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## DEVELOPMENT OF A SWAT PATCH FOR BETTER ESTIMATION OF SEDIMENT YIELD IN STEEP SLOPING WATERSHEDS<sup>1</sup>

*Jong-Gun Kim, Younshik Park, Dongsun Yoo, Nam-Won Kim, Bernard A. Engel, Seong-joon Kim, Ki-Sung Kim, and Kyoung Jae Lim<sup>2</sup>*

**ABSTRACT:** The watershed scale Soil and Water Assessment Tool (SWAT) model divides watersheds into smaller subwatersheds for simulation of rainfall-runoff and sediment loading at the field level and routing through stream networks. Typically, the SWAT model first needs to be calibrated and validated for accurate estimation through adjustment of sensitive input parameters (i.e., Curve Number values, USLE P, slope and slope-length, and so on). However, in some instances, SWAT-simulated results are greatly affected by the watershed delineation and Digital Elevation Models (DEM) cell size. In this study, the SWAT ArcView GIS Patch II was developed for steep sloping watersheds, and its performance was evaluated for various threshold values and DEM cell size scenarios when delineating subwatersheds using the SWAT model. The SWAT ArcView GIS Patch II was developed using the ArcView GIS Avenue program and Spatial Analyst libraries. The SWAT ArcView GIS Patch II improves upon the SWAT ArcView GIS Patch I because it reflects the topographic factor in calculating the field slope-length of Hydrologic Response Units in the SWAT model. The simulated sediment value for 321 subwatersheds (watershed delineation threshold value of 25 ha) is greater than that for 43 subwatersheds (watershed delineation threshold value of 200 ha) by 201% without applying the SWAT ArcView GIS Patch II. However, when the SWAT ArcView GIS Patch II was applied, the difference in simulated sediment yield decreases for the same scenario (i.e., difference in simulated sediment with 321 subwatersheds and 43 subwatersheds) was 12%. The simulated sediment value for DEM cell size of 50 m is greater than that for DEM cell size of 10 m by 19.8% without the SWAT ArcView GIS Patch II. However, the difference becomes smaller (3.4% difference) between 50 and 10 m with the SWAT ArcView GIS Patch II for the DEM scenarios. As shown in this study, the SWAT ArcView GIS Patch II can reduce differences in simulated sediment values for various watershed delineation and DEM cell size scenarios. Without the SWAT ArcView GIS Patch II, variations in the SWAT-simulated results using various watershed delineation and DEM cell size scenarios could be greater than those from input parameter calibration. Thus, the results obtained in this study show that the SWAT ArcView GIS Patch II should be used when simulating hydrology and sediment yield for steep sloping watersheds (especially if average slope of the subwatershed is >25%) for more accurate simulation of hydrology and sediment using the SWAT model. The SWAT ArcView GIS Patch II is available at <http://www.EnvSys.co.kr/~swat> for free download.

(KEY TERMS: ArcView GIS Patch; DEM; slope-length; subwatershed; SWAT; watershed delineation.)

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## INTRODUCTION

The Soil and Water Assessment Tool (SWAT) model has been widely used worldwide in simulating hydrology and water quality at the watershed scale. The SWAT model was developed and enhanced over 15 years for hydrologic and water quality simulation. However, there are many aspects that need to be fixed and enhanced to improve the accuracy of the model when it is applied to steep terrain watersheds.

Sometimes, the SWAT model watershed division has more impact on simulated results than model input parameter adjustments, indicating the SWAT model can be calibrated with watershed delineation to some degree. The impact of subwatershed scaling upon a watershed simulation is directly related to parameters that vary, which include the watershed topography, soils, land use, weather data, and streams (Arnold *et al.*, 1998). According to Goodrich's (1992) study, watershed scale can affect the characterization of geometric properties. Goodrich (1992) determined that alteration of the watershed precision influences the accuracy of simulated results. Also, Mamillapalli *et al.* (1996) found that increasing the number of subwatersheds and the number of Hydrologic Response Units (HRUs) improved accuracy of SWAT flow prediction for the Bosque River watershed. However, most SWAT users tend to use the default threshold values to delineate subwatersheds and generate HRUs from land uses and soil data in study watersheds and then calibrate and validate the model with observed data, without worrying about the potential impacts on SWAT-simulated results of the subwatershed delineation.

When the SWAT model is applied to sloping watersheds, the impacts of watershed subdivision on simulated sediment is beyond expectation (Heo *et al.*, 2006). This occurs because the SWAT ArcView GIS system uses the relationship between subwatershed average slopes *vs.* average field slope-length for subwatersheds for estimating HRU field slope-length. As the solution to the problem, the SWAT ArcView GIS Patch I was developed, available from <http://www.EnvSys.co.kr/~swat>, using the regression equation derived from the relationship between average watershed slope and field slope-length for estimating HRU field slope-length.

In the Heo *et al.* (2008) study, SWAT-estimated results were compared with and without applying the SWAT ArcView GIS Patch I for four watershed delineation scenarios. In the results, the SWAT-estimated results with the SWAT ArcView GIS Patch I are less affected by the number of subwatersheds delineated. However, there are still 29.8% differences in simulated sediment with SWAT ArcView GIS Patch I

(Figure 1). This can be explained in that the SWAT ArcView GIS Patch I does not reflect topography in estimating field slope-length of SWAT HRUs. Thus, the SWAT ArcView GIS Patch I should be modified to eliminate errors for accurate estimation of sediment. Also, in the Arabi *et al.* (2006) study, the evaluation of appropriate level of watershed subdivision on modeling the effectiveness of best management practices (BMPs), such as field border, parallel terrace, grassed waterway, and grade stabilization structure, were examined for two small watersheds in Indiana using the SWAT model. In the results, the average subwatershed area at a critical source area corresponding to approximately 4% of the total watershed area was identified to be adequate for description of the BMPs. However, these results are not a solution to this problem because it was applied to flat watersheds in Indiana. The average slope value of these watersheds was approximately 2%, which is much flatter than most watersheds in Korea to which SWAT might be applied. Thus, to apply the SWAT model for steep sloping watersheds, a 4% threshold value will not be the appropriate level in watershed delineation.

In addition, because of computational time and limitations, many SWAT users tend to use Digital Elevation Models (DEM) with cell sizes of 100 m or greater as the topography data for bigger watersheds. However, use of DEMs with cell size of 100 m or above could result in misrepresentation of true topography. Previous studies by Bingner *et al.* (1997), FitzHugh and MacKay (2000), Jha *et al.* (2004), and Mamillapalli (1998) indicate that the SWAT model sediment and nutrient-simulated results differ quite dramatically with the number and size of subwatersheds. Because model results are affected by topographical resolution, the predicted performance of BMPs will be influenced as well. However, previous

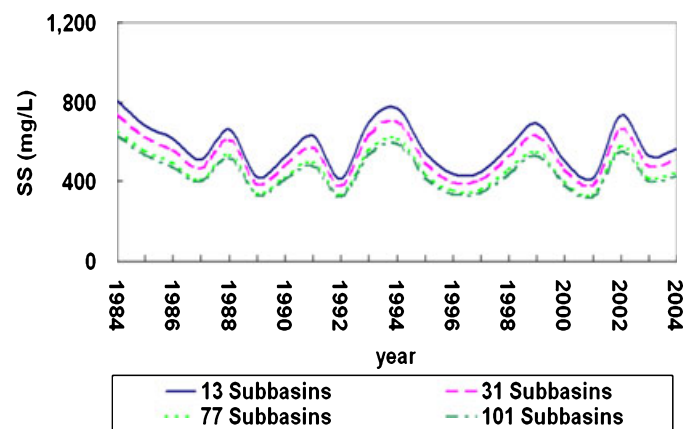


FIGURE 1. The SWAT-Simulated Sediment for Four Subwatershed Delineation Scenarios With SWAT ArcView GIS Patch I (Lim *et al.*, 2007; Heo *et al.*, 2008).

research on evaluation of the effectiveness of BMPs did not consider the effects of topographical resolution. So, Kim *et al.* (2007) generated five DEMs with various spatial resolutions and compared the SWAT-estimated sediment values with and without applying the SWAT ArcView GIS Patch I. The simulated sediment losses with the SWAT ArcView GIS Patch I were less impacted by the spatial resolution of the DEM. Although error was reduced by the SWAT ArcView GIS Patch I, the existing SWAT ArcView GIS system and the SWAT ArcView GIS Patch I do not consider watershed topography for computing field slope-length of HRUs. For these reasons, it is necessary to develop an improved SWAT ArcView GIS Patch to reflect topographic features in estimating field slope-length for HRUs in SWAT.

Therefore, the objective of this study was to develop a module of an average slope-length computation using the DEM, flow accumulation and user-provided maximum slope-length from topography of the watershed, which was called SWAT ArcView GIS Patch II. The Patch II will be a useful tool for SWAT application in steep sloping watersheds for accurate simulation of hydrology and sediment yield.

STUDY WATERSHED

The Doam-dam watershed at Pyeongchang-gun, Gangwon-do in South Korea was selected for evaluation of the SWAT ArcView GIS Patch II (Figure 2). The Doam-dam watershed is 145.6 km<sup>2</sup> in size. Topography characteristics in Doam-dam watershed are shown in Table 1 and Figure 3. As shown in Table 1, areas with average slope of 40-60% cover 31.2 km<sup>2</sup> (21.5% of watershed); 25-40% represent

TABLE 1. Analysis of Slope in Doam-Dam Watershed.

	Over 80%	80-60%	60-40%	40-25%	25-10%	10-0%
Area (km <sup>2</sup> )	2.85	11.87	31.23	31.45	24.30	43.90
Ratio (%)	1.96	8.15	21.45	21.60	16.69	30.14

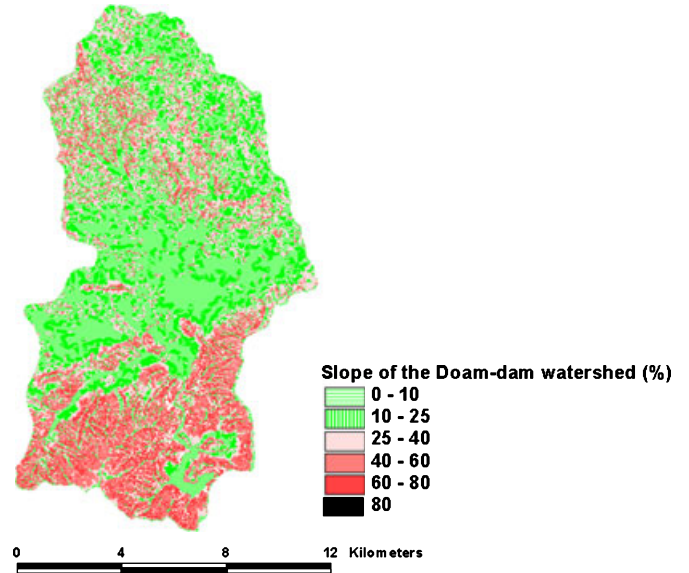


FIGURE 3. Slope of the Doam-Dam Watershed.

31.5 km<sup>2</sup> (21.6% of watershed); 10-25% is 24.3 km<sup>2</sup> (16.7% of watershed); and 0-10% is 43.9 km<sup>2</sup> (30.1% of watershed). Areas with slope >25% are approximately 53.2% of the Doam-dam watershed. Also, land use in this area is mostly forest (61.8% of the whole watershed) in the upper portion, while agriculture and pasture occupies 31.7 and 2.3% of the area, respectively. Brown forest soils and entisols are the dominant soil types within the watershed with a few

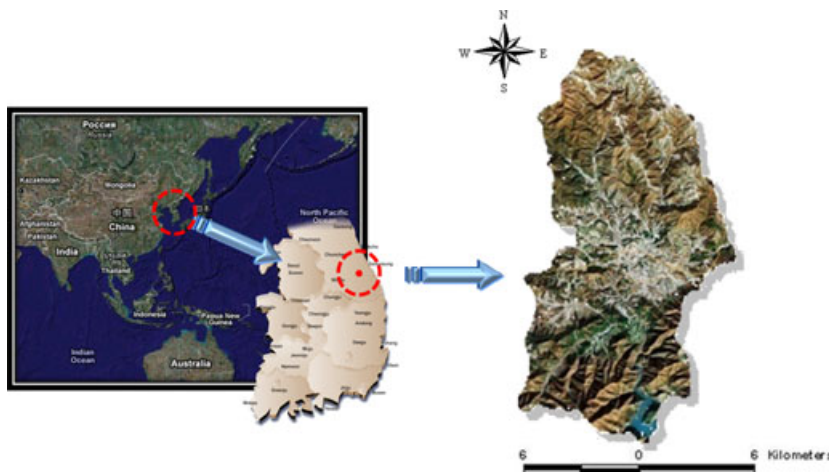


FIGURE 2. Location of the Doam-Dam Watershed at Pyeongchang-Gun, Gangwon-Do in South Korea.



fertile sedimentary soils. Loam and silt loam soil textures account for 62 and 17%, respectively, of soil surface textures. Clay loams and sandy loams occupy 49 and 30%, respectively, of subsoil textures.

METHODS

*Development of SWAT ArcView GIS Patch II*

In the SWAT model, sediment yields from HRUs are computed using the Modified Universal Soil Loss Equation (MUSLE) (Arnold *et al.*, 1993), which is dependent on field slope and slope-length. Thus, sediment yields are affected by field slope and slope-length, with sediment yield increasing as slope-length increases in the SWAT model. The slope-length is calculated as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978). Surface runoff will usually concentrate in <122 m (400 ft), which is a practical slope-length limit in many situations (Wischmeier and Smith, 1978), although longer slope-lengths of up to 305 m (1,000 ft) are occasionally found. Thus, the SWAT ArcView GIS Patch II, which calculates an average slope-length of an HRU considering topography, flow accumulation, and an upper bound of slope-length provided by users, such

as 122 m (400 ft), was developed in this study. This patch was developed as an ArcView Extension using the ArcView Avenue programming and Spatial Analyst libraries because the SWAT 2000/2005 GIS interface is provided in the ArcView GIS 3.x platform. The SWAT ArcView GIS Patch II first reads and fills the DEM, and then estimates the flow direction and flow accumulation using the Spatial Analyst library. Then field slope-length for each subwatershed is computed with user-provided maximum field slope-length and flow accumulation module data. This is somewhat similar to the USLE LS factor computation (Lim *et al.*, 2005), however, only slope-length is computed in the SWAT ArcView GIS Patch II. Next, average field slope-length is calculated for each subwatershed automatically. So, to apply the SWAT ArcView GIS Patch II, only the DEM and subwatershed boundary shape files, which are both required and available data in SWAT, are needed. Figure 4 shows the overview of the SWAT ArcView GIS Patch II to explain how the SWAT ArcView GIS Patch II extracts field slope-length from the DEM (Figure 4a), and shows the SWAT ArcView GIS Patch II interface (marked in a circle) embedded in the ArcView GIS system (Figure 4b).

*SWAT Model Input Data*

Land use, soil, topography, and weather data needed to run the SWAT model were prepared to evaluate the SWAT ArcView GIS Patch II developed

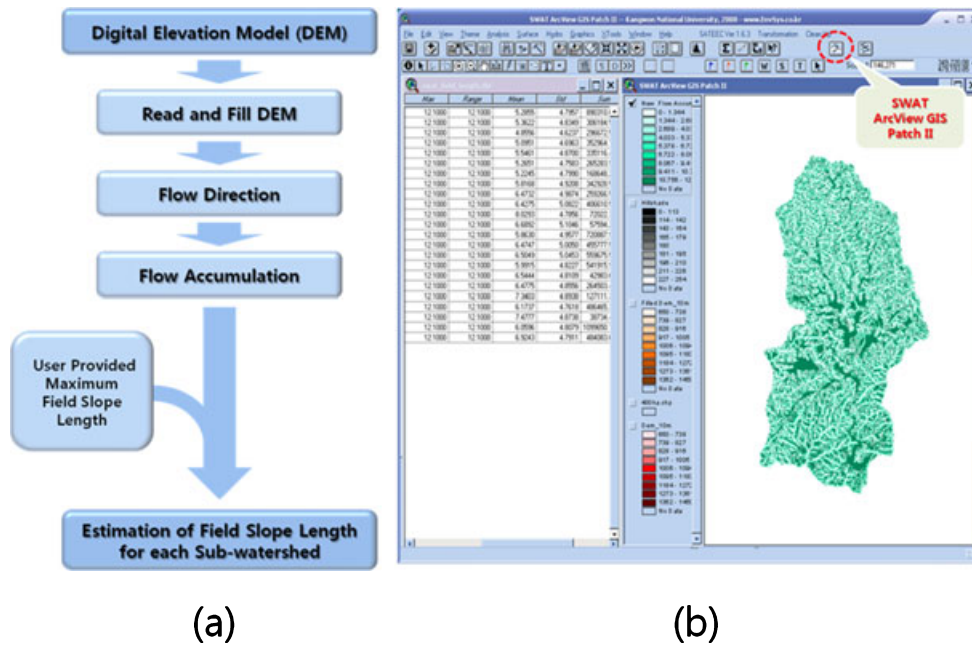


FIGURE 4. Overview of the SWAT ArcView GIS Patch II (a) and the SWAT ArcView GIS Patch II Interface (b).

in this study. The SWAT model generates basic computation elements, called HRUs, which are a combination of land use and soil data and play a significant role in watershed runoff and water quality characteristics. The digital high resolution soil map (1:25,000) from the Korea Rural Resource Development Institute was used (Figure 5). Digital land cover data (1:25,000) (Figure 6) provided from the Korea Ministry of Environment (Heo *et al.*, 2007) was used to represent HRUs in the study watershed with the soil data shown in Figure 5. Long-term (1974-2005) daily precipitation, wind speed, solar radiation, maximum and minimum temperature, and relative humidity were prepared to represent weather characteristics in the study watershed. DEMs with cell sizes of 10 m, 20 m, 30 m, 40 m, and 50 m were prepared using the 1:5,000 digital map provided from the Korea National Geographic Information Institute to evaluate the SWAT ArcView GIS Patch II.

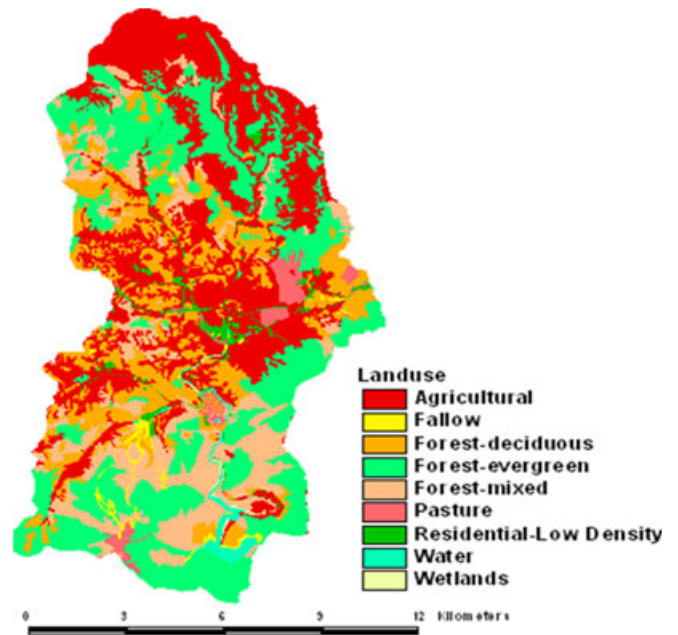


FIGURE 6. Land Uses for the Doam-Dam Watershed.

*Evaluation of SWAT ArcView GIS Patch II*

In this study, the SWAT model was run for two scenarios to evaluate SWAT ArcView GIS Patch II applicability: (1) with and without SWAT ArcView GIS Patch II for different threshold values in subwatershed delineation, and (2) with and without SWAT ArcView GIS Patch II for different DEM cell sizes. First, the SWAT model was run for different threshold value scenarios with and without the SWAT ArcView GIS Patch II applied and 321, 151, and 43 subwatersheds were delineated with threshold values of 25, 50 and 250 ha, respectively (Figure 7). Second,

5 DEMs with spatial resolutions of 10 m, 20 m, 30 m, 40 m, and 50, m were prepared to evaluate effects of cell size on SWAT-estimated results with the SWAT ArcView GIS Patch II (Figure 8). The SWAT model was run for these 2 scenarios with and without the SWAT ArcView GIS Patch II applied, and then the SWAT-simulated streamflow and sediment values were compared to investigate effects of the SWAT ArcView GIS Patch II.

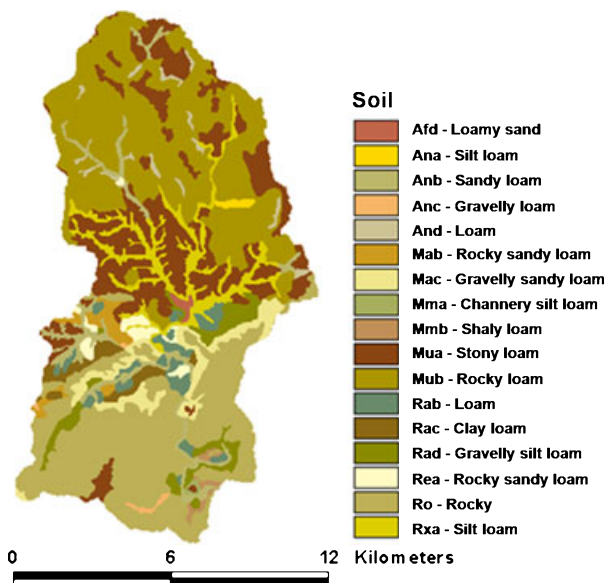


FIGURE 5. Soil for the Doam-Dam Watershed.

RESULTS

*Comparison of SWAT-Simulated Streamflow and Sediment for Different Threshold Value Scenarios in Watershed Delineation*

The SWAT-simulated streamflow and sediment values for 321, 151, and 43 subwatershed scenario (threshold values of 25, 50, and 250 ha) with and without applying the SWAT ArcView GIS Patch II were compared to examine how the SWAT ArcView GIS Patch II eliminates variations in simulated results. Figures 9 and 10 show the SWAT-simulated streamflow for three subwatershed scenarios with and without the SWAT ArcView GIS Patch II applied. Also, average yearly streamflow values were compared for three subwatershed scenarios with and without the SWAT ArcView GIS Patch II applied as shown in Figure 11.

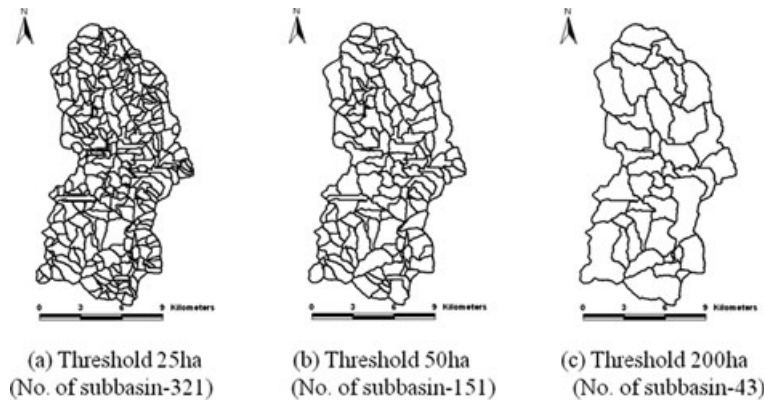


FIGURE 7. Subwatershed Delineation for the Doam-Dam Watershed With Threshold Values of 25, 50, and 200 ha.

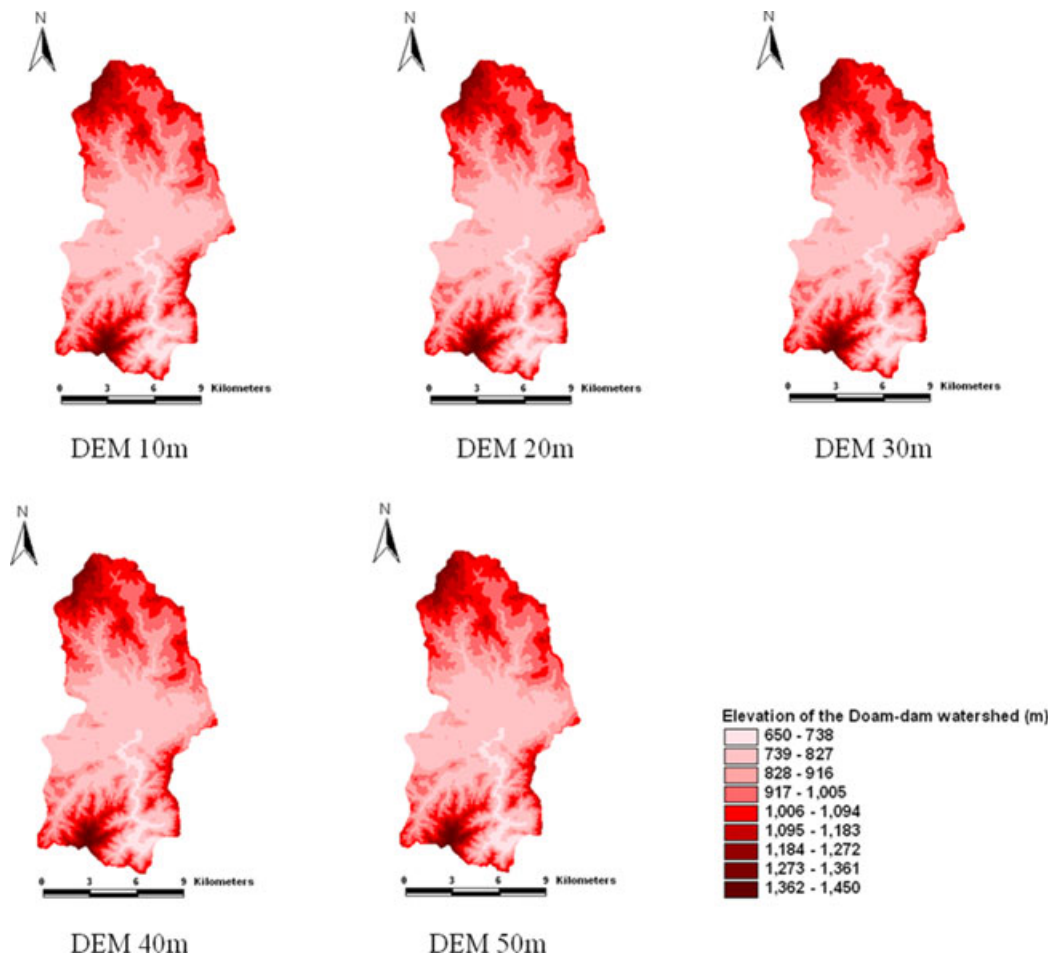


FIGURE 8. DEM With Cell Size of 10, 20, 30, 40, and 50 m at the Doam-Dam Watershed.

As shown in these results, there are negligible differences in simulated streamflow for the three subwatershed scenarios.

On the other hand, Figure 12 shows the SWAT-simulated sediment yield for three watersheds without the SWAT ArcView GIS Patch II applied. When

the threshold value of 200 ha is used in watershed delineation, SWAT-estimated sediment yield values were the greatest, while the simulated results with threshold values of 25 ha were the smallest among the three scenarios. The long-term average sediment yield values for 321 subwatersheds (threshold



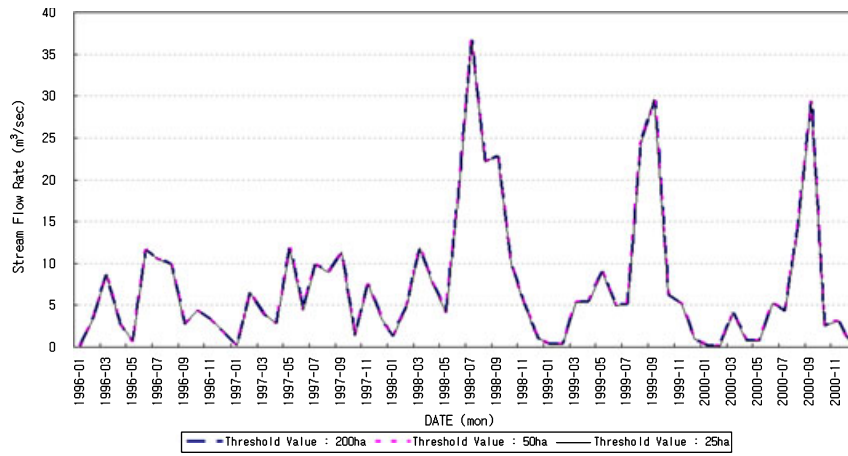


FIGURE 9. Comparison of SWAT-Estimated Monthly Streamflow Without SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.

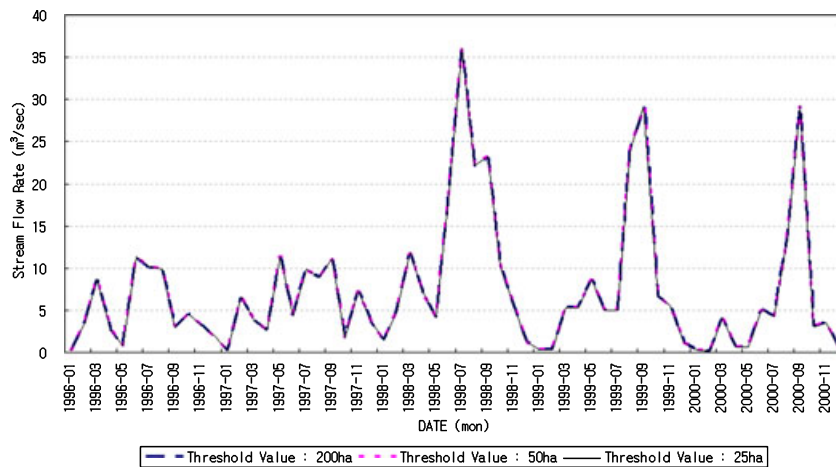


FIGURE 10. Comparison of SWAT-Estimated Monthly Streamflow With SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.

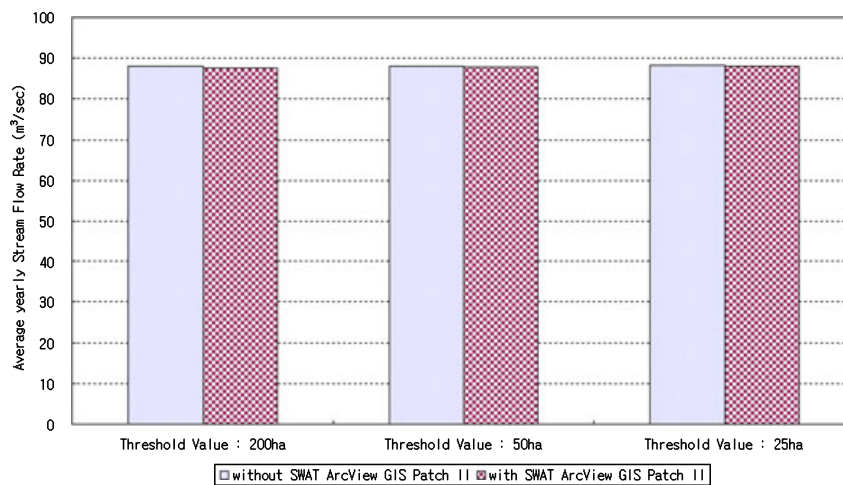


FIGURE 11. Comparison of Simulated Average Yearly Streamflow With and Without SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.



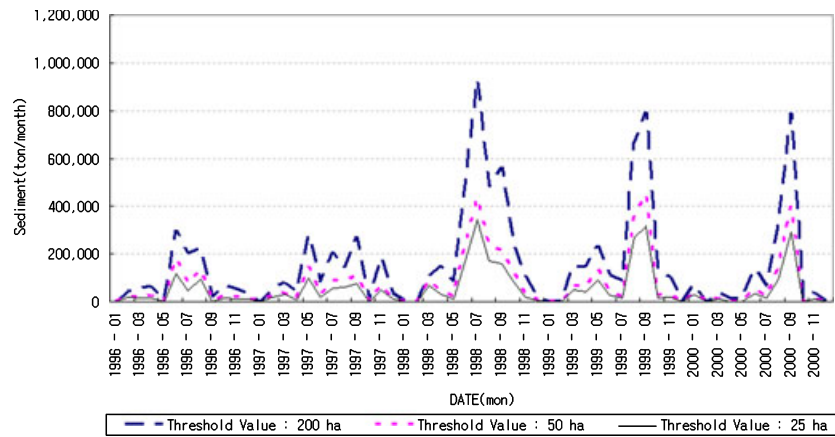


FIGURE 12. Comparison of SWAT-Estimated Monthly Sediment Without SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.

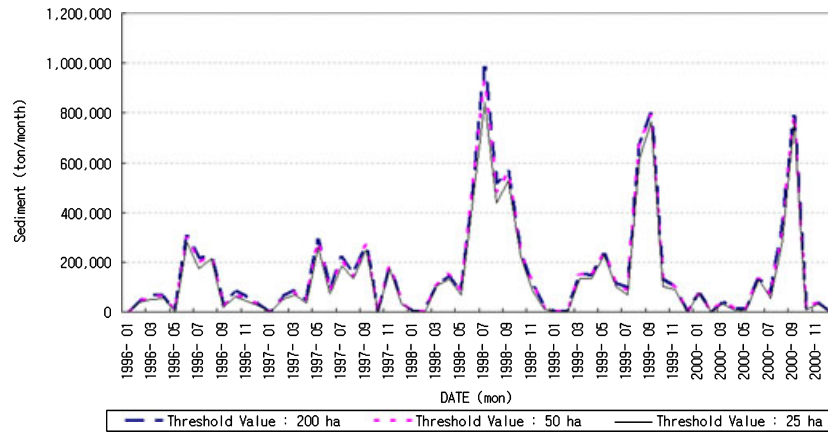


FIGURE 13. Comparison of SWAT-Estimated Monthly Sediment With SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.

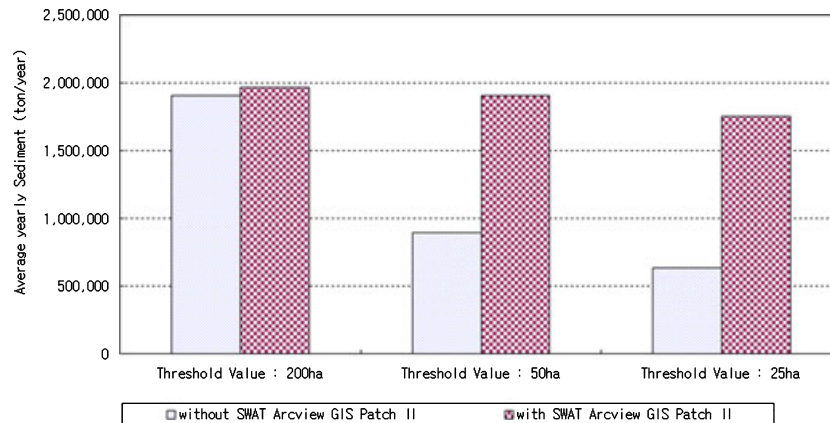


FIGURE 14. Comparison of Simulated Average Yearly Sediment With and Without SWAT ArcView GIS Patch II for Various Threshold Value Scenarios.

value of 25 ha) without the SWAT ArcView GIS Patch II were 201% greater than those for 43 subwatersheds (threshold value of 200 ha). The long-term average sediment yield values for 321

subwatersheds (threshold value of 25 ha) with the SWAT ArcView GIS Patch II were 12% greater than those for 43 subwatersheds (threshold value of 200 ha) (Figure 13). When the SWAT ArcView GIS

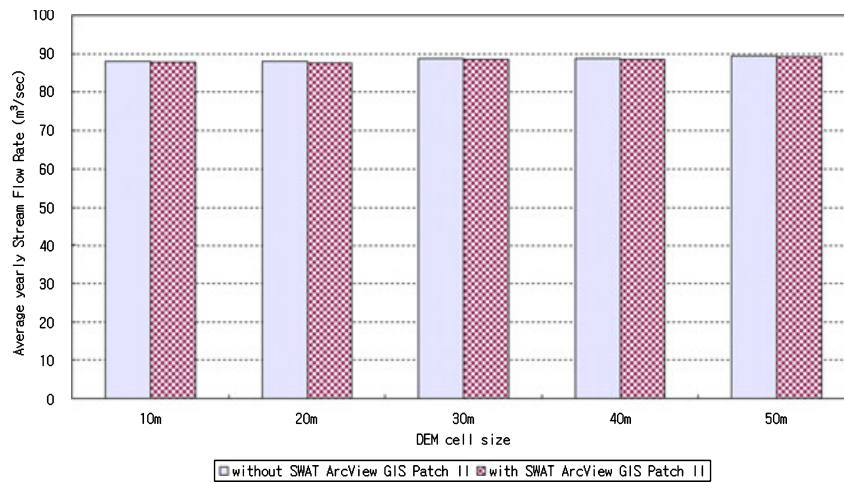


FIGURE 15. Comparison of Simulated Average Yearly Streamflow With and Without SWAT ArcView GIS Patch II for Various DEM Cell Sizes.

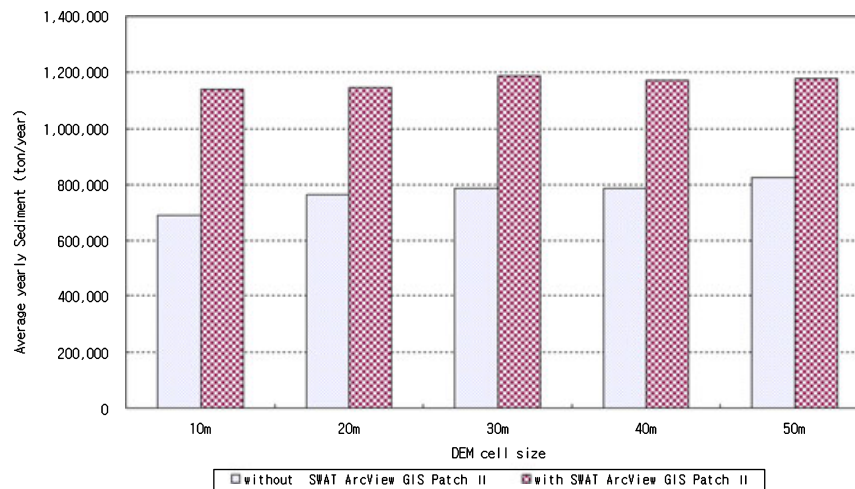


FIGURE 16. Comparison of Simulated Average Yearly Sediment With and Without SWAT ArcView GIS Patch II for Various DEM Cell Sizes.

Patch II was applied, variation in SWAT-simulated sediment for various watershed threshold values was reduced compared to results without SWAT ArcView GIS Patch II, which indicates the SWAT model becomes insensitive to the number of sub-watersheds with the SWAT ArcView GIS Patch II (Figure 14).

*Comparison of SWAT-Simulated Streamflow and Sediment for Different DEM Cell Size in Watershed Delineation*

The SWAT-simulated streamflow and sediment values using DEM cell sizes of 10 m, 20 m, 30 m, 40 m, and 50 m were estimated with and without the SWAT ArcView GIS Patch II. Figure 15 shows the SWAT-simulated streamflow for the 5 DEMs

with and without the SWAT ArcView GIS Patch II. There were no significant differences in the simulated SWAT streamflow for the 5 DEMs. In contrast, there were notable differences in simulated sediment yield without the SWAT ArcView GIS Patch II for the various DEM cell size data. There was a 19.8% difference in annual average sediment yield with the use of different DEM cell sizes in SWAT runs (10 m DEM vs. 50 m DEM). This shows that the SWAT-simulated results can change up to 19.8% if a different cell size DEM was used in model runs. However, with the use of the SWAT ArcView GIS Patch II, the SWAT-simulated sediment values using DEM cell size of 10 m, 20 m, 30 m, 40 m, and 50 m were similar with maximum annual average sediment yield values of 3.4% difference for 10 m DEM and 50 m DEM (Figure 16).

## DISCUSSION AND SUMMARY

In this study, the SWAT ArcView GIS Patch II was developed for steep sloping watersheds, and its performance was evaluated for various threshold values and DEM cell size scenarios when delineating subwatersheds using SWAT. The SWAT ArcView GIS Patch II was developed using the ArcView GIS Avenue program and Spatial Analyst libraries (Figure 2).

The simulated sediment yield value for 321 subwatersheds (threshold value of 200 ha in watershed delineation) was greater than that for 43 subwatersheds (threshold value of 25 ha) by 201% without applying the SWAT ArcView GIS Patch II as shown in Figure 12. However, when the SWAT ArcView GIS Patch II was applied, the difference in simulated sediment yield was greatly reduced (12% difference) for the same scenario (Figure 13). The simulated sediment yield value for DEM cell size of 50 m was greater than that for DEM cell size of 10 m by 19.8% without the SWAT ArcView GIS Patch II. However, the difference in simulated sediment yield becomes smaller (3.4% difference) between the 50 and 10 m DEM scenarios (Figure 16).

As shown in this study, the SWAT ArcView GIS Patch II can reduce differences in simulated sediment yield for various watershed delineation and DEM cell size scenarios. Without the SWAT ArcView GIS Patch II, variations in the SWAT-simulated sediment yields using various watershed delineation and DEM cell size scenarios could be greater than those from input parameter calibration.

The SWAT ArcView GIS Patch II is an improvement of the SWAT ArcView GIS Patch I because it considers the topographic factor in calculating the field slope-length of the HRU in the SWAT model, while the SWAT ArcView GIS Patch I uses the regression equation between average slope of subwatersheds and field slope-length. Thus, when the SWAT ArcView GIS Patch I is used, the field slope-length may be inappropriate for use as the representative field slope-length of all HRUs within the subwatershed.

The results obtained in this study show that the SWAT ArcView GIS Patch II should be used (especially if average slope of the subwatershed is >25%) for accurate simulation of hydrology and sediment yield using the SWAT model. The SWAT ArcView GIS Patch II is available at <http://www.EnvSys.co.kr/~swat> for free download.

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