2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 084527

Development of Web GIS based VFSMOD System to Simulate Sediment Reduction Efficiency with Vegetative Filter Strip

Younshik Park, MS Student, Kangwon National University
Korea, caron-ys@nate.com
Nam-Won Kim, Researcher, Korea Institute of Construction Technology
Korea, nwkim@kict.re.kr
Bernie Engel, Professor, Purdue University
Indiana, USA, engelb@purdue.edu
Jong-Gun Kim, MS Student, Kangwon National University
Korea, kimjg23@gmail.com
Won-Seok Jang, MS Student, Kangwon National University
Korea, sabal81@hotmail.com
Jun-Ho Park, BS Student, Kangwon National University
Korea, gispjh@nate.com
Joongdae Choi, professor, Kangwon National University
Korea, jdchoi@kangwon.ac.kr
Kyoung Jae Lim, Assistant professor, Kangwon National University
Korea, kjlim@kangwon.ac.kr

Written for presentation at the
2008 ASABE Annual International Meeting
Sponsored by ASABE
Rhode Island Convention Center
Providence, Rhode Island
June 29 – July 2, 2008

Abstract

In recent years, Non Point Source Pollution has been rising as a significant environmental issue. The muddy water problem is causing serious impacts on river ecosystems not only in Korea but also in most countries. Accordingly, many methods to manage and prevent this problem have been investigated such as greet chamber, reservoir or debris barrier. However, the vegetative filter strip (VFS) is thought to be one of the most effective methods. However, the effective width of the VFS first needs to be determined before VFS installation in the field. To provide ease-of-use interface with a scientific VFS modeling engine, the Web GIS based VFSMOD system was developed in this study. The

Web GIS based VFSMOD uses UH and VFSM as core engines to simulate rainfall-runoff and sediment trapping. To provide soil information for a point of interest, the Google Map interface to the Mapserver soil database system was developed using the Google Map API, Javascript, Perl/CGI, and Oracle DB programming. Two versions of the Web GIS based VFSMOD system were developed; one is the Single Storm Event Analysis and the other is the Multiple Storm Event Analysis option. With these two options in the Web GIS based VFSMOD system, the users can easily simulate the effects of filter strips under given rainfall events using the Single Storm Event Analysis mode and determine optimum filter strip width using the Multiple Storm Event Analysis mode. These two versions were applied to the study watershed located at Gangwon province in Korea to demonstrate how the Web GIS based VFSMOD system can be used in VFS analysis. It was found that the VFS efficiencies are dependant on storm amounts and filter strip width.

The Web GIS based VFSMOD system has several merits over conventional desktop-based modeling systems. 1) The model input data are provided through the Web GIS database, especially Google Map interface to the Web GIS database was developed in this study for easy identification of a point of interest; 2) Most other input data can be prepared based on the recommended or default values provided with the Web GIS based VFSMOD input interface; 3) Maximum 45 batch runs can be simulated in the 'Multiple Storm Events Analysis' mode for optimum effective VFS width design, which is not possible with the desktop-based VFSMOD system; 4) The Web GIS based VFSMOD system is available online for 24-hr 7days for free with only Internet access and a Web browser; 5) The Web GIS based VFSMOD system users do NOT need to install VFSMOD-w system and prepare the input datasets because the Web GIS based system provides everything for VFS analysis.

Currently work is underway to extend the Google Map interface to the 48 states soil database for wide application of the Web GIS based VFSMOD system. The Web GIS based VFSMOD system is available at http://www.EnvSys.co.kr/~vfsmos. The Google Map interface provides a world wide graphical interface, thus soil databases for any country can be easily integrated with the Web GIS based VFSMOD system, as shown in this study,

Keywords: Filter strip, soil erosion, sediment, water quality, VFSMOD, Web GIS VFSMOD

Introduction

In recent years, environmental problems have been arising in most countries. Especially, accelerated soil erosion within watersheds is quite serious worldwide, and it is difficult to simulate its economic and environmental impacts accurately because it is occurring in large areas and is a complex process associated with rainfall (Lal, 1994). Many kinds of human activities, such as mining, construction, and agricultural activities disturb the land surfaces, resulting in accelerated erosion. Soil erosion from agricultural areas is typically higher than that from non-agricultural areas (Brown, 1984). The soil loss is the major cause of muddy water in Korea recently, and can occur everywhere and whenever with rainfall-runoff processes, and muddy water problem arises when significant amounts of sediment flows into streams with runoff or surface flow. The muddy water can cause serious problems such as disruption of the ecosystem in stream, malfunction of dams, pulling down water resources worth, and so on. The important fact is that the muddy water is a natural phenomenon, thus it cannot be prevented perfectly, but it can be reduced to some degree not to cause these serious problems in watersheds. There are so many methods to manage and prevent this muddy water problem such as sediment basins, erosion control dams, greet chamber, reservoir or debris barrier. There is another method which is better than those from an environmental perspective. Vegetative filter strip (VFS) has been increasingly used because of its environment-friendly aspect. The VFS is designed to remove not only sediment, but also other pollutants such as nutrients from surface water runoff by filtration, deposition, infiltration, adsorption, absorption, decomposition, and plant uptake (Muñoz-Carpena, 1999). Reducing the velocity of runoff from source areas such as farmland or agricultural areas, the VFS causes sediment to be deposited. Usually located at edge of agricultural areas and adjacent to streams or drainage ditches, the VFS traps sediment effectively, and moreover, have been shown to effectively remove solubles and chemicals from runoff (Dillaha et al., 1989b; Arora et al., 1996). However, if the VFS is set up with an irrational plan or simulation, sometimes it is not possible to expect effective results in field experiments, because the VFS is located with crop field which is human activity area and it is concerned with many factors such as rainfall, soil, and vegetation property. In field experiments, sediment was reduced by different types of the VFS with reductions ranging from 50 to 98% (Gharabaghi et al., 2001). So, the effect of the VFS needs to be studied for effective width design of the VFS before being set up in a field. Therefore a model, capable of calculating the effective VFS width, is needed before being set up at the field. Also, a Web based model can be better than a desktop based model because a Web based model has advantages over a desktop based model, even though many kinds of desktop based models are used in many studies. Recently, Web based techniques are less expensive, more efficient and lately have been the target of the most development (Tarantilis, 2008). Web-based models are not needed to be installed in personal desktop, or even updated. But the desktop-based models should be installed, need to be updated; moreover, different results can be calculated without timely updates (Lim et al., 2003, 2005). Especially, desktop-based models require users to prepare many kinds of input data. The Vegetated Filter Strip model (VFSMOD), developed by Muñoz-Carpena and Parsons (1999), is a desktop-based model, so it requires many various input data as it considers various conditions of upland field and VFS. It remains not only merit, but also demerit that it can consider various conditions of field.

The objectives of this study are: 1) to develop Web GIS based VFSMOD system (available at the http://www. EnvSys.co.kr/~vfsmod), utilizing the VFSMOD as a core engine and 2) to apply the Web GIS based VFSMOD system to design effective width of VFS at the study watershed using Web GIS based VFSMOD system.

The Web GIS based VFSMOD can be used everywhere and anytime through the Internet, also it is very convenient that so many input data are provided or recommended from the VFSMOD database and Google Map-based Mapserver database, even for non-experts to simulate the VFS performance and calculate the sediment reduction effect of VFS.

Literature Review

One of the Best Management Practices (BMP) promoted by state and federal agencies to protect water resources from non-point source pollution is the installment of VFS. The VFS are land areas of planted vegetation, usually grasses, installed at the edge of agricultural areas or animal production facilities to filter nutrient, sediment, organics, pathogens, and pesticides from agricultural runoff before it reaches a water system such as streams or rivers. The VFS is effective in reducing sediment (Neibling and Alberts, 1979) and other pollutants (Lee et al., 1999; Mersie et al., 1999). These studies reported that the VFS can reduce pollutant loads by reducing velocity of surface flow from agricultural areas and causing infiltration. The performance of VFS is affected by many parameters, such as slope, volume of runoff, soil type, and vegetation characteristics. The VFS is a dynamic system with many parameters; also these time-variant factors can affect the VFS performance. Therefore, site specific management methods need to be evaluated and developed for successful functioning of the VFS (Otto et al., 2008). These important and various factors affecting VFS performance have to be considered by the Vegetated Filter Strip model (VFSMOD), developed by Muñoz-Carpena and Parsons (1999). The VFSMOD system is a desktop based model, and it requires many and various input data as it considers various conditions of field and VFS. The field-scale, mechanistic, storm-based VFSMOD is designed to simulate the hydrograph by rainfall and sediment inflow from an adjacent upper field. The model calculates the outflow, infiltration, and sediment reduction through VFS from adjacent upper field (Muñoz-Carpena, 2005). So, the model can be used to predict sediment transport through VFS, simulates outflow and sediment reduction in VFS based overland flow hydraulics and infiltration into the soil layer (Amanda et al., 2005) (Fig. 1).

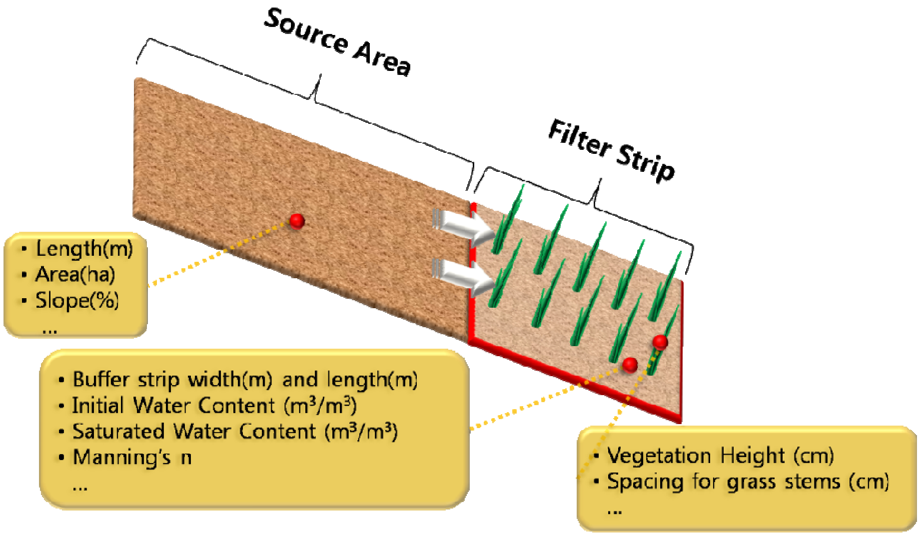


Fig. 1. Source area and Filter strip in VFSMOD-w

The VFSMOD was successfully tested with natural events with North Carolina Piedmont data (Muñoz-Carpena, 1999) and Coastal Plain (Muñoz-Carpena, 1993). Researchers, at the University of Guelph in Canada, tested the model with field experimental data (Abu-Zreig et al., 2001). They reported good agreement between model simulations (infiltration, outflow, and sediment trapping) and measured values. Recently the model has been used to model the effect of VFS in a small watershed (817 m ∗ 875 m) (Kizil and Disrud, 2002), also a study to simulate fecal pathogen transport and filtering in VFS (Zhang et al., 2001). Also the model has been tested against field experimental data, and it showed good agreement (R^2=0.9) with a linear relationship between model predictions and observed values (Gharabaghi et al., 2001).

The VFSMOD requires input data such as 'rainfall', 'storm duration', 'curve number' ,and 'storm type' for 'Rainfall event and Runoff' option, 'length along area', 'slope as a fraction' ,and 'area' for 'Source Area' option, 'soil erodibility', 'soil type', 'percent organic matter', 'particle class diameter', 'crop factor', 'practice factor' for 'Erosion Parameter' option in source area parameter. Also, it requires input data such as 'buffer length', 'width of the strip' for 'overland flow inputs' option, 'vertical saturated K', 'initial water content', 'saturated water content' for 'Soil properties', 'spacing for grass stems', 'height of grass', 'roughness' for 'Buffer vegetation properties' option in filter strip parameter (Fig. 2).

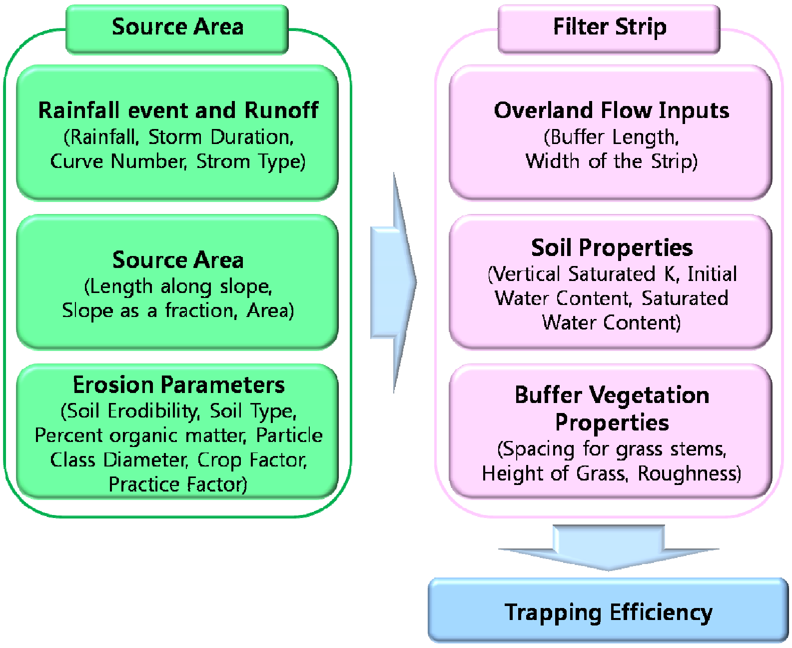


Fig. 2. Input data of Source Area and Filter Strip Component of the VFSMOD

The VFSMOD model handles time based hyetographs, spatially distributed filter parameters (vegetation roughness or stem spacing, slope of source area and buffer strip, infiltration characteristics of buffer strip soil) and different particle size of sediment from the source area. The sub modules are used such as 'Green-Ampt infiltration module' for calculating the water balance in the soil surface, 'kinematic wave overland module' for calculating flow depth and rates in the infiltrating soil surface, 'sediment filtration module' for simulating transport and deposition of the incoming sediment along the VFS from source area (Fig. 3).

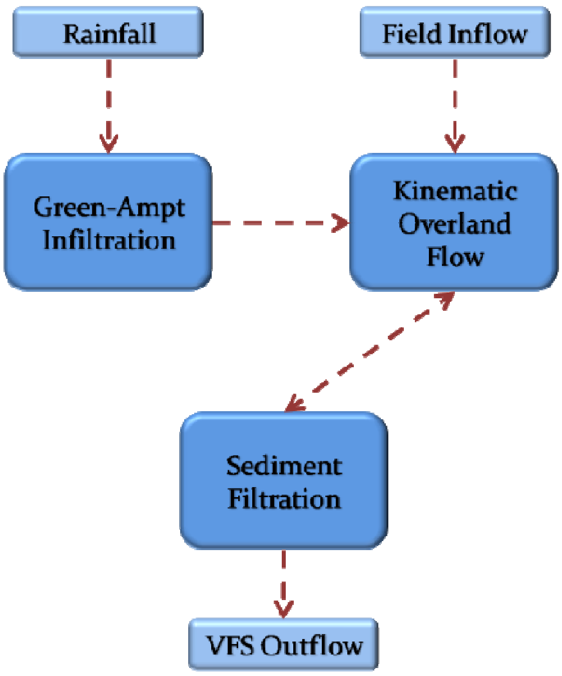


Fig. 3. Overview of sub-modules in VFSMOD-w

In the process of hydrology, the rainfall excess is calculated from the hyetograph and a modification to the Greem-Ampt infiltration method at every time step is calculated for a given rainfall distribution for each node and time step by the infiltration model. The model can be operated to simulate the various effect of soil type (infiltration), slope of source area, slope of VFS, surface roughness, filter length, storm pattern, vegetation type, and field inflow on VFS performance. Also it describes the flow rate, velocity, and depth throughout the filter for each time step (Muñoz-Carpena, 2005).

The VFSMOD model is composed of separated processes which are 'UH' for source area and 'VFSM' for filter strip. The 'UH' is run by INP file which contains the information of source area such as 'Rainfall event and Runoff' option, 'Source Area' option, and 'Erosion Parameters' option. The outputs of 'UH' are IRN file that is regarding the rainfall hyetograph and the runoff hydrograph from the source area, IRO file is about sediment properties for the filtration sub-module, ISD file is a summary of the inputs and outputs from 'UH', OUT file is detailed summary of MUSLE, and HYT file is runoff hydrograph. 'VFSM' is run using IKW file that contains the information of 'Overland Flow Inputs' option, ISO file contains the information of 'Soil Properties' option, and IGR file contains the information of 'Buffer vegetation properties' option. Also ISD, IRN, and IRO files are outputs of 'UH' which are in need of this process. The outputs of 'VFSM' are OG1 file that describes the sediment transport and deposition within the buffer by detailed time series, OG2 file that contains detailed information in the singular points defined in the theory section, OHY file is detailed outputs on the inflow and outflow hydrographs, OSM file is detailed summary of the water and sediment balance, final geometry of the filter, and OSP file is overall summary of the filter performance with comparisons between the source area and VFS.

Development of Web GIS based VFSMOD

Development of Input Interface of Web GIS based VFSMOD System

In this study, the Web GIS based VFSMOD system was developed to simulate VFS performance and calculate sediment reduction effect of the VFS. Two versions of the Web GIS based VFSMOD systems were developed; one is the 'Single Storm Event Analysis' version and the other is the 'Multiple Storm Events Analysis' version (Fig. 4). The 'Multiple Storm Events Analysis' version runs 'Single Storm Event Analysis' version for up to 45 times in batch mode. The Web GIS based VFSMOD system is comprised of a client-side interface, server-side pre and post-processors, and UH and VFSM engine (Fig. 5).

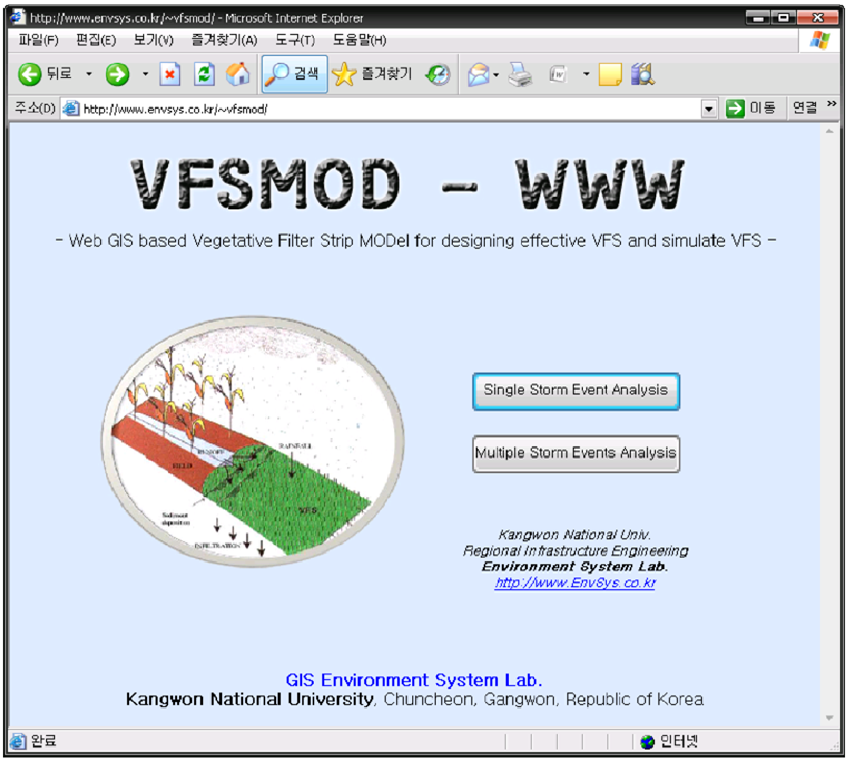


Fig. 4. Single Storm Event and Multiple Storm Events Analysis Options in the Web GIS based VFSMOD System (http://www.EnvSys.co.kr/~vfsmod)

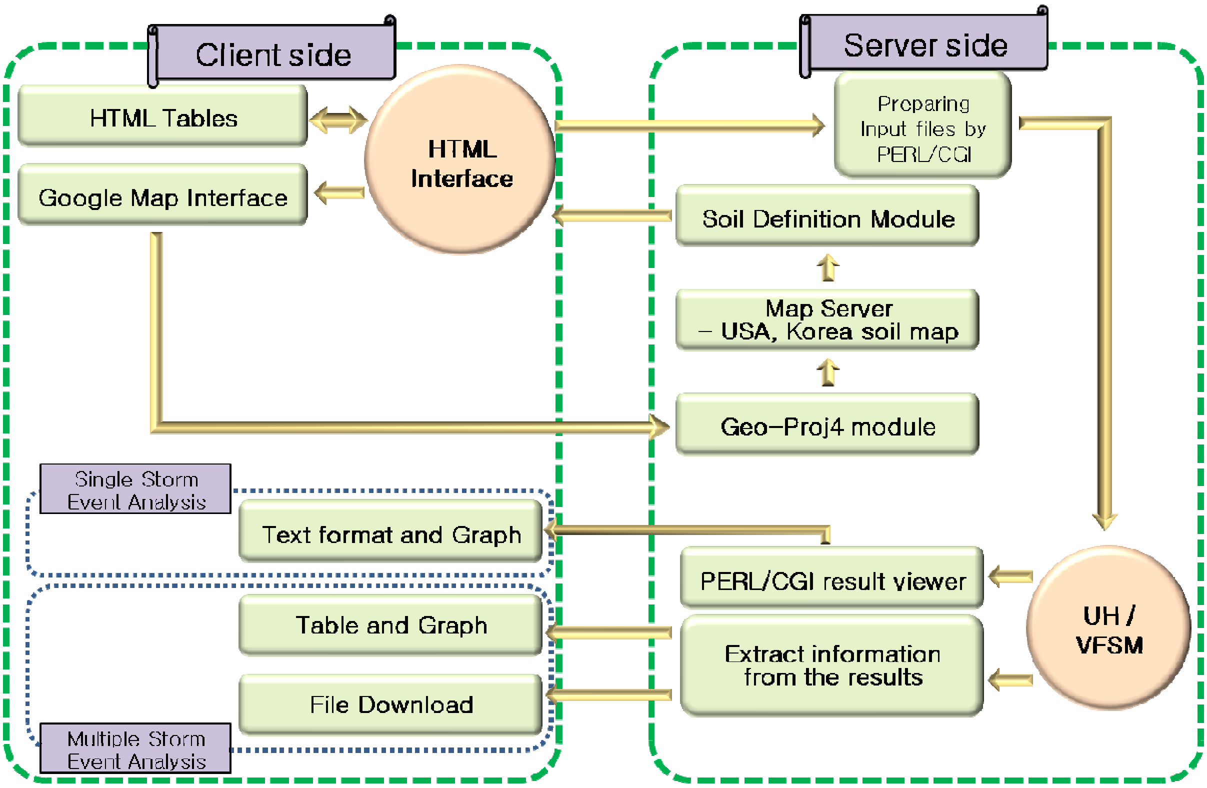


Fig. 5. Overview of Web GIS based VFSMOD.

The client-side was developed with the languages of HTML, DHTML, Perl/CGI, Java script, Google Map API, and Map Sever Web GIS application. The input interface is comprised of “Rainfall Event and Runoff”, “Source Area”, “Erosion Parameter”, “ Rainfall Factor”, “Buffer Dimension”, “Green-Ampt Infiltration Parameter”, and “Vegetation Parameter” section (Fig. 6). The input menu has been rearranged, and the range of each input data and available/recommended values are provided as a table for users to understand and choose proper input values. Also the superfluous repetition of data input has been reduced. Thus, with limited input data, users can run the VFSMOD system and analyze the output for site-specific design of filter strip with several clicks of the mouse button, which were not possible with the desktop-based VFSMOD (Fig. 6).

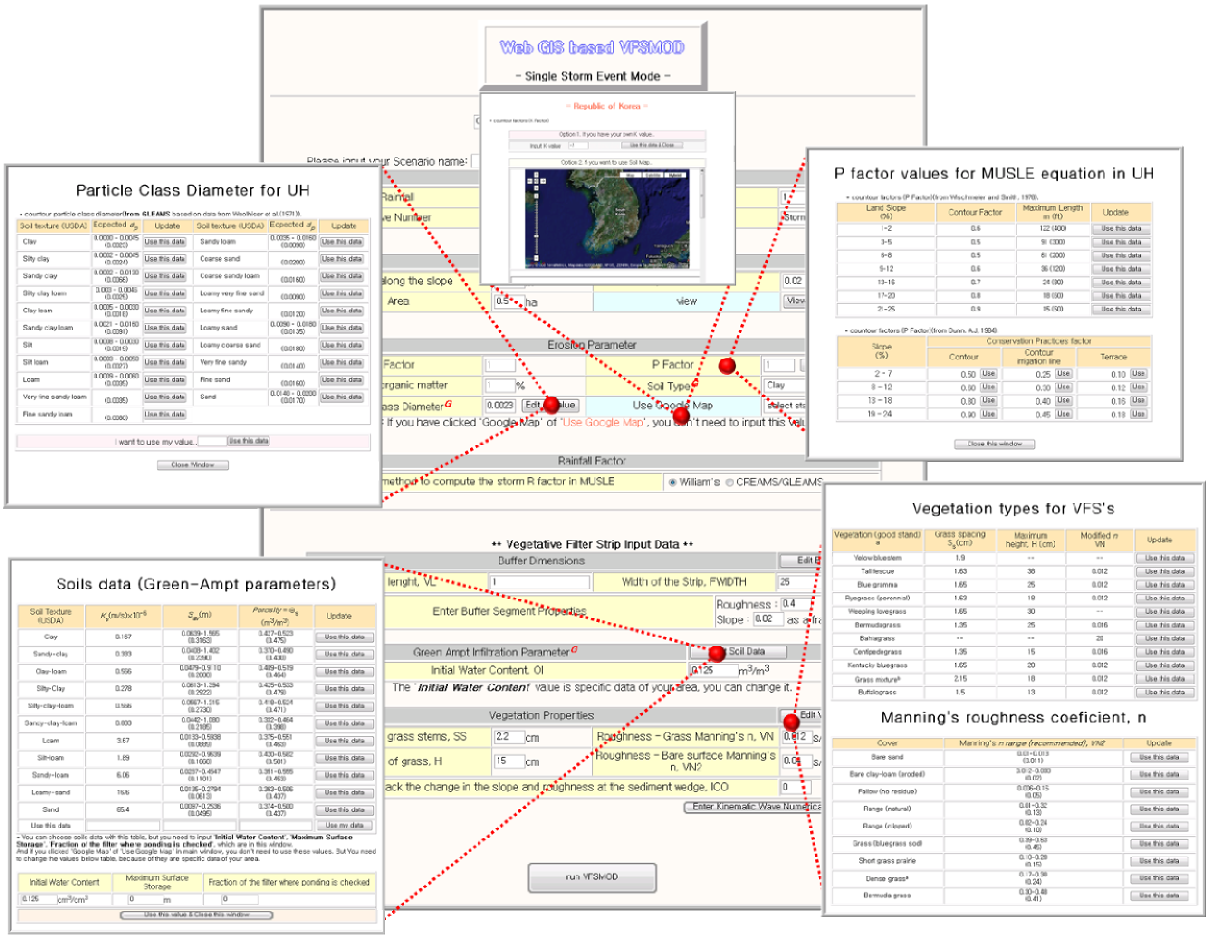


Fig. 6. Interface of Web GIS based VFSMOD (Single Storm Event mode)

In the input process of ‘Source Area’, the input data ‘soil type’, ‘class diameter’, and ‘practice factor’ in the ‘Erosion parameters’ option are given in a HTML table or through a Google Map interface to a Map Server soil database. However, ‘Rainfall event and Runoff’ and ‘Source Area’ options are left to the users because these are specific to each simulation. The input data ‘soil type’ is defined by relative ratio of silt, sand, and clay composition which are stored in the Web GIS VFSMOD sever. The input data ‘Particle class diameter’ (Table 1) is determined with ‘soil type’, thus can be determined with the Google Map interface to the Map Server soil database system. The recommended input data ‘practice factor’ (Wischmeier and Smith, 1978) is provided in HTML tabular format (Table 2).

Table 1. Particle class diameter for UH

Soil texture (USDA)	Expected d_p	Soil texture (USDA)	Expected d_p
Clay	0.0023	Sandy Loam	0.0098
Silty Clay	0.0024	Coarse Sand	0.0020
Sandy Clay	0.0066	Coarse Sandy Loam	0.0160
Silty Clay Loam	0.0025	Loamy very fine Sand	0.0090
Clay Loam	0.0018	Loamy fine Sandy	0.0120
Sandy Clay Loam	0.0091	Loamy Sand	0.0135
Silt	0.0019	Loamy coarse Sand	0.0180
Silt Loam	0.0027	Very fine Sandy	0.0140
Loam	0.0035	Fine Sand	0.0160
Very fine Sandy Loam	0.0035	Sand	0.0170
Dine Sandy Loam	0.0080		

Table 2. P factor value for MUSLE in UH

Land Slope (%)	Contour Factor	Maximum Length (m)
1 - 2	0.6	122 (400 ft)
3 - 5	0.5	91 (300 ft)
6 - 8	0.5	61 (200 ft)
9 - 12	0.6	36 (120 ft)
13 - 16	0.7	24 (80 ft)
17 - 20	0.8	18 (60 ft)
21 - 25	0.9	15 (50 ft)

Also, in the process of ‘Filter Strip’, the input ‘buffer length’, and ‘width of the strip’ of ‘overland flow inputs’ option are left to the users because these information are site-specific in each simulation of study. However, recommended values of ‘Soil Properties’ and ‘Buffer Vegetation Properties’ are given in an HTML table, or queried using the Google Map interface to the Mapserver soil database. First, the input data ‘vertical saturated K’ and ‘saturated water content’ (Green-Ampt parameter; Rawls and Brakensiek, 1983) of ‘Soil Properties’ (Table 3) by ‘soil type’ can be determined with the Google Map interface. Second, the recommended input data ‘spacing for grass stems’, ‘height of grass’, and ‘roughness’ of ‘Buffer Vegetative Properties’ are provided in tabular format (Haan, 1994) (Tables 4, 5) to help model users select appropriate values.

Table 3. Soil data (Green-Ampt parameter)

Soil Texture (USDA)	Ks(m/s)x10-6	Sav(m)	Porosity = Θs(m3/m3)
Clay	0.167	0.3163	0.475
Sandy Clay	0.333	0.2390	0.430
Clay Loam	0.556	0.2088	0.464
Silty Clay	0.278	0.2922	0.479
Silty Clay Loam	0.556	0.2730	0.471
Sandy Clay Loam	0.833	0.2185	0.398
Loam	3.670	0.0889	0.463
Silt Loam	1.890	0.1668	0.501
Sandy Loam	6.060	0.1101	0.453
Loamy Sand	16.600	0.0613	0.437
Sand	65.400	0.0495	0.437

Table 4. Vegetation types for VFS

Vegetation	Grass spacing	Maximum	Modified n
Yelow bluestem	1.9	--	--
Tall fescue	1.63	38	0.012
Blue gramma	1.65	25	0.012
Ryegrass (perennial)	1.63	18	0.012
Weeping lovegrass	1.65	30	--
Bermudagrass	1.35	25	0.016
Bahiagrass	--	--	20
Centipedegrass	1.35	15	0.016
Kentucky bluegrass	1.65	20	0.012
Grass mixture	2.15	18	0.012
Buffalograss	1.5	13	0.012

Table 5. Manning's roughness coefficient, n

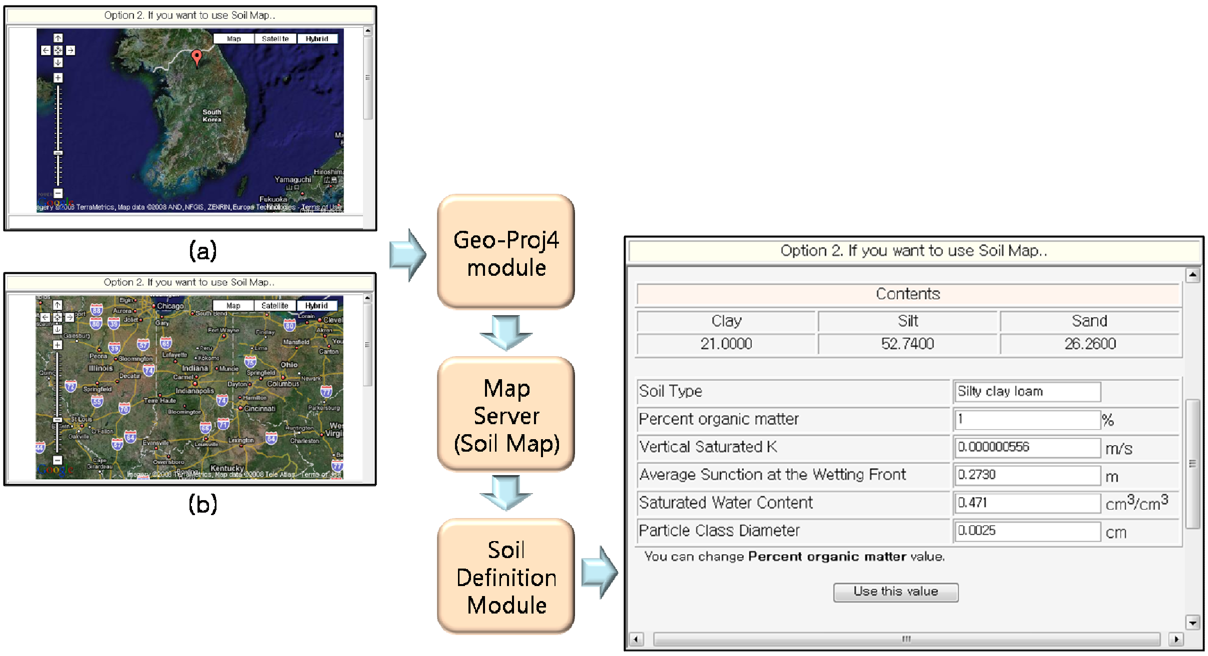
Cover	Manning's n
Bare Sand	0.011
Bare Clay Loam	0.020
Fallow (no residue)	0.050
Range (natural)	0.013
Range (clipped)	0.010
Grass (bluegrass sod)	0.450
Short grass prairie	0.150
Dense grass	0.240
Bermuda grass	0.410

Development of On-the-fly Google Map Interface to Mapserver Soil Database

Although the Web GIS based interface helps model users run the VFSMOD with less input data, compared with the desktop version of the VFSMOD, the users need to prepare soil property of the area of interest, which is sometimes time-consuming and hard to find for novice users. Thus, the Google Map interface was developed to query soil properties of the point of interest through server-side Mapserver application. The soil maps for South Korea and Alabama (AL), Indiana (IN), Illinois (IL), Kentucky (KY), Michigan (MI), Mississippi (MS), Tennessee (TN), and Wisconsin (WI) STATSGO soil database is stored at server-side for automatic soil property extraction from the Google Map interface. The work is underway to extend this to 48 states for practical application of VFSMOD system in the continental USA.

The Google Map interface to Map Server soil database was developed to help users find and choose the study area easily and comfortably. Because the Google Map uses 'coordinate of Latitude and Longitude; Lat/Lng' and the soil map uses 'coordinate of Transverse Mercator (TM)' for South Korea or with 'coordinate of Universal Transverse Mercator (UTM)' for Alabama (AL), Indiana (IN), Illinois (IL), Kentucky (KY), Michigan (MI), Mississippi (MS), Tennessee (TN), Wisconsin (WI). Thus Geo-Proj4 module (http://search.cpan.org/dist/Geo-Proj4/) was used for on-the-fly projection for automatic soil property query from Lat/Long-based Google Map interface to TM/UTM soil data stored in Mapserver application. Also another sub-module was developed, named 'Soil Type Definition' using Perl/CGI, to define soil type by the ratio of silt, sand, and clay composition. This module classifies soil types as Sand, Sandy loam, Loam, Silt Loam, Clay loam, Silty clay loam, Sandy clay, Silty clay, Clay. These modules were integrated with the Web GIS based VFSMOD model as a sub-module.

The Korean soil database contains the ratio of silt, sand, and clay of the point of interest. Thus, the 'Soil Type Definition' module determines the soil type name for the VFSMOD system on-the-fly. However, the STATSGO soil database for AL, IN, IL, KY, MI, MS, TN, WI contains MUID, not the soil composition ratio. Thus, CGI programs were written to query soil database stored at Purdue University ECN server from the VFSMOD Mapserver domain and retrieves soil information for 'Soil Type Definition' module. To implement this capability, the CGI program was written and stored at the Purdue ECN server to process the query from the VFSMOD web server. It takes less than a second for this process. The soil type, particle class diameter, vertical saturated K, average suction head at the wetting front, saturated water content information are provided to the users with this Google Map interface to the Mapserver soil database. With this Google Map-based Web GIS interface, the complex soil input data are prepared within a second on-the-fly (Fig. 8).



(a) Republic of Korea (b) U. S. A. (AL, IN, IL, KY, MI, MS, TN, WI)

Fig. 8. Google Map Interface for using many input data

Multiple Storm Events Analysis Options

The desktop based VFSMOD-w can be run only once for each input data. The effect of the VFS on reduction of sediment or flow can be simulated under only one condition of rainfall and VFS width (Single Storm Event Analysis option, as shown in Fig. 6). Because of this limitation in the desktop-based VFSMOD system, the model users have to run the desktop-based system dozens of times to determine effective VFS width under various rainfall conditions in the field. The Single Storm Event Analysis option uses various files, described earlier, such as INP, IKW, ISO, IGR, ISD, IRN, and IRO files. The INP and IKW files contain the rainfall and VFS width value, respectively. Thus, a number of INP and IKW files are needed to simulate various filter strip scenarios in the field. In this study 'Multiple Storm Events Analysis' option was developed to automate the single storm analysis for up to 45 times with 5 INP files and 9 IKW files. Most of the functions are similar with Single Storm Event mode, but maximum 5 design storm values and maximum 9 VFS width values can be simulated. The 'Multiple Storm Events Analysis' mode in the Web GIS based VFSMOD generates the INP and IKW files with user-provided rainfall and VFS width values, The Multiple Storm Events Analysis' mode uses these INP and IKW files with other ISO, IGR, ISD, IRN, and IRO files to determine optimum filter width under given conditions (Fig. 9). The Google Map interface to the Mapserver soil database is also provided in the Multiple Storm Events interface.

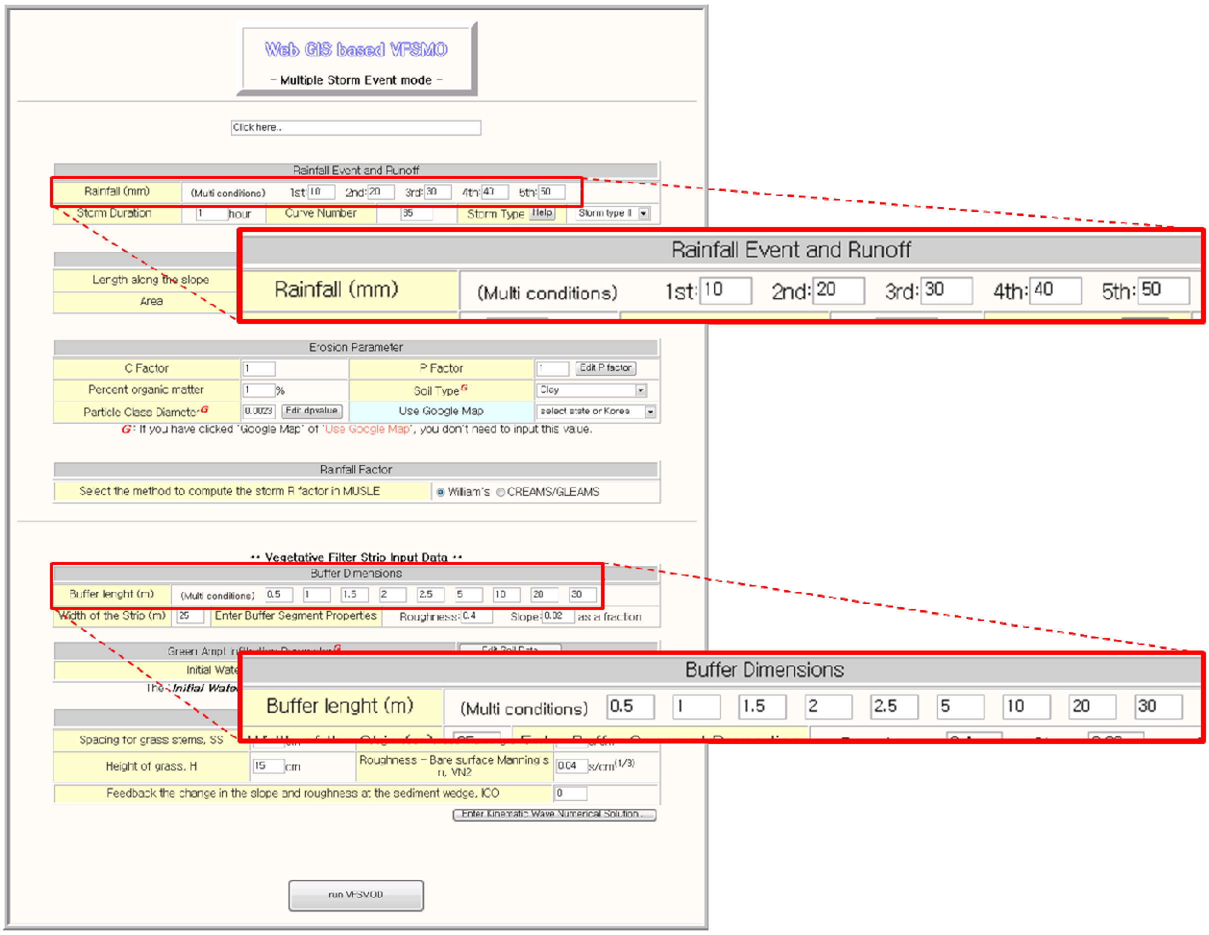
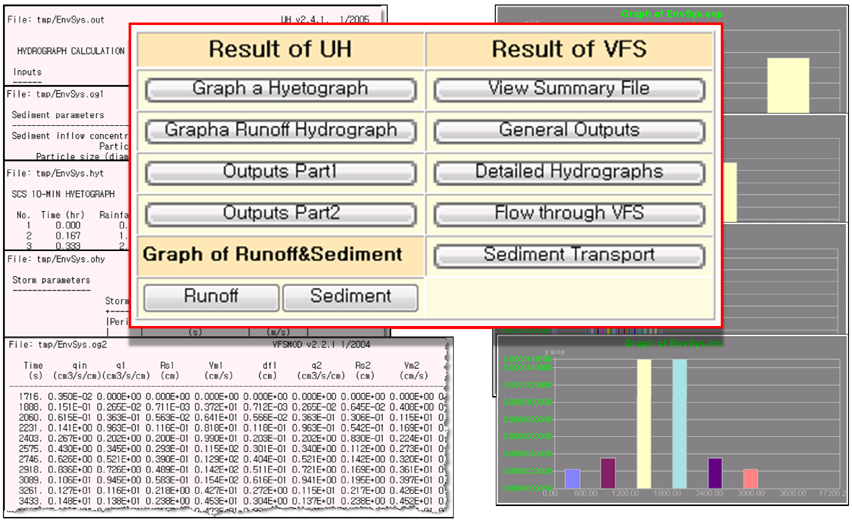


Fig. 9. Multiple Storm Events Analysis in the Web GIS based VFSMOD System

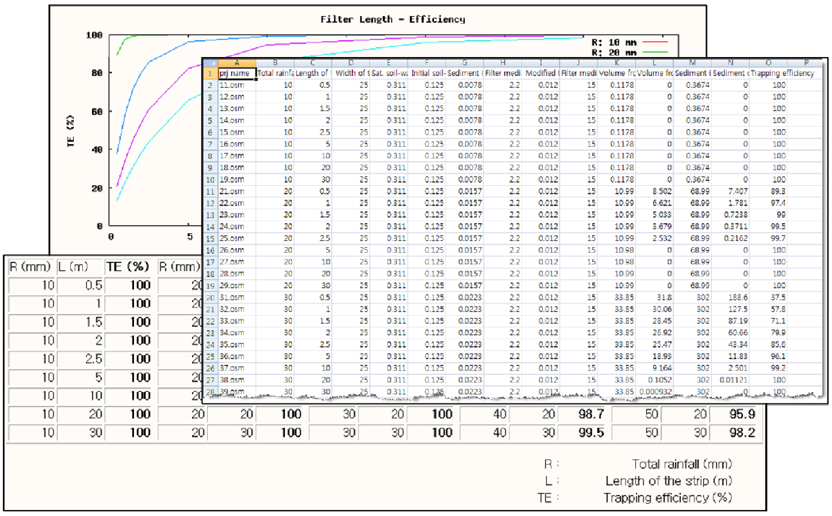
Development of Output Interface of Web GIS based VFSMOD System

Once the model is run, the post processors at the server-side compile the model output and generate tabular and graphical output for easy understanding of the simulation. For the Single Storm Event option, the graphs of hyetograph, hydrograph, sediment are generated using Java applet and Perl/CGI programming (Fig. 10(a)). Also, other output files from the UH and VFSM are provided in textural format for further analysis if needed. With the output interface, the Web GIS based VFSMOD users can easily find the effects of different scale of the VFS on its performance under the user specified condition quickly.

For Multiple Storm Events mode, the post processors rearrange the output files to compile output information for VFS width design. The trapping efficiencies under various VFS width and design storm events are provided in tabular format. The output can be downloaded into a desktop spreadsheet program for further analysis and reporting purpose. The trapping efficiencies are provided in graphical format also with the cross-hair interface for quick identification of optimum VFS width or trapping efficiency under a certain condition (Fig. 10(b)).



(a) Results of Single Storm Event Analysis of Web GIS based VFSMOD System



(b) Results of Multiple Storm Events Analysis of Web GIS based VFSMOD System

Fig. 10. Tabular and Graphical Output of Web GIS based VFSMOD System

Application of Web GIS based VFSMOD

To demonstrate how the Web GIS based VFSMOD can be used to simulate the trapping efficiency and to determine optimum VFS width, the Web GIS based VFSMOD system was applied to an agricultural field of Su-dong watershed, located at Gangwon Province, Korea in this study (Fig. 11). The area of this agricultural field is 0.5 ha. The field is located near the stream, thus it is deemed that the VFS needs to be installed along the edge of the field to prevent sediment inflow into downstream water bodies.

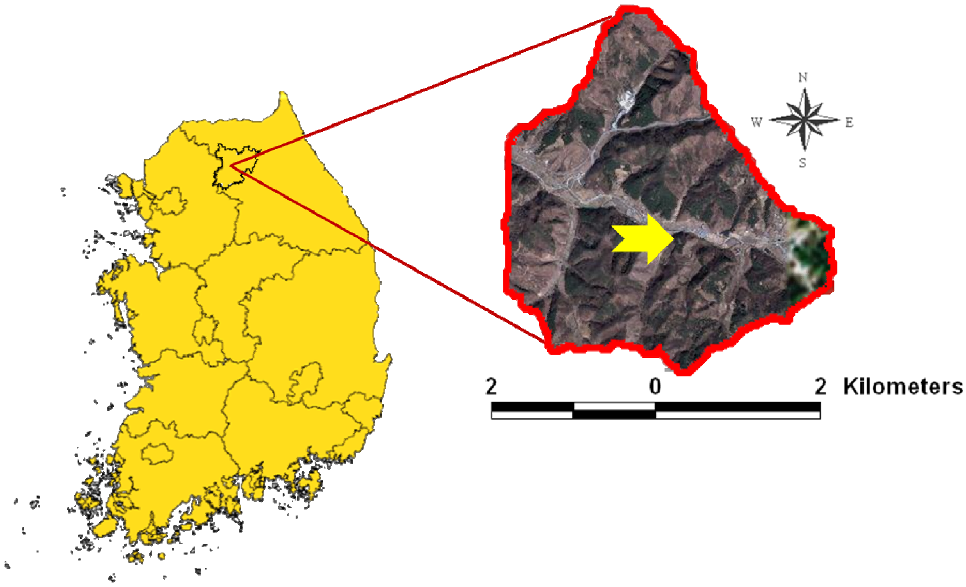
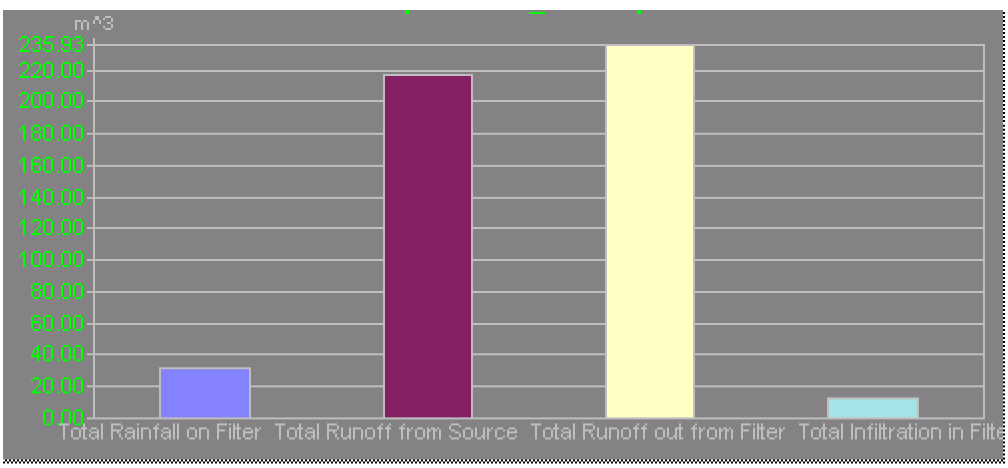


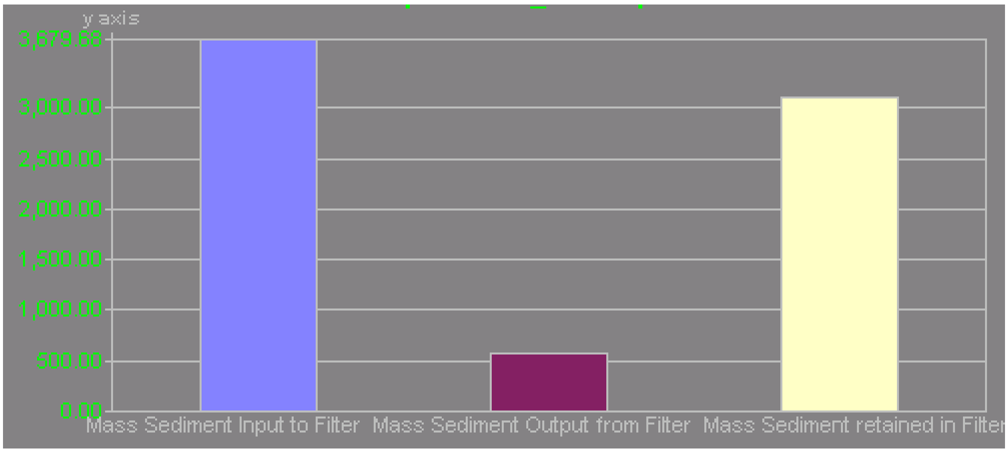
Fig. 11. Location of study area at Su-dong watershed

Single Storm Event Analysis Option

To demonstrate the Web GIS based VFSMOD system performance, two rainfall scenarios were determined. The VFS width of 8m under 1 hour storm duration – 100 year return period and 500 year return period were simulated for Su-dong watershed. The total amount of rainfall on the VFS of 8 m width under 1 hour storm duration, 100 year return period storm event was 31.72 m3, total runoff from the source area was 216.50 m3, total runoff out from the filter was 235.90 m3, total infiltration in the VFS was 12.24 m3 (Fig. 12(a)). The total sediment input to filter was 3,679.7 kg; sediment out from filter was 579.0 kg. The 3,100.7 kg of sediment retained in filter (Fig. 12(b)). This means that only 15.7 % of sediment leaves the filter, with 84.3 % of sediment trapped in the VFS. .



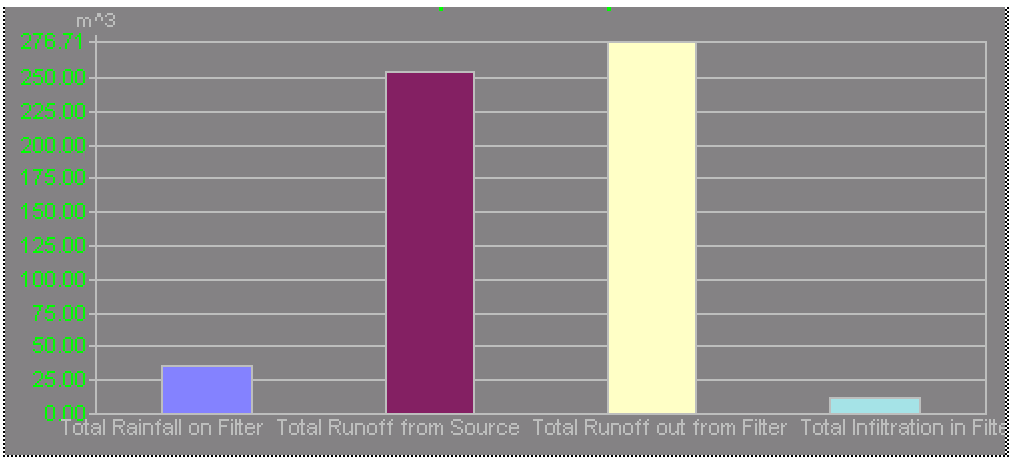
(a) Total Rainfall on Filter, Total Runoff from Source Area, Total Runoff out from the Filter, Total Infiltration in the Filter under the Given Rainfall and VFS Width Condition



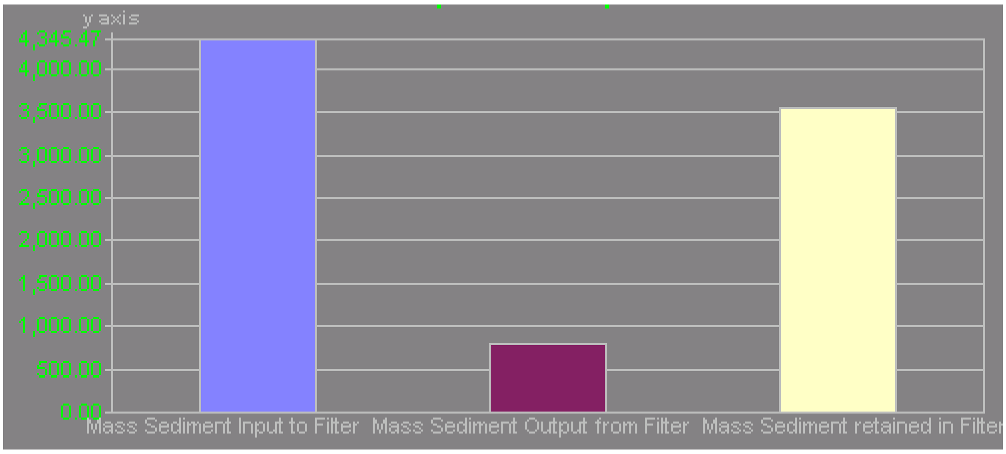
(b) Mass Sediment Input to Filter, Mass Sediment Output from Filter, Mass Sediment retained in Filter Under the Given Rainfall and VFS Width Condition

Fig. 12. Single Storm Event Output of the Web GIS based VFSMOD System (8 m VFS width against 1 hour duration – 100 year Return Period)

The total amount of rainfall on the VFS of 8 m width under 1 hour storm duration, 500 year return period storm event was 35.20 m3, total runoff from the source area was 254.10 m3, total runoff out from the filter was 276.70 m3, total infiltration in the VFS was 12.61 m3 (Fig. 13(a)). The total sediment input to the filter was 4,345.5 kg; sediment out from filter was 796.2 kg. The 3,549.3 kg of sediment retained in filter (Fig. 13(b)). This means that only 18.3 % of sediment leaves the filter, with 81.7 % of sediment trapped in the VFS. .



(a) Total Rainfall on Filter, Total Runoff from Source Area, Total Runoff out from the Filter, Total Infiltration in the Filter under the Given Rainfall and VFS Width Condition



(b) Mass Sediment Input to Filter, Mass Sediment Output from Filter, Mass Sediment retained in Filter Under the Given Rainfall and VFS Width Condition

Fig. 13. Single Storm Event Output of the Web GIS based VFSMOD System (8 m VFS width against 1 hour duration – 500 year Return Period)

Multiple Storm Events Analysis Option

In the Multiple Storm Events Analysis option, five design storm events and nine VFS widths can be simulated to determine effective VFS width. The 5 design storm events for 1 hour duration and 10, 50, 80, 200, and 500 year return period for Chuncheon were 32.4, 66.0, 70.5, 79.3, 88.0 mm, respectively (Korea Ministry of Construction and Transportation, 1999). The slope length, slope, and area are 100 m, 0.05, and 0.5 ha respectably. The C factor value of 0.26 was applied to the agricultural field (Jung et al., 1985). The P factor of 0.5 was used. The soil type, particle class diameter, and Green-Ampt Infiltration parameters from the Google Map interface to the Mapserver soil database were used in this run. Nine tall fescue VFS width values of 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, 8.0, 10.0, and 15.0 m were simulated to examine optimum VFS width and trapping efficiency under various conditions. It takes approximately 25 minutes to complete ‘Multiple Storm Events mode’ for 45 combinations. Table 5 shows the trapping efficiency under various rainfall and VFS width conditions. For 1hr-2 year return period event, the trapping efficiency were over 90% with vFS of 1.5 m wide, while the trapping efficiency was over 90% with VFS of 15.0 m wide. This indicates the trapping efficiency of the VFS depends on the amount of storm events.

Fig. 14 shows that Trapping Efficiencies for 45 rainfall-VFS width combinations. For the VFS width of 8 m, the trapping efficiency was over 80%. To reduce sediment out from the filter by 50%, it was found that the VFS of at least 3 m is needed. For 2-year, 10-year, 50-year, 100-year, and 500-year return periods and 1 hour rainfall events, VFS width of 0.5m, 1.7m, 2.0m, 2.5m, and 3m is needed to expect 50% of sediment reduction with the VFS installation. For 80% sediment reduction, 1.0m, 4.5m, 5.0m, 6.5m, and 8.0m VFS are needed under the same condition.

Table 5. Trapping Efficiency of various conditions by rainfall and VFS width

VFS width	2 year Return Period (32.4 mm)	10 year Return Period (66.0 mm)	50 year Return Period (70.5 mm)	100 year Return Period (79.3 mm)	500 year Return Period (88.0 mm)
0.5	65.7	20.1	18.1	15.1	12.9
1.0	85.6	34.9	31.9	27.1	23.6
1.5	92.5	46.4	42.7	36.9	32.5
2.0	95.3	55.5	51.6	45.2	40.1
3.0	97.5	68.6	64.8	58.0	52.4
5.0	98.8	82.6	79.7	74.1	68.9
8.0	99.3	90.8	89.0	85.4	81.7
10.0	99.5	93.2	91.8	89.1	86.2
15.0	99.6	95.9	95.1	93.5	91.9

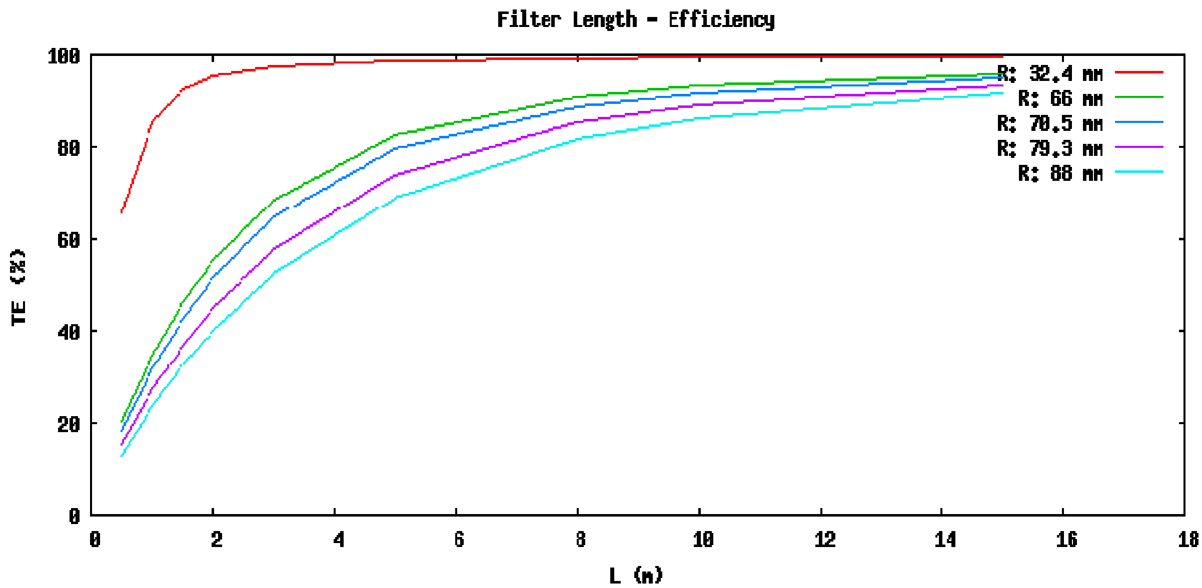


Fig. 14. Trapping Efficiency under Various Design Storm Event and Filter Strip Width Conditions - Multiple Storm Events Analysis Output Interface of the Web GIS based VFSMOD System

Conclusions

To provide an easy to use interface with a scientific VFS modeling engine, the Web GIS based VFSMOD system was developed in this study. The Web GIS based VFSMOD uses UH and VFSM as core engines to simulate rainfall-runoff and sediment trapping. To provide soil information for a point of interest, the Google Map interface to the Mapserver soil database system was developed using the Google Map API, Javascript, Perl/CGI, and

Oracle DB programming. Two versions of the Web GIS based VFSMOD system were developed; one is a Single Storm Event Analysis and the other is the Multiple Storm Event Analysis option. With these two options in the Web GIS based VFSMOD system, the users can easily simulate the effects of filter strips under a given rainfall event using the Single Storm Event Analysis mode and determine optimum filter strip width using the Multiple Storm Event Analysis mode. These two versions were applied to the study watershed located at Gangwon province in Korea to demonstrate how the Web GIS based VFSMOD system can be used in VFS analysis. It was found that the VFS width of 8 m was capable of reducing the sediment out from the filter by 15.7% for 1hr-100 year design storm, and 18.3% sediment trapping for 1hr-500 year design storm. For the VFS width of 8 m, the trapping efficiency was over 80% for 1-hour and 2-year, 10-year, 50-year, 100-year, and 500-year return period storms. To reduce sediment out from the filter by 50%, it was found that the VFS of at least 3 m is needed.

The Web GIS based VFSMOD system has several advantages over conventional desktop-based modeling systems. 1) The model input data are provided through the Web GIS database, especially Google Map interface to the Web GIS database was developed in this study for ease location of point of interest; 2) Most of other input data can be prepared based on the recommended or default values provided with the Web GIS based VFSMOD input interface; 3) Maximum 45 batch runs can be simulated in the 'Multiple Storm Events Analysis' mode for optimum effective VFS width design, which were not possible with the desktop-based VFSMOD system; 4) The Web GIS based VFSMOD system is available online for 24-hr 7days for free with only Internet access and a Web browser; 5) The Web GIS based VFSMOD system users do NOT need to install VFSMOD-w system and prepare the input dataset because the Web GIS based system provides everything for VFS analysis.

Currently work is underway to extend the Google Map interface to the 48 states soil database for wide application of the Web GIS based VFSMOD system. The Web GIS based VFSMOD system is available at http://www.EnvSys.co.kr/~vfsmos. The Google Map provides world wide graphical interface, thus soil database at any countries can be easily integrated with the Web GIS based VFSMOD system, as shown in this study,

Acknowledgements

This research was supported by a grant (code: 2-2-3) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program.

References

Abu−Zreig, M., R. P. Rudra, and H. R. Whiteley. 2001. Validation of a vegetated filter strip model (VFSMOD). Hydrol. Process. 15(5): 729−742.

Amanda, L.F., Dean, E.E., Michael, G.D., 2005. Modeling Water and Sediment Trapping by Vegetated Filter Using VFSMOD: Comparing Methods for Estimating Infiltration Parameters. ASAE Paper No. 052118, 2-4.

Arora, K., Mickelson, S.K., Baker, J.L., Tierney, J.L., Peters, C.J., 1996. Herbicide retention by vegetative buffer from runoff under natural rainfall. *Trans. ASAE* 39, 2155–2162.

Baker, J.L., Mickelson, S.K., Hatfield, J.L., Fawcett, R.S., Hoffman, D.W., Franti, T.G., Tierney, D.P., 1995. Reducing herbicide runoff: role of best management practices. *In British Crop Port. Conf. — Weeds. BCPC Publications*, Farnham, pp. 479– 487.

Barfield B. J., E. W. Tollner and J. C. Hayes. 1978. The use of grass filters for sediment control in strip mining drainage. Vol. I: Theoretical studies on artificial media. Pub. no. 35-RRR2-78. Institute for Mining and Minerals Research, University of Kentucky, Lexington.

Barfield B. J., E. W. Tollner and J. C. Hayes. 1979. Filtration of sediment by simulated vegetation I. Steady-state flow with homogeneous sediment. *Transactions of ASAE*. 22(5):540-545.

Brown, L.R., 1984. Conserving soils. In: Brown, L.R. (Ed.), State of the World. Norton, New York, pp. 53– 75.

Daniels, R.B., Gilliam, J.W., 1989. Effect of grass and riparian filters on runoff and water quality. *North Carolina. Soil Science Soc. Proc.* (32): 37–45.

Dillaha, T.A., Reneau, R.B., Mostaghimi, S., Lee, D., 1989a. Vegetative filter strip for agricultural nonpoint source pollution control. *Transactions of ASAE* 32 (2): 491–519.

Gharabaghi, B. R. P. Rudra, H. R. Whiteley, and W. T. Dickinson. 2001. Sediment removal efficiency of vegetative filter strips*. ASAE Paper* No. 012071. St. Joseph, Mich.: ASAE.38-39.

Haan, C. T., Barfield, B.J, Hayes, J.C., 1994. Design Hydrology and Sedimentology for Small Catchments. San Diego: Academic Press

Hayes, J. C., B. J. Barfield and R. I. Barnhisel. 1979. Filtration of sediment by simulated vegetation II. Unsteady flow with non-homogeneous sediment. *Transactions of ASAE*. 22(5):1063-1967.

Hayes, J. C., B. J. Barfield and R. I. Barnhisel. 1984. Performance of grass filters under laboratory and field conditions. *Transactions of ASAE*. 27(5):1321-1331.

Jung, P. K., M. H. Ko and K. T., Um. 1985. Discussion of Cropping Management Factor for Estimating Soil Loss*. Korean Society of Soil Science and Fertilizer.* 18(1):7-13.

Kizil, U., and L. A. Disrud. 2002. Vegetative filter strips modeling of a small watershed*. ASAE Paper* No. 022133. St. Joseph, Mich.: ASAE.

Lal, R., 1994. Soil erosion by wind and water: problems and propects. In: Lal, R. (Ed.), Soil Erosion Research Methods, (Second edition) Soil and Water Conservation Society, St. Lucie Press, Delray Beach, FL.

Lee, K.H., Isenhart, T.M., Schultz, R.C., Mickelson, S.K., 1999. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, *USA. Agrofor. Syst.* (44): 121–132.

Lim, K. J. and B. A. Engel. 2003. Extension and Enhancement of National Agricultural Pesticide Risk Analysis (NAPRA) WWW Decision Support System to Include Nutrients. Computers and Electronics in Agriculture 38(3):227-236. Magette, W.L., Brinsfield, R.B., Palmer, R.E., Wood, J.D., 1989. Nutrient and sediment removal by vegetated filter strips. Transaction of ASAE 32 (2): 663–667.

Lim, K. J., B. A. Engel, Z. Tang, J. Choi, K. S. Kim, S. Muthukrishnan and D. Tripathy. 2005. Automated Web GIS based Hydrograph Analysis Tool, WHAT. Journal of the American Water Resources Association. 1407-1416.

Mersie, W., Seybold, C.A., McNamee, C., Lawson, M.A., 2003. Abating endosulfan from runoff using vegetative filter strips: the importance of plant species and flow rate. *Agriculature,Ecosystem and Environment 97*, 216.

Mersie, W., Seybold, C.A., McNamee, C.M., Huang, J., 1999. Effectiveness of switchgrass filter strips in removing dissolved atrazine and metolachlor from runoff. *J. Environ. Qual.* (2): 816–821.

Ministry of Construction and Transportation. 2000. 1999 Research of Water Resource Management Development. Regulation of Probabilistic Rainfall in Korea.

Muñoz−Carpena, R., and J. E. Parsons. 2005. VFSMOD, versoin 2.x, User's Maunal. 2-9.

Muñoz−Carpena, R., C. T. Miller, and J. E. Parsons. 1993. A quadratic Petrov−Galerkin solution for kinematic wave overland flow. *Water Resour. Res.* 29(8): 2615−2627.

Muñoz−Carpena, R., J. E. Parsons, and J. W. Gilliam. 1999. Modeling hydrology and sediment transport in vegetative filter strips and riparian areas. *J. Hydrology* 214(1−4): 111−129.

Neibling, W.H. and Alberts, E.E. 1979. Composition and Yield of Soil Particles Transported Through Sod Strips, Paper No. 792065. *Trans. ASAE*, St. Joseph, MI, USA.

Otto, S., Vianello, M., Infantino, A., Zanin, G., Di Guardo, A., 2008. Effect of a full-grown vegetative filter strip on herbicide runoff: Maintaining of filter capacity over time. *Chemosphere* 71-75.

Patty L., 1997. Limitation du transfert par ruissellement vers les eaux superficielles de deux herbicides (isoproturon et diflufe´nicanil). Me´thodologie analytique et e´tude de l'efficacite´ de bandes enherbe´es. PhD Thesis. Universite´ Joseph Fourier, Grenoble, France.

Muñoz−Carpena, R., J. E. Parsons and J. W. Gilliam, 1999. Modeling hydrology and sediment transport in vegetative filter strips. *Journal of Hydrology* (214):111-112.

Rawls, W.J. and D.L. Brakensiek. 1983. A procedure to predict Green-Apmt infiltration parameters. Adv. in Infiltration, pp. 102-112. *ASAE* Pub. no. 11-83.

Tarantilis, C.D., Kiranoudis, C.T., Theodorakopoulos, N.D., 2008. A Web-based ERP system for business servies and supply chain management: Application to real-world process scheduling. *European Journal of Operational Research* (187): 1311.

Tollner, E. W., B. J. Barfield, C. T. Haan and T. Y. Kao. 1976. Suspended sediment filtration capacity of simulated vegetation. *Transactions of ASAE* 19(4):678-682.

Tollner, E.W., B.J. Barfield, C. Vachirakornwatana and C.T. Haan. 1977. Sediment deposition patterns in simulated grass filters. *Transactions of ASAE*. 20(5):940-944.

Wilson, B.N., B.J. Barfield and I.D. Moore. 1981. A Hydrology and Sedimentology Watershed Model, Part I: Modeling Techniques. Technical Report. Department of Agricultural Engineering. University of Kentucky. Lexington.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses-a guide to conservation planning. Agriculture Handbook No.537, USDA, Washington,DC,55

Young, R.A., Huntrods, R., Anderson, W., 1980. Effectiveness of vegetative buffer strips in controlling pollution from feedlot runoff. *J. Environ. Qual.* (9): 483–487.

Zhang, Q., C. G. Okoren, and K. R. Mankin. 2001. Modeling fecal pathogen transport in vegetative filter strips. *ASAE Paper* No. 012194. St. Joseph, Mich.: ASAE.