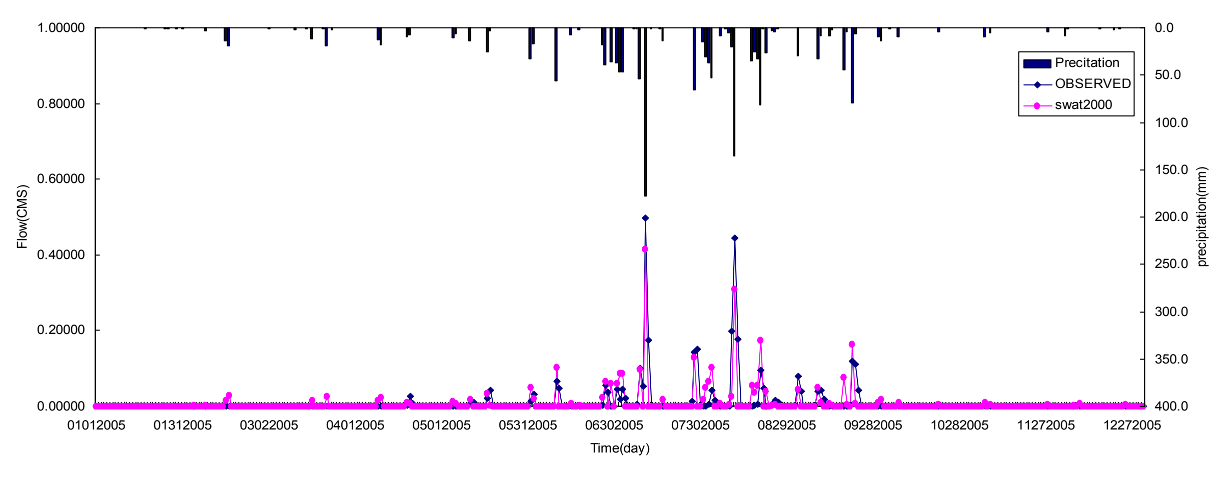

Figure 6. Simulated and observed values of runoff flowrate on daily base (point 2)

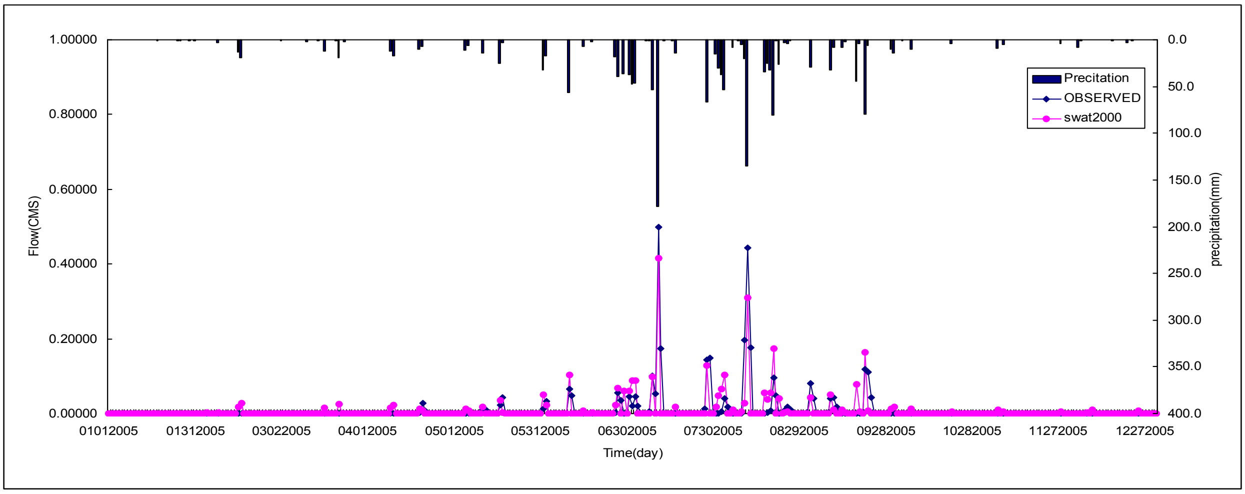

Figure 7. Simulated and observed values of runoff flowrate on daily base (point 4)

(C) Calibration of nutrients

This study calibrated values by selecting parameters using calibration tool provided by SWAT model itself. As a result, NPERCO was increased by 0.3, PPERCO by 10, PHOSKD by 180, SOL_LABP by 0.95, SOL_NO_3 by 0.01, correcting parameters.

Table 7 shows parameters that are used for calibrating total phosphorus and total nitrogen and optimal values.

Table 7. Nutrient parameters and opimal values

Input file	Parameters	Corrected values
*.bsn	NPERCO	0.3
*.bsn	PPERCO	10
*.bsn	PHOSKD	180
*.chm	SOL_LABP	0.95
*.chm	SOL_NO_3	0.01

From Figure 8 to Figure 11 show correlations between T-N, T-P nutrient observed values and simulated values about point 2 in 2005. From Figure 12 to Figure 15 show correlations between T-N, T-P nutrients observed values and simulated values about point 4 in 2005. As the figures show, calibrated values relatively well reflect observed values.

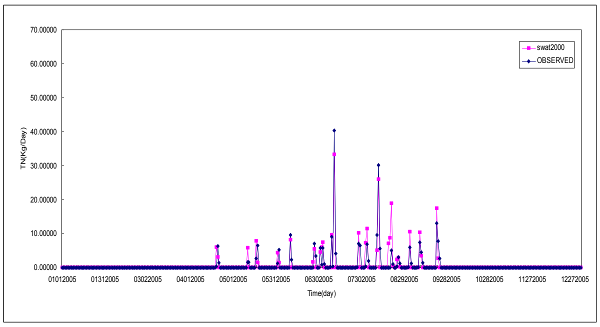

Figure 8. T-N simulated and observed values (point 2)

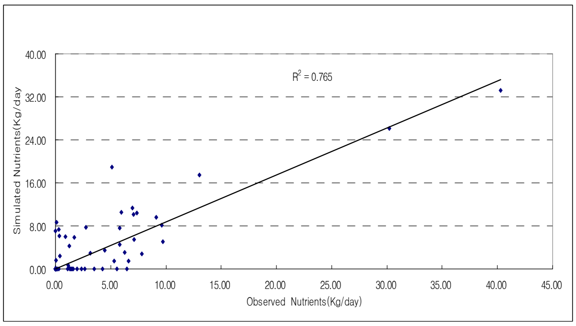

Figure 9. T-N simulated and observed values correlations (point 2)

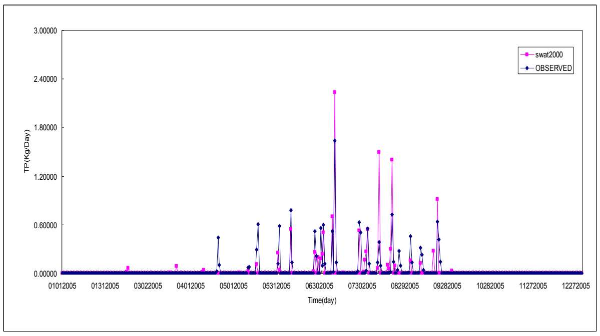

Figure 10. T-P simulated and observed values (point 2)

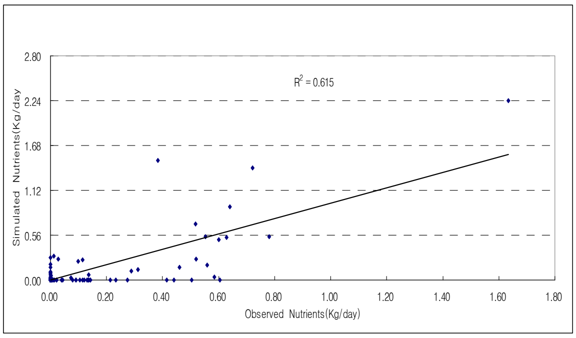

Figure 11. T-P simulated and observed values correlations (point 2)

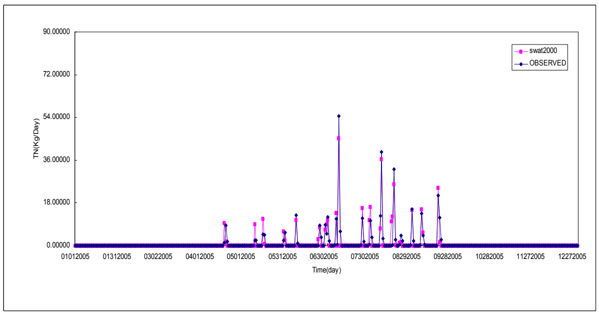

Figure 12. T-N simulated and observed values (point 4)

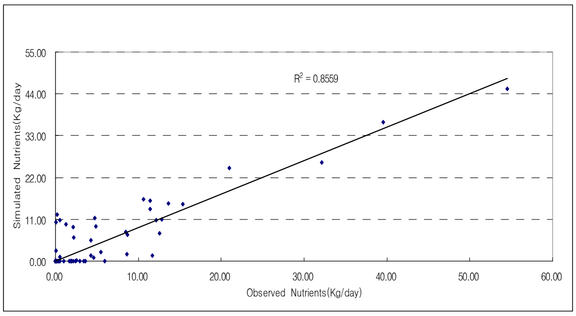

Figure 13. T-N simulated and observed values correlations (point 4)

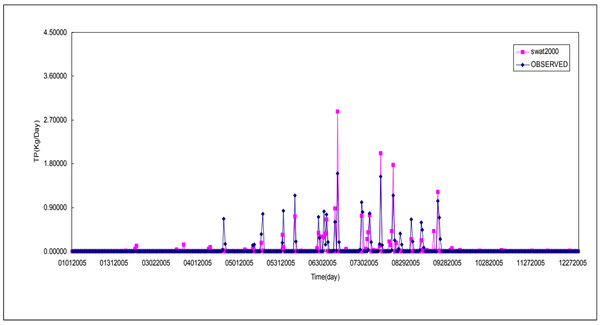

Figure 14. T-P simulated and observed values (point 4)

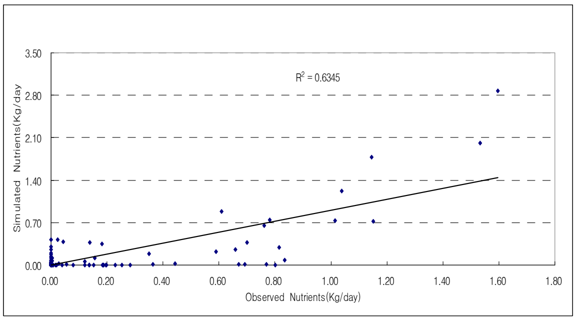

Figure 15. T-P simulated and observed values correlations (point 4)

Table 8. Evaluation index and coefficient of determination of total nitrogen and total phosphorus by point

Classification	T-N		T-P	
	Point 2	Point 4	Point 2	Point 4
Nash-Sutcliffe coefficient(NTD)	0.65	0.72	0.54	0.54
Coefficient of Determination(R^2)	0.77	0.86	0.62	0.63

Long term simulation and result analysis

(1) Yearly load calculation

Table 9 shows calibrated result of SWAT model and observed T-N, T-P loads. Loads of field and nutrients load calculation set as the difference between point 4 and point 2, and in the case of forest area, for nutrients calculation value of point 2 was used.

Table 9. Yearly load calculation of observed and simulated values (2005)

※ Precipitation In 2005		1656.1 mm	
Classification		Forest land (kg/year)	Field (kg/year)
T-N	Observed loads	241.8	113.5
	Simulated loads	251.5	96.8
T-P	Observed loads	13.8	6.7
	Simulated loads	12.1	5.2

(2) Yearly unit calculation

It was divided by forest area and field area respectively and Table 10 shows unit calculation like the following.

Table 10. Unit calculation of forest area and field area (2005)

Area (㎢)		0.23	0.02
Classification		Forest land(kg/㎢.day)	Field(kg/㎢.day)
T-N	Observed loads	2.88	14.55
	Simulated loads	2.99	12.41
T-P	Observed loads	0.16	0.86
	Simulated loads	0.14	0.67

(3) Load calculation of the past decade through SWAT model

Calibrated parameters through SWAT model and 2005 observed data were applied and for the past decade (1997~2006), at point 2 and 4, as Table 11 shows, average loads were calculated.

Table 11. Load calculation of the past decade through SWAT model

Classification(year)	Precipitation (mm)	Point 2(kg/year)		Point 4(kg/year)	
		T-N	T-P	T-N	T-P
1997	1765.9	494.8	53.1	595.2	62.8
1998	2070.0	359.5	12.2	481.8	18.8
1999	1455.2	265.1	6.6	343.9	11.0
2000	1707.5	297.6	10.5	400.5	15.9
2001	828.7	143.0	2.8	178.5	5.1
2002	1378.7	257.6	9.5	321.7	14.0
2003	1748.9	267.0	8.8	362.1	14.1
2004	1496.5	235.7	7.9	327.4	12.3
2005	1656.1	251.5	12.1	348.3	17.3
2006	977.0	150.5	5.2	213.0	8.1

From 1997 to 2006, through SWAT simulation of the past ten years, nutrient load calculation of sloping field in Bonggok stream watershed were calculated with the average difference of the past ten years of point 4 and 2, and for forest areas' nutrient calculation, the average value of point 2 of the past ten years was used. The calculation results showed that load per unit was 3.29kg/㎢/day in forest area, and load of T-P unit area was 0.15kg/㎢/day. Load per T-N unit are in sloping field was 11.15kg/㎢/day and load per T-P unit area was 0.70kg/㎢/day.

Conclusion

In this study, Flowrate, T-N and T-P were measured for the SWAT calibration and verification from 2005 to 2006 in Bonggok watershed which located at Banpo-Myeon, Gongju City, Chungcheongnam-DO of the Republic of Korea as a representative forest area including reclamated sloping cropland. and then unit area load of T-N and T-P was estimated from sloping cropland and forest

As the result of implementing calibration and verification of SWAT model by using daily runoff discharge data which were actually measured during 2005~2006, Nash-Sutcliffe coefficient (NTD) for flowrate was 0.70~0.76 and Coefficient of Detemination (R^2) showed values of 0.80~83 and Nash-Sutcliffe coefficient (NTD) for T-N and T-P load was 0.54~0.72 and Coefficient of Detemination (R^2) showed values of 0.62~0.86. And then SWAT simulation was performed from 1997 to 2006 with optimal parameters determined through calibration process so as to estimate long-term unit area load from sloping cropland and forest in experimental watershed

As the result of calculating unit area load for T-N and T-P for the past 10 years with SWAT model, T-N unit area load from forest was 3.29kg/㎢/day and T-P unit area load was 0.15kg/㎢/day and T-N unit area load from sloping cropland was 11.15kg/㎢/day and T-P unit area load was 0.70kg/㎢/day. It showed that a little smaller than the unit area load suggested by calculation based on short-term measured data, it was judged that we can manage more efficiently nonpoint pollution sources in Target watershed by using average annual discharge load which was estimated with long-term simulation data of SWAT model.

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SESSION PB2

InStream Sediment and Pollutant Transport

PB2-1

Modification of BOD Simulation Module in SWAT for Proper Water Quality Management in Korea

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Abstract

Accumulation of pollutants due to various reservoirs, dams and reduction of velocity downstream is one of the emerging difficulties in water quality management in Korea. Therefore, algae and organic matter are now being major concerns in water quality modeling rather than DO. It is also needed to enhance the structures of water quality models to have capability of simulating laboratory experiment BOD (Bottle BOD_5) which is a water quality standard of the TMDL program in Korea. However, it is difficult to solve these problems with the SWAT model which is one of the widely used water quality models in Korea, on account of the limitations of channel water quality module in simulating algae, organic matter and Bottle BOD_5 etc. To overcome these limitations, in this study, the enhanced channel water quality module of the SWAT model (SWAT-KQ) was suggested by linking the algorithms of the QUAL-NIER model to the SWAT model. The algorithms estimating the increase of internal organic matter by fractionization algal metabolism process and calculating Bottle BOD_5 were added and the results of proposed model were compared to those of the original SWAT2005 model. It is revealed that more accurate BOD values could be obtained with the SWAT-KQ model. Through the analysis on the BOD load duration curves based on flow exceedance probability, it is concluded that the BOD load particularly for the high flow seasons, which highlight the need for different management approaches depending on the stream flow durations. Finally, the SWAT-KQ model can be used as an effective tool for water quality management through the precise water quality simulation and long term pollution source analysis.

KEYWORDS: Bottle BOD_5, QUAL-NIER, SWAT-KQ

Introduction

For effective watershed management, the behavior of pollutants on a watershed scale as well as their impact on water quality should be well understood, and appropriate management measures should be developed and implemented. Since water quality predictions with a suitable simulation model plays an important role in watershed and stream management. Water quality models allow for one to three dimensional simulations depending on the characteristics of the water bodies. QUAL2E, which is one of the most widely used models for this purpose, was developed as a one dimensional simulation model in support by the US TWDB (Texas Water Development Board)(Masch et al., 1970). Brown and Barnwell (1985) from the Water Resources Engineers improved the limitation of QUAL-Ⅰ (Masch et al., 1970) model to QUAL-II by adding simulation modules for the water quality parameters of nitrogen compounds, phosphorus, Chl-a, etc. The QUAL2E model has also been incorporated into the US EPA's BASINS tool for effective implementation of the US TMDL program and is used widely by many users throughout the world.

However, QUAL2E is a steady state simulation model that requires continuous flow as the simulation condition. This make it difficult to apply the model to Korean streams, of which the flows are often discontinuous or intermittent due to stream hydraulic structures, such as diversion or dams, and a large stream gradient with a seasonal concentration of annual rainfall in summer. Therefore, a water quality simulation model that is relevant to discontinuous stream conditions in Korea needs to be developed. The National Institute of Environment Research (NIER) combined the QUAL2E with WASP5 model to develop QUALKO in 2001 (NIER, 2001). This model is equipped with a module to simulate the change in CBOD (Carbonaceous Biochemical Oxygen Demand) by algae death and decay, and also allows for bottle BOD_5. QUALKO was further evolved to QUAL-NIER in 2004 by considering the simulation of internal organic matter changes, subtypes of nitrogen and phosphorus and TOC (Total Organic Carbon) (NIER, 2004).

Therefore, the original QUAL2E model was modified to fit the stream conditions in Korea. A series of QUAL-based models were developed for event flow simulations and are unsuitable for long-term simulations on a continuous basis. To overcome these limitations, long-term continuous simulation models that are capable of simulating the hydraulics, hydrology, and water quality on a watershed scale were developed, including HSPF(Hydrological Simulation Program-FORTRAN) and SWAT(Soil and Water Assessment Tool). In particular, the original SWAT model was developed by USDA ARS (Agricultural Research Service) by combining SWRRB (Simulator for Water Resources in Rural Basins) and ROTO (Routing Outputs to Outlet). The early version of SWAT adopted the SWRRB to simulate the water quality. The QUAL2E model was incorporated into the SWAT 96.2 version to simulate the instream water quality (Neitsch et al., 2001). This SWAT model has been used throughout the world. Therefore, a large scale watershed model, such as SWAT, is needed to modify the water quality simulation which used QUAL2E for an instream water quality simulation. In addition, BOD_5 is one of the most important water quality parameters in Korea. BOD is composed of CBOD, oxygen consumption for algae respiration and nitrification. However, in Korea, bottle BOD_5, which includes the oxygen demand for nitrification, is measured using the Standard Methods for an Examination of Water Pollution. Accordingly, the CBOD simulation by the original SWAT should be modified to consider the nitrification oxygen demand.

In this study, the QUAL-NIER model allowing for a long-term daily simulation was incorporated into SWAT 2005 to improve the algae metabolism and modify the BOD simulation structure. The modified model was also applied to the Chungju Dam watershed to test its applicability by confirming the improvement. Moreover, the TMDL concept was used to evaluate the modified model by estimating the loads duration curve and subsequent BOD pollutant load.

Methodology

Conversion of main structure in model

Most stream water quality models have been developed based on the continuous channel flow condition and are centered to a DO simulation. Typical Korean stream flows decrease as they travel toward downstream due to the gradually decreasing stream gradient. During this process, an oxygen reaeration process is relatively active so a DO depletion phenomenon seldom occurs. On the other hand, internal organic matter reproduction takes place actively. Therefore, the DO oriented modeling structure needs to be modified to an organic matter and nutrient centered simulation, as shown in Figure 1. Accordingly, in this study, the QUAL-NIER module was selected to replace the QUAL2E module of SWAT to improve the channel water quality simulation, particularly for BOD and organic matter. This will allow for a continuous daily water quality simulation, which is impossible with QUAL2E. The performance of a BOD simulation would also be improved for the simulation of a 5-day bottle BOD by considering the internal organic matter dynamics due to algae growth and death, nitrification oxygen demand (NOD), and algae respiration oxygen demand (AOD).

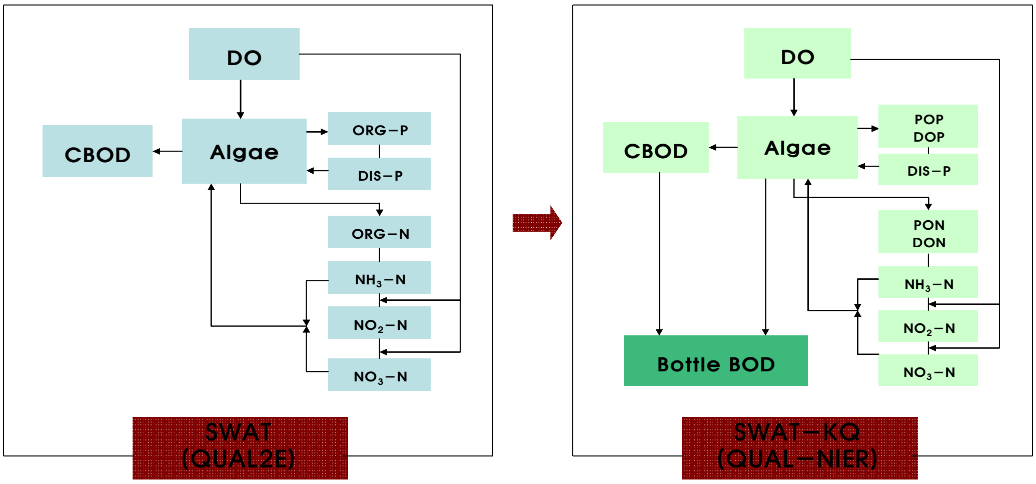


Figure 1. Conversion of the main structure of the water quality model.

Study watershed and Model inputs

The study area, Chungju Dam watershed is 6,648 km^2, occupying approximately 50% of the South Han River watershed. The total stream length is 375 km. The study watershed is located at a typical mountainous region with an average elevation and slope of 607 m and 42.3 %, respectively, as shown in Figure 2. Administratively, the area crosses over three provinces and thirteen counties or cities.

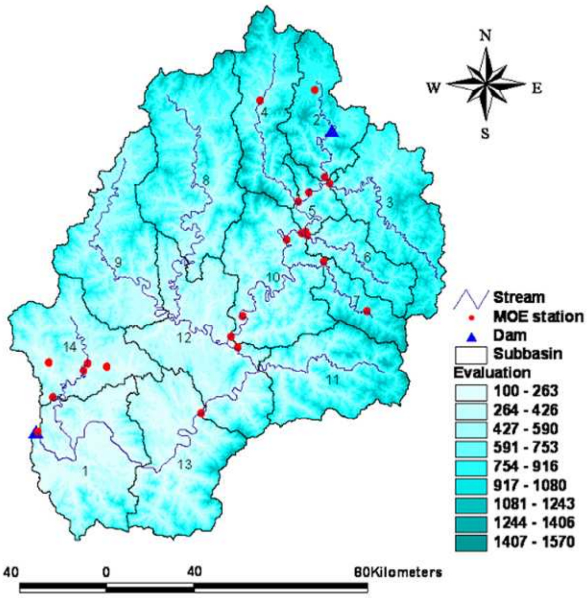


Figure 2. Location of the study area.

As the spatial model input for the SWAT simulation, the land use map on a 1:50,000 scale and DEM with a 100m×100m resolution were obtained from the Ministry of Environment. The soil map on a 1:25,000 scale was also acquired from the National Academy of Agricultural Science. The study watershed was divided into 14 sub-watersheds based on the flow characteristics and locations of the national water stage and water quality monitoring station. Each sub-watershed was further subdivided into 406 HRUs identified by the same soil and land use types. Meteorological data from 1990 to 2006 was obtained from the nine weather stations under the National Meteorological Administration. The Thiessen method was used to further process the meteorological data of temperature, rainfall, solar radiation, wind speed and relative humidity.

Results and Discussion

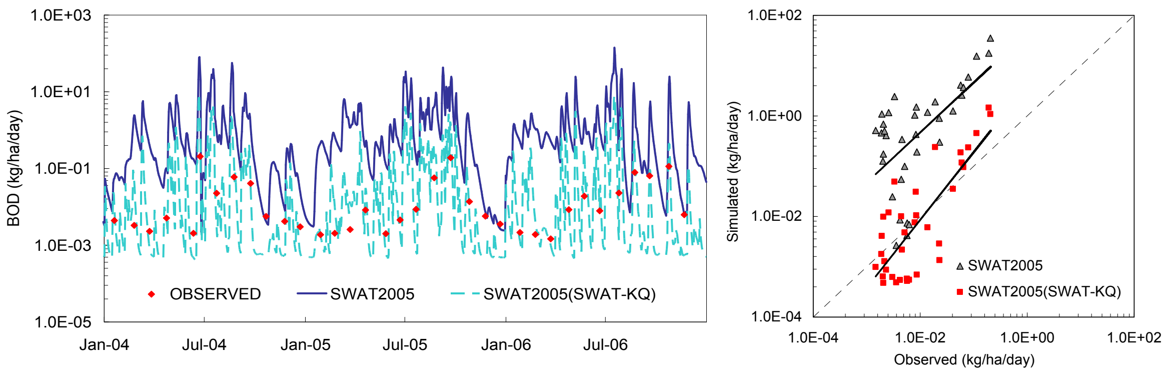
Before the channel water quality simulation, the stream runoff affects on the water quality factors, was simulated and calibrated at the outlet of the Chungju Dam watershed for 1998 to 2006. SWAT 2005 was equipped with the TWACN (Temporally Weighted Average Curve Number) module and NSR (Nonlinear Storage Method) module proposed by Kim and Lee (2008) and Kim and Lee (2010), respectively. The TWACN module considered the soil water changes into an hourly weighted average curve number to amend the peak flow underestimation tendency of SWAT, a nonlinear storage equation that was obtained by coupling the continuity equation and the Manning equation for delicate stream flow simulation. The model parameters were calibrated using a trial and error method beginning with the parameters with greater sensitivity.

To evaluate the performance of the modified model in the BOD simulation, the monthly measured data of the Chungju Dam station from 1998 to 2006 were compared with the respective simulation results between the original and modified SWAT, i.e. SWAT 2005 and SWAT-KQ, respectively. The same parameter values, including the BOD related factors of RK1 and RK3 were used for both models for comparison.

Comparison of the BOD simulation before and after modification

Figure 3 compares the BOD simulation results for 2004 to 2006 before and after model modification. The values simulated with the modified model were similar to the measured values. The modified model reduced considerably the overestimation tendency of SWAT 2005 in the BOD simulation. The original model also demonstrated a delay in the occurrence of the BOD peak loads. The modified model solved these delay phenomena to a certain degree. Previous studies indicated a hydrological runoff delay and an underestimation of the peak flows with the original SWAT, and improved these phenomena by incorporating the TWACN and the NSR modules into the SWAT-K. Indeed, the improved module of SWAT-K was applied to SWAT-KQ, the hydrological correction may in part have resulted in an improved BOD simulation.

As shown in Figure 3(b), a comparison of the measured and simulated BOD values from 2004 to 2006 indicates a greater deviation from the 1:1 line, which means a better match with SWAT 2005 than SWAT-KQ. This was particularly obvious for the Chungju Dam, possibly because the station was located near the inlet of the Chungju Dam, so the stream flows might have been affected considerably by the downstream reservoir.



(a) Total BOD **(b) 1:1 line**

Figure 3. Comparison of the BOD simulation before and after modification.

Derivation of the load duration curve

The TMDL concept was used to evaluate the modified model by estimating the loads duration curve and subsequent BOD pollutant loads. The current TMDL program in Korea regulates the pollutant loads by BOD_5 based on the mean low stream flow for a certain period. Pollutant control based on the average BOD_5 for a certain flow condition may allow the water quality goal to be achieved. However, this approach has limited applications, particularly when the seasonal flow fluctuation is severe, which is the case in Korea. It is desirable that seasonal variations in stream flow should be considered in a TMDL implementation, but the measured flow data have insufficiency and omission problems for long-term simulations. Therefore, in this study, a flow duration curve was first developed using the simulated daily stream flows of the six years from 1998 to 2003, and loads duration curve derivation was then followed. The BOD pollutant loads were plotted as a function of the exceedance probability for the entire simulation period (Figure 4). As a result, the BOD values do not necessarily match the flow duration, particularly as the stream flow decreased. However, the BOD loads in zones Ⅰ and Ⅱ followed the flow duration patterns, probably because most pollution sources are washed out during the great rainfall events and thus are high pollutant load conditions. In general, nonpoint source pollutants contribute to the pollutant load in waterbodies during high flow conditions, therefore, the zones Ⅰ and Ⅱ as nonpoint source dominant ranges, can be a useful strategy for developing appropriate measures for watershed water quality management.

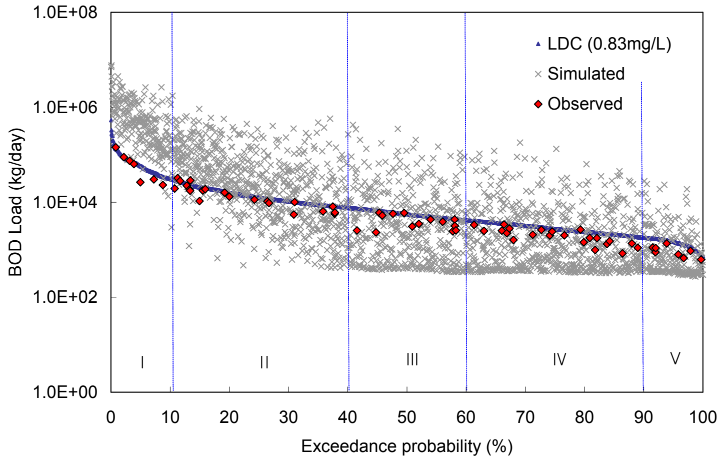


Figure 4. Comparison of the Load Duration Curve.

Conclusion

In this study, SWAT was modified by incorporating the QUAL-NIER into the channel BOD simulation module that allows for detailed algal dynamics and subsequent internal organic matter of stream flow. The primary improvement to the previous CBOD only simulation with SWAT in this study was that the oxygen demand for nitrification and algal respiration were considered, leading to a more accurate prediction of the BOD_5, which is the target water quality parameter in the Korean TMDL program. The modified model then was applied to the study watersheds in the Chungju Dam basin to estimate the BOD pollutant loads for the entire flow exceedance probability. The modified model demonstrated a better stream BOD prediction than the original SWAT showing closer matches to the measured values for monitoring stations. In particular, the tendency of a BOD overestimation by SWAT 2005 was corrected considerably using the modified SWAT-KQ model. The estimated BOD loads exceeded the allowable loads for all stream flow conditions, particularly for the high flow seasons, which highlight the need for different management approaches depending on the stream flow durations. This study, the SWAT modification in the channel water quality simulation module improved the accuracy of the BOD_5 simulation considerably. Therefore, the proposed model can be used to determine the allowable pollutant loads and further for the development of more efficient management strategies based on Korean conditions.

Acknowledgement

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SESSION PB7

Environmental Applications

PB7-1

A Study of Modeling using Linkage of Watershed Model and River Water Quality Model

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It is important to establish quantitative analysis in the non-point sources for efficient management of water quality. Recently, we has been to have hard time with non-point quantitative analysis, a necessary and sufficient condition of total maximum daily load analysis, because of representing natural complex phenomena. For accurate water quality modeling, Watershed and water quality model were linked and applied to a Milyang River Basin located on the Nakdong river. Each of the model has advantages to simulate water quality. Especially, SWAT model simulates non-point sources and QUALKO model simulates point sources. So. The simulation is linked to these model. A Watershed model of SWAT and a water quality model of QUALKO were applied to the study area.

The study watershed was divided into 2 sub-watershed such as Milyang A and Milyang B unit watershed. First, SWAT watershed model was estimated by using DEM(Digital Elevation Model), land use data, soil data, weather data, precipitation data and point load data. The result of the simulation was daily non-point load and flow data. The SWAT simulation results shows good agreements in terms of discharge, BOD, T-N, T-P. Additionally, for more exact simulation, it should be kept studying about variables and parameters which are needed for simulation. Secondly, the water quality model, QUALKO is a static model. It reflects head water, pollutant load and withdrawal very well. It consist of 3 head water source, 2 junction, 17 reach, 100 element, 27 point source. And it is connected to SWAT for non point source at the incremental flow section. As a result, concentration of the BOD increases about 10.65%, concentration of the T-N increases about 2.73% and concentration of the T-P increases about 7.32%. Totally, simulation results shows 5~10% increase of the concentration.

Additionally, accurate simulation of point and non-point source for water quality management are useful in evaluating and deciding the water resource and environment management plan. And quantitative analysis plays an important roles in the non-point source treatment efficiency assessments. Through this study, point source and non-point source quantitative analysis system construction accomplish. And linking watershed model and river water quality model through each process is estimated in small watershed. The suggested technique will improve the accuracy of the water quality analysis. The methodologies presented in this study will contribute to basin-wide water quantity and quality management.

Keywords: SWAT, QUALKO, Point and nonpoint source

PB7-2

Study for Protection of Water Resources from Pollution using SWAT

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Abstract

Due to recent urbanization and development, heavy rainfall has been more frequently occurring and there have been a lot of changes and efforts made to reflect contemporary trends in the runoff system. Furthermore, global warming is more severe than expected and the total amount of runoff is increasing with the current social infrastructures. In addition, non-point sources which are related to rainfall characteristics show tendency to increase.

The preliminary implementation of quantitative analysis should be required for the management of non-point sources. However, a lot of difficulties arise in conducting quantitative analysis because of complex topography. In addition to the relation between rainfall and runoff, it is difficult to analyze the travel time of contaminants and to divide point and non-point sources. In order to overcome these difficulties, the objective of this study consists of the establishment of accurate system for predicting non-point sources. The quantitative analysis of non-point sources in Nakdong river is performed in this study based on geographic information. And non-point sources are selected by calibrating loads using SWAT model with the condition in which both point and non-point sources coexist.

Therefore, this study is to get over these problems though non-point source analysis is estimated by watershed model, SWAT(Soil and Water Assessment Tools). Industrial dataset, sewage and wastewater plant databases are collected for the non-point source analysis by watershed model in the first place. And, the model is calibrated and validated using hydrograph and pollutograph (contaminants .vs. time) at the pour point . In this circumstance, point source data is ejected. The results can be estimated by non-point source loading data. Results show that the portion of non-point source pollution in the target watershed is about 40% of the total pollution.

Also the capacity of the riparian area for remediation of the non-point source such as SS, TP, and TN is analyzed.

In order to analyze water quality and the hydrologic characteristics of a watershed, SWAT model can be used as practical and worthwhile reference. By using the results from those models, quantitative analysis on water quality improvement for numerous conditions will be carried out and the best land use plans can be also established. Furthermore, continued implementation of management, assessment and monitoring will be conducted following the constructed riparian area.

Keywords: SWAT, Quantity analysis, Riparian area.

Introduction

Water resource is essential for maintaining our secure life and sustainable environments. Large portion of available water resources in Korea relies on natural rivers. There are several kinds of pollution types in a watershed such as point and non-point sources. Therefore proper analysis of variability of water quality in the target watersheds is necessary for water resources planning and management. The regional impact of climate change and urbanization cause variation of temporal and spatial characteristics water quality in natural rivers in Korea which are associated with regional changes in temperature and precipitation.

The purpose of this study is analyzing the variability of water quality in a target watershed and developing appropriate index which can represent the current areal averaged status of water quality for the target watershed for proper water quality management. In this study, the SWAT model was used to evaluate the behavior of water quality in the target watershed. The applicability of the SWAT model was verified by applying several watersheds which has relatively reliable data for verification. We analyzed the applicability of indices such as the areal ratio and length ratio according to water quality classes to show potential for index of water quality assessment and management for the target watershed.

Quantitative Approach for the Non-point Sources of Gumho Watershed

Due to recent urbanization and development, heavy rainfall has been more frequently occurring and there have been a lot of changes and efforts made to reflect contemporary trends in the runoff system. Furthermore, global warming is more severe than expected and the total amount of runoff is increasing with the current social infrastructures. In addition, non-point sources which are related to rainfall characteristics show tendency to increase.

The preliminary implementation of quantitative analysis should be required for the management of non-point sources. However, a lot of difficulties arise in conducting quantitative analysis because of complex topography. In addition to the relation between rainfall and runoff, it is difficult to analyze the travel time of contaminants and to divide point and non-point sources. In order to overcome these difficulties, the objective of this study consists of the establishment of accurate system for predicting non-point sources. The quantitative analysis of non-point sources in Nakdong river is performed in this study based on geographic information. And non-point sources are selected by calibrating loads using SWAT model with the condition in which both point and non-point sources coexist

Current effluent load in Nakdong River

Now that the locations of industries in a unit watershed of Nakdong River is not accurately identified, effluent load is determined based on flow discharge and water quality of the weight centroid of subbasin in the watershed. Even if more industries than described in the following figures exist in this area, the industries which don't have any influence on the point sources are ignored based on the flow discharge. The figures below show the representative industries and larger points in the figures indicate larger effluent loads. According to the figures, Gumho watershed has the largest effluent loadings of BOD, TN and TP. Therefore, the influences of Gumho watershed, which has the largest effluent loadings, are selected as a target area in this study.

YoungChun dam watershed is located in the upstream of Gumho river which is a tributary of Nakdong river and the rivers of this area are composed of a number of subbasins including Jaho-Cheon, Imgo-Cheon, Gohyun-Cheon, Daejang-Cheon, Chungtong-Cheon, Baksa-Cheon, Suk-Cheon, Omok-Cheon, Nam-Cheon, Uksoo-Cheon, Maeho-Cheon, Yulha-Cheon, Bulro-Cheon, Donghwa-Cheon, Neungsung-Cheon, Yongsoo-Cheon, Jimyo-Cheon, Bumuh-Cheon, Palgeo-Cheon and Dalseo-Cheon. The total area of the watershed is 2,092.42km^2. The main channel has the length of 68.11km and the elevation of the outlet is 15m. The maximum and mean elevation of the watershed is 1,180.10m and 236.30m respectively. The mean channel width of GumHo watershed is 17.55m. And the left and right side of the river has the area of 1,003.97km^2 and 1088.45km^2 respectively. Urban area, rice fields, crop area, forest and other area occupy the area ratio of 3.7%, 18.3%, 10.5%, 66.4% and 1.1% of the total area of 2,092.42km^2. This reflects GumHo watershed mainly consist of forest rather than crop fields. The forest resources of the area consist of state forest, public-owned forest and private forest lands and the area for each forest is 5,937ha, 9,190ha and 117,900ha, respectively.

Simulation Results

GumHo River is a tributary located near the midstream of Nakdong River. Also it originates from Youngchun dam and flows through Daegu metropolitan city. As shown figures above, main sources of pollution is "Gumho-C" area located at the downstream of Gumho River. Accordingly, the total Gumho river watershed is divided into two parts and the simulation starts with Youngchun dam area known to be relatively less influenced by non-point sources. And then the simulation results are set as the inlet of lower part of Gumho watershed. Also, in order to reflect pollution load and the accurate location from which sources of pollution originate, the watershed is divided into minor ones.

Gumho River basin simulation results

Gumho River basin is located in the middle part of the Nakdong River. Daegu is located in the middle part of the Gumho River and Youngchun dam is located at the upstream of Gumho River. Detailed geographical data on the basin is shown in the following figure. Weather and rainfall data is the same as the data used for the simulation on Youngchun dam. However, simulation period in this case is limited to 2 years since non point source data for 2005 and 2006 are used for the simulation.

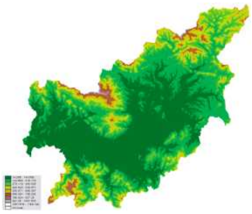

Figure 1. Gumho River Basin (DEM)

Figure 2. Gumho River Basin (Land use Condition)

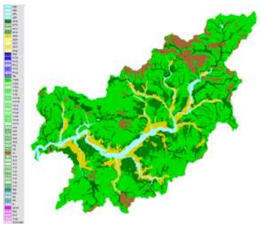

Figure 3. Gumho River Basin (Soil Map)

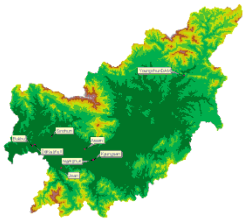

Figure 4. Point sources distributions in Gumho River Basin

There are 7 point sources in Gumho River basin. In this study, in order to accurately determine point sources, data for sources of pollution is presented in this study and then simulation is conducted with the divided watershed. Also, as mentioned above, data from 2005 to 2006 is used for the simulation. The locations of point sources and Youngchun dam are illustrated in Figure 4. As shown in figures above point sources are mainly located at the downstream of Gumho River, which has significant impact on point sources.

Peak flow when compared with the observed values is slightly lower during several days, however derived results are similar to overall trends. Especially, BOD concentrations are in good agreement with overall measured data. The quantitative analysis of non-point pollution sources is performed in this study with the above simulated results. The simulation results including discharge load of point sources are examined and calibrated. Because the results obtained without the influence of point sources in the simulation is attributed to non-point sources. As shown in Figure 7, there is a huge difference between the simulation results with and without the influence of point sources.

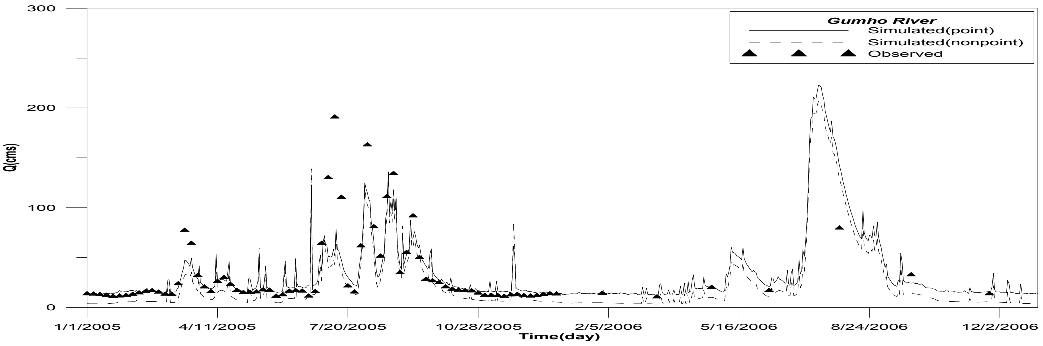

Figure 5. Discharge simulation result in Gumho River Basin

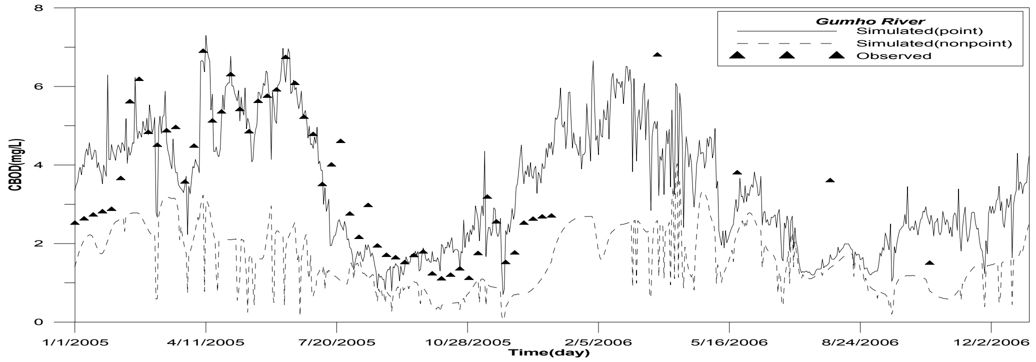

Figure 6. BOD Simulation result in Gumho River Basin

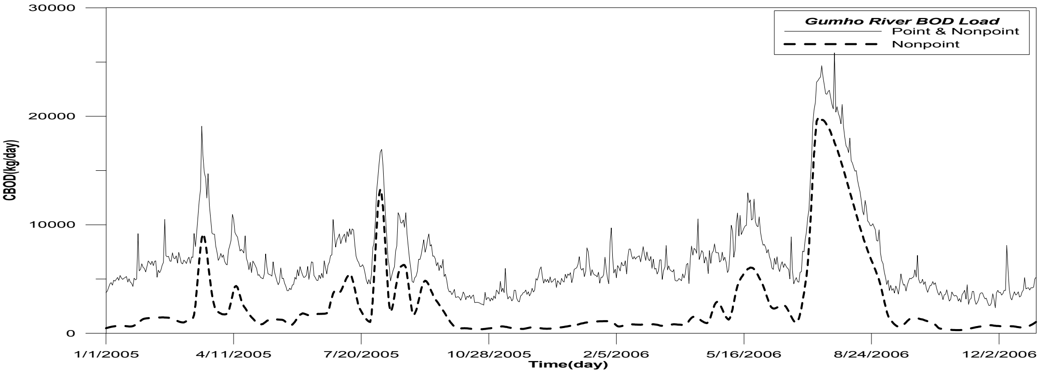

Figure 7. BOD Load in Gumho River Basin

In the simulation including the influence of point sources, discharge load of BOD shows 7023.21 kg/day, while the simulation without the influences of non point sources yielded discharge load of 2790.20 kg/day in BOD. Since the results of the effect of point source shows 39.73%, the resulting non-point source loads are approximately 40 percent of the overall pollution loads in the Gumho river area.

Conclusions

(1) Pollutant loadings from non point sources are estimated by disregarding the correlation between river water quality and pollutant loads. However, pollutant loads are linked with and river water quality through the watershed model. To analyze the loadings from non point sources, industry effluents and discharges from water treatment plants were also considered for quantification of non point sources from total sources

(2) The presence of point sources in the watershed plays a key role in estimating effluent loads in a watershed. Thus, the simulation with and without point sources were conducted to estimate the portion of non point sources and this showed that non point sources take up 40% of the total pollutant loads in the Gumho River basin.

(3) Until now loadings of non point sources are estimated by disregarding the correlation between river water quality and pollutant loads. However, pollutant loads are linked with and river water quality through the watershed model. And in analyzing the loadings from non point sources, industry effluents and discharges from water treatment plants were also reflected for quantification of non point sources. Thus, if the average concentration is investigated in each watershed by Environment Research Foundation, high reproducibility will be ensured with the analysis of the load of non point source pollutants

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PB7-3

Simulation of Runoff and Water Quality Data in the Jiseok Stream, Korea by SWAT Model

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In the present study, runoff and water quality data were simulated in the Jiseok stream basin which is located in Hwasun county and Naju city in Korea by using Soil-Water Assessment Tool (SWAT) model. The Nampyung station which is the outlet point of the study basin was chosen for the application of SWAT model and the runoff and water quality data measured in 8-day interval could be readily collected for the station. The data period of 2002 was used for calibration of the model and the data from 2003 to 2005 were applied for verification of the model. Point source pollution data in the study basin were added to the model for accurate simulation of water quality. The simulation results revealed that the observed and simulated data for runoff were very similar and the pollution load data for water quality also showed similar tendency. However, the correlation coefficient between the observed and simulated data for water quality was relatively lower than the coefficient for runoff data. Consequently, it can be concluded that the SWAT model has strong applicability for hydrological and environmental data simulation.

Soil & Water Assessment Tool | SWAT

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