Analysis of Sediment Reduction with VFS and Diversion Channel with Enhancements in SWAT Landuse-Subbasin Overland Flow and VFS Modules

Youn Shik Park[*], Jonggun Kim[**], Nam Won Kim[***], Bernie Engel[****], and Kyoung Jae Lim[*****]

Abstract

In the last decade, many methods such as greet chamber, reservoir, or debris barrier, have been utilized to manage and prevent muddy water problem. The Vegetative Filter Strip (VFS) has been thought to be one of the most effective methods to trap sediment effectively. The VFS are usually installed at the edge of agricultural areas adjacent to stream or drainage ditches, and it has been shown that the VFS effectively removes pollutants transported with upland runoff. But, if the VFS is installed without any scientific analysis of rainfall-runoff characteristics, soil erosion, and sediment analysis, it may not reduce the sediment as much as expected. Although Soil and Water Assessment Tool (SWAT) model has been used worldwide for many hydrologic and Non-Point Source Pollution (NPSP) analysis at a watershed scale. but it has many limitations in simulating the VFS. Because it considers only 'filter strip width' when the model estimates sediment trapping efficiency, and does not consider the routing of sediment with overland flow option which is expected to maximize the sediment trapping efficiency from upper agricultural subbasin to lower spatially-explicit filter strip. Therefore, the SWAT overland flow option between landuse-subbasins with sediment routing capability was enhanced with modifications in SWAT watershed configuration and SWAT engine. The enhanced SWAT can simulate the sediment trapping efficiency of the VFS in the similar way as the desktop VFSMOD-w system does. Also it now can simulate the effects of overland flow from upper subbasin to reflect the increased runoff volume at the receiving subbasin, which is what is occurring at the field if no diversion channel is installed. In this study, the enhanced SWAT model was applied to small watershed located at Jaun-ri in South Korea to simulate diversion channel and spatially-explicit VFS. It was found that approximately sediment can be reduced by 31%, 65%, 68%, with diversion channel, the VFS, and the VFS with diversion channel, respectively.

Keywords: Vegetative Filter Strip, HRU Routing, SWAT, VFSMOD

1. Introduction

Environmental problems have been arising worldwide. Especially, the muddy

* 정회원·강원대학교 대학원·E-mail : caron-ys@nate.com

** 정회원·강원대학교 대학원·E-mail : jong0923@naver.com

*** 정회원·한국건설기술연구원 수문연구실·E-mail : nwkim@kict.re.kr

**** 비회원·Purdue University, USA·E-mail : engelb@purdue.edu

***** 정회원·강원대학교 지역건설공학과 교수·E-mail : kjlim@kanwwon.ac.kr

water problem is deemed as one of the serious environmental problems. The soil erosion is one of the major causes of muddy water, can occur everywhere with rainfall-runoff processes. There are many methods to prevent the muddy problem in watersheds. Among these methods to prevent muddy problems, the Vegetative Filter Strip (VFS) has been deemed that it is better than other methods from an environmental perspective. The filter strip isusually installed at the edge of cultivated or agricultural area along the stream, and it is designed to remove not only sediment but also other pollutants, such as nutrients from runoff by filtration, infiltration, adsorption, absorption, deposition, decomposition, and plant uptake (Mu�oz-Carpena, 1999). But before installation at the field for desired pollutant removal results, the effects of filter strip have to be simulated with a physically-based model, capable of simulating the sediment behavior in the filter strip and source areas such as cultivated areas.

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998; Arnold and Fohrer, 2005) has beenused as an effective tool for assessing water resource and Non-Point Source Pollution (NPSP) problem worldwide. The SWAT model is a watershed-scale and continuous daily time step model. The model can be used for simulation of flow, sediment, and agricultural chemicals, and nutrient generation and transport. The SWAT model divides the watershed into several or a number of subwatersheds, and they are further divided for each Hydrologic Response Units (HRUs) which are unique combination of land use/cover and soil types within each watershed. But the current SWAT model has some limitations to simulate the effect of filter strip. The SWAT model does not consider the routing of sediment under overland flow condition which is deemed as usual flow type from upper cultivated subbasin to lower filter strip subbasin. In addition, the SWAT considers only filter strip width to calculate the sediment trapping efficiency.

In this study, the model has been enhanced to route the sediment under the overland condition, and the sediment trapping efficiency equation has been modified to consider another sensitive factor of filter strip sediment reduction processes.

2. Enhancement and Application of SWAT model

2.1 Limitation of Filter Strip Module in the Current SWAT model

The sediment trapping efficiency of the filter strip in the current SWAT model is calculated with Equation 1.

$$trap_{ef} = 0.367 \cdot (width_{filter\ strip})^{0.2967} \text{ ------------------------------ Equation (1)}$$

This equation indicates that sediment trapping efficiency in the current SWAT is calculated with only filter strip width. However, the sediment trapping efficiency of filter strip can vary under many conditions; also there are many influencing factors on sediment trapping efficiency such as filter strip slope, runoff volume from upland, and so on. The sediment trapping efficiency of filter strip can be calculated by the equation (1), but it needs to be enhanced or modified to estimate sediment trapping efficiency reflecting other sensitivefactors. TheSWAT model considers only filter strip width in filter efficiency simulations, In addition the spatial location of the filter strip is notconsidered in the current SWAT filter strip module. The limitation of spatial distribution of filter strip in the SWAT is extended from the limitation of HRU/subbasin routing. Because sediment is not routed with overland flow from the upper subbasin to the lower one, increased sediment with increased overland surface runoff cannot be calculated in lower subbasin. When the filter strip is installed at the edge of cultivated area in the field, the cultivated area is reduced; also sediment generation and transport from the cultivated area is also reduced.

However, the current SWAT cannot simulate the spatial location of filter strip and decreased size of agricultural areas by the area of filter strip. Thus, the SWAT model needs to be modified to consider the spatial distribution of filter strip and overland flow and sediment routing from agricultural areas to filter strip.

2.2 Enhancement of Current SWAT model

The current SWAT model has various limitationsto simulate spatially distributed filter strip. Thus the current SWAT model was enhanced in this study. In the overland flow process, the current SWAT model does not calculate the sediment from upper subbasins to lower subbasins, so the model was slightly modified to route the sediment from upper subbasins to lower subbasins with overland flow. Total sediment delivered to the lower subbasin is calculated by multiplyingthe total sediment estimated for upper subbasin by area-based sediment delivery ratio (SDR) suggested by Vanoni (1975). This updated process is used in sediment inflow to the filter strip. As explained in Equation 1, the filter strip module of the current SWAT model only considers only filter strip width. However the sedimenttrapping efficiency of the filter strip is affected by other factors. Park et al. (2008) analyzed the desktop-based VFSMOD-w system to identify the most sensitive factors affecting thesediment trapping efficiency and derived the regression equation to explain VFSMOD behaviors with filter strip width and overland flow volume. Equation 2 shows the trapping efficiency regression equation (R2 value of 0.99) from the study by Park et al. (2008). The SWAT trapping efficiency module was modified with this result.

Trapping Efficiency =

$$(-0.00007345046 \times L^3 + 0.001558 \times L^2 - 0.006376 \times L - 0.001189) \times (\ln(V))^3 +$$
$$(0.0009688469 \times L^3 - 0.020779 \times L^2 + 0.095153 \times L + 0.019348) \times (\ln(V))^2 +$$

$$(-0.004274\times L^3 + 0.092846 \times L^2 - 0.487355 \times L - 0.10563) \times (\ln(V)) + (0.006381 \times L^3 - 0.140713 \times L^2 + 0.869293 \times L + 0.19386) \text{ ----------- Equation (2)}$$

(Where, L is Vegetative filter strip Width, V is Overland flow from field, $V > 1 \text{ m}^3$)

2.3 Application of Enhanced SWAT for Small Watershed

In this study, the enhanced SWAT was applied to the small watershed experiencing severe muddy water problems in recently years, located at Jaun-ri, Gangwon province, Korea to simulate the filter strip. The watershed has two dominant land uses; forest (23.83 ha, 96.17 %) and cultivated area (1.06 ha, 3.83%).

In this study, 24 subbasins were delineated for application of enhanced SWAT with cultivated area boundary burned with the DEM for isolation of cultivated area as separate subbasin. The 1st subbasin group includes sub-basin of 1, 4, 5, 11, 10, and 22 which are the upper subbasin of cultivated area (subbasin marked with no. 2 subbasin). The 2nd subbasin group is the cultivated area (subbasin marked with no. 2). The 3rd subbasin group includesforest dominant subbasins. For 3rd subbasin group, subbasin of no. 6, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21. The 4th subbasins group includes subbasins of 3, 23, and 24.

To simulate overland flow/sediment from the cultivated area to filter strip for filter strip effect, the 26 subbasins were regrouped. The 1st subbasin group includes sub-basin of 1, 6, 7, 12, 13, and 24 which are the upper subbasin of cultivated area(subbasin marked with no. 2 subbasin). The 2ndsubbasin group is the cultivated area (subbasin marked with no. 2). The 3rd subbasin group includesforest dominant subbasins. For 3rdsubbasin group, subbasin of no. 8, 9, 10, 11, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23. The 4th subbasins group includes subbasins of 5, 25, and 26. The 5thsubbasins group is the filter strip area (subbasin marked with no. 4 subbasin).

As explained before, the current SWAT has limitations in simulating the effects of filter strip properly. To verify the filter strip for sediment reduction analysis, two scenarios (Scenario 1 and Scenario 2) were made. The subbasins were rearranged with modification in the file "fig.fig" to be compatible with "Scenario 1 and Scenario 2" overland flow and channelized flow in the stream networks. It is assumed that flow and sediment from the SG1 flow into SG2 as overland flow, and flow and sediment from SG2 flow into filter strip subbasin group SG5, and flow and sediment from SG3 and SG5 flow into SG4 as channelized flow for "Scenario 1". For "Scenario 2", flow and sediment from SG1directly flow into SG4, and flow and sediment from SG2 flow into filter strip subbasin group SG5. Scenarios 1 and 2 were run and the sediment reduction efficiencies were analyzed.

3. Results

Monthly average flow rate of Scenarios 1 and 2 were 0.01387 m3/s and 0.01184 m3/s respectively. The maximum flow value of Scenario 1 was 0.13860 m3/s on July 2006, and the minimum value was 0.00003 m3/s on February 2005, the maximum flow value of Scenario 2 was 0.11750 m3/s on July 2006, and the minimum value was 0.00023 m3/s on February 2005. It was found that there was no significant difference in estimated flow rates with filter strip. The monthly average sediment values of Scenario 1 and Scenario 2 were 2.68657 metric tons and 0.93284 metric tons respectively. The maximum value of Scenario 1 was 39.85000 metric tons on July 2006, and the minimum value was 0.00013 metric tons on February 2005. But the maximum monthly sediment value of Scenario 2 was 6.26300 metric tons on July 2006, and the minimum value was 0.00007 metric tons on February 2005. The analysis revealed that monthly sediment values reduced by 33.58700 metric ton on July 2006. For the entire simulation period, it is expected that 65.28% of sediment can be reduced with filter strip.

4. Conclusion

In this study, the SWAT model was enhanced to simulate diversion channel and filter strip and applied to the small watershed located at Jaun-ri, Gangwon, Korea. The current SWAT model has some limitation to simulate the filter strip, because the current SWAT model does not consider thesediment routing with overland flow, and the trapping efficiency equation consider only filter strip width even though there are many kind of sensitive factors in filter strip. Especially, the sediment routing is needed to be considered with overland flow, because the flow type from cultivated area to filter strip area is usually overland flow, not the channelized type. Also another limitation of current SWAT model is the trapping efficiency by the filter strip, which calculates the trapping efficiency considering only filter strip width. The equation of current SWAT model can be suitable, but the trapping efficiency is calculated considering another sensitive factor, such as field runoff volume. In the steep area, the runoff can increase very quickly, accordingly sudden increases in the runoff volume can result in increased sediment, thus the trapping efficiency will vary under the same filter strip condition.

Thus, the SWAT model has been enhanced in this study to consider the sediment routing under the overland flow condition, and to calculate the trapping efficiency with filter strip width and runoff volume additionally. The effect of filter strip for the sediment reduction was analyzed. The results showed that there were little differences at the outlet between each Scenarioin flow simulations, but filter strip are effective to reduce the sediment. In the monthly simulations, the effect of sediment reduction was average 65.28 % by filter strip.

In further study, calibration and validation will be performed with long-term measured data collected at the fields experiencing flow and sediment routing in overland flow type.

References

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. Journal of American Water Resources Association. 34 (1):73- 89.

Arnold, J.G., Fohrer. N., 2005. SWAT2000: Current Capabilities and research opportunities in applied watershed modeling. Hydrol. Process.19(3):563−572.

Grassman, P.W., Reyes, M.R., Green, C.H., Arnold, J.G., 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Direstions. Transactions of the ASABE. 50(4):1211−1250.

Green, W.H., Ampt, A., 1911. Studies on soil physics:1. The flow of air and water through soils. J. Agric. Sci. 4:11−24.

Monteith, J. L., 1965. Evaporation and the environment. In The State and Movement of Water in Living Organisms, Proc. 19th Symp. Swansea,U.K.: Society of Experimental Biology, Cambridge University Press.

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.

Park, Y.S., Kim, J., Kim, N., Park, J., Jang, W.S., Choi, J., Lim, K.J. 2008. Improvement of Sediment Trapping Efficiency Module in SWAT using VFSMOD−W model. Journal of Korean Society on Water Quality. 24(4): 473−479.

Priestly, C. H. B., Taylor, R. J., 1972. On the assessment of surface heat flux and evaporation using large−scale parameters.Monthly Weather Rev.100(2): 81−92.