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GIS-based sediment assessment tool

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Abstract

Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. To effectively estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. The Revised Universal Soil Loss Equation (RUSLE) has been used in many countries, and input parameter data for RUSLE have been well established over the years. However, RUSLE cannot be used to estimate the sediment yield for a watershed. Thus, the GIS-based Sediment Assessment Tool for Effective Erosion Control (SATEEC) was developed to estimate soil loss and sediment yield for any location within a watershed using RUSLE and a spatially distributed sediment delivery ratio. SATEEC was enhanced in this study by developing new modules to: 1) simulate the effects of sediment retention basins on the receiving water bodies, 2) estimate the sediment yield from a single storm event, and 3) prepare input parameters for the Web-based sediment decision support system using a GIS interface. The enhanced SATEEC system was applied to the study watershed to demonstrate how the enhanced system can be effectively used for soil erosion control. All the procedures are fully automated with Avenue, CGI, and database programming; thus the enhanced SATEEC system does not require experienced GIS

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users to operate the system. This easy-to-operate SATEEC system can be used to identify areas vulnerable to soil loss and to develop efficient soil erosion management plans.

Keywords: Soil erosion; Sediment delivery ratio; Sediment yield; RUSLE; SATEEC GIS

1. Introduction

Accelerated soil erosion is a serious concern worldwide, and it is difficult to assess its economic and environmental impacts accurately because of its extent, magnitude, rate, and complex processes associated with it (Lal, 1994). Many human-induced activities, such as mining, construction, and agricultural activities, disturb land surfaces, resulting in accelerated erosion. Soil erosion from cultivated areas is typically higher than that from uncultivated areas (Brown, 1984). The United Nations Environmental Program reported that crop productivity is reduced and becomes uneconomic on about 20 million ha/year due to soil erosion and degradation (United Nation Environmental Program, 1991). Soil erosion can pose a great concern to the environment because cultivated areas can act as a pathway for transporting nutrients, especially phosphorus attached to sediment particles, to river systems (Ouyang and Bartholic, 1997). Soil erosion is a natural process and it refers to processes by which earth materials are entrained and transported across a given surface. Soil loss is the amount of material that is actually removed from a particular slope. Due to the possible on-site deposition of soil materials due to changes in topography, vegetation, and soil characteristics, soil loss is usually less than soil erosion. Thus, sediment yield is used to refer to the amount of eroded material that is actually transported from a plot, field, channel, or watershed (Renard et al., 1997).

To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998), have been developed and used over the years. Among these models, the USLE has remained the most practical method of estimating soil erosion potential in fields and to estimate the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000) while other process-based erosion models have intensive data and computation requirements. The new version of the USLE, called the Revised Universal Soil Loss Equation (RUSLE), was developed by modifying the USLE to more accurately estimate R, K, C, P factors, and soil erosion (Renard et al., 1991). Van Remortel et al. (2004) developed an array-based C++ program to automate the calculation of the LS factor from a digital elevation data because the ArcInfo Macro Language (AML) program was not efficient and fast. The USLE has been used/integrated with Geographic Information Systems (GIS) to estimate soil erosion because GIS helps users manipulate and analyze the spatial data easily, and it also helps users identify the spatial locations vulnerable to soil erosion (Yitayew et al., 1999; Ouyang and Bartholic, 2001; Lufafa et al., 2002). However, these studies using the USLE did not consider the sediment delivery ratio to estimate the sediment delivered to the downstream point of interest. Regional variations in sediment yields are very important since sediment delivery processes vary in space and time.

The WinGrid system by Lin et al. (2002) considered the sediment delivery ratio based on receiving drainage length ratio to total drainage length to compute soil erosion and sediment yield using USLE and a sediment delivery ratio. However, this system has separate component programs rather than being fully integrated with a GIS system. Hence, it is not readily available to soil erosion decision makers because it was developed for research purposes.

Thus, a GIS integrated prototype version of the Sediment Assessment Tool for Effective Erosion Control (SATEEC) (Lim et al., 2003) was developed to provide an easy-to-use GIS interface to estimate soil erosion and sediment yield without additional input parameter data other than those for the USLE model. With the USLE input parameter maps, the SATEEC can estimate soil erosion and the sediment yield at any point within a watershed with a menu-driven SATEEC GIS interface. However, the prototype version of the SATEEC GIS system cannot be used to assess the effects of sediment retention basins on the sediment yield of the receiving water bodies. Also, it cannot be used to estimate the sediment yield from a single storm event for an effective sediment control management. In addition, the SATEEC GIS system does not have any sediment and erosion control structure design capability. In the prototype version of the SATEEC GIS system, three methods are provided to compute the spatially distributed sediment delivery ratios (SDR), derived from measured data from hundreds of watersheds. However, users may need to use their watershed-specific SDR power function for better estimation of sediment yield. Therefore, there is a need to enhance the functionalities of the prototype SATEEC GIS system.

The objectives of this study were to:

1. Enhance the prototype version of the SATEEC GIS system by developing new modules to: 1) simulate the impact of sediment retention basins on the sediment yield; 2) simulate the sediment yield from storm events; and 3) provide a GIS interface to the Web-based sediment decision support system for sediment retention basin design,
2. Apply the enhanced SATEEC GIS system to a study watershed to demonstrate how the enhanced SATEEC GIS system can be used as an effective soil erosion and sediment management tool.

2. Literature review

2.1. Soil erosion and sediment yield

Development of effective erosion control plans requires the identification of areas vulnerable to soil erosion and quantification of the amounts of soil erosion from various areas. The empirically based USLE and newly revised RUSLE have been used in many countries since the late 1960s (Wischmeier and Smith, 1978). It is designed to estimate the long-term average annual soil loss for fields with specified cropping and management systems as well as rangeland (Renard et al., 1997). RUSLE estimates annual soil loss per unit area from rill and interill erosion caused by rainfall splash and overland flow, but not from gully and channel erosion. The RUSLE does not consider the runoff process explicitly, nor soil detachment, transport, and deposition individually (Renard et al., 1994). Eq. (1) shows how the RUSLE computes the average annual soil loss.

$$A = RK\,\mathrm{LS}\,CP \tag{1}$$

where

A average annual soil loss (ton/ac/year),
R rainfall/runoff erosivity,
K soil erodibility,
LS slope length and steepness,
C cover management,
P support practice.

The R factor in RUSLE is composed of total storm kinetic energy (E) times the maximum 30 min intensity (I_{30}), and the numerical value of R is the average annual value for storm events for at least 22 years (Wischmeier and Smith, 1978; Renard et al., 1997). Hence, RUSLE cannot be used to estimate soil erosion and sediment yield for a single storm event. Thus, the Modified Universal Soil Loss Equation (MUSLE) has been widely used to estimate the sediment yield from a single storm event (Williams and Berndt, 1977). Eq. (2) shows how the MUSLE computes sediment yield from a single storm event.

$$Y = 11.8\left(Q^{*}q_{\mathrm{p}}\right)^{0.56} KCP\,\mathrm{LS} \tag{2}$$

where

Y sediment yield from a single storm event (ton),
Q storm runoff volume (m^3),
q_{p} peak runoff rate (m^3/s),
K soil erodibility,
LS slope length and steepness,
C cover management,
P support practice.

RUSLE is a field scale model, thus it cannot be directly used to estimate the amount of sediment reaching downstream areas because some portion of the eroded soil may be deposited while traveling to the watershed outlet, or the downstream point of interest. To account for these processes, the Sediment Delivery Ratio (SDR) for a given watershed should be used to estimate the total sediment transported to the watershed outlet. The SDR can be expressed as follows (Eq. (3)).

$$\mathrm{SDR} = \mathrm{SY}/E \tag{3}$$

where

SDR Sediment Delivery Ratio,
SY Sediment Yield,
E Gross Erosion for Entire Watershed.

As stated before, RUSLE only estimates soil erosion from rill and interrill erosion processes. However, gross erosion (E) in Eq. (3) includes the erosion from gully and channel erosion as well as rill and interrill erosion (Ouyang and Bartholic, 1997). According to the study by Wade and Heady (1976), the soil losses from rill and interrill erosion in the Great Lakes Basin area are responsible for more than 67% of gross erosion. Thus, the use of Eq. (3) in SATEEC is valid only if there is no significant erosion occurring from gully and channel processes. Simanton et al. (1980) applied the USLE for four watersheds and found USLE estimated soil losses matched reasonably for two watersheds having no gullies or significant alluvial channels, while USLE results did not match well for two watersheds with significant gullies and channels. These results indicate USLE should not be applied to large watersheds, experiencing significant gully and channel erosion.

Erskine et al. (2002) compared RUSLE estimated soil loss with the measured sediment yield for 12 subwatersheds in Australia. The coefficient of determination was 0.88 for this comparison, although it did not consider the sediment delivery ratio in the estimated soil erosion using RUSLE. This is because the average area for the 12 subwatersheds is around 5 ha, and 3 ha for 10 smallest subwatersheds. Thus, the SDR for these small watersheds is high; meaning most soil eroded moves to the downstream areas without significant deposition. The SDR decreases with the size of watersheds, thus, the SDR needs to be considered when RUSLE is applied for a large watershed.

Significant research has been performed to estimate the SDR, finding that SDR is related to watershed size. The relationship for SDR and watershed size is known as the SDR curve (USDA, 1972). The SDR curve based on watershed size is widely used because of its simplicity. A power function (Eq. (4)) was derived from the data for 300 watersheds to develop a generalized SDR curve (Vanoni, 1975). Boyce (1975) and USDA (1972) also developed SDR curves (Eqs. (5) and (6), respectively).

$$\mathrm{SDR} = 0.4724\ A^{-0.125} \tag{4}$$

where, A = watershed area (km^2)

$$\mathrm{SDR} = 0.3750\ A^{-0.2382} \tag{5}$$

where, A = watershed area (km^2)

$$\mathrm{SDR} = 0.5656\ A^{-0.11} \tag{6}$$

where, A = watershed area (km^2).

As shown in Eqs. (4)–(6), the SDR curves developed by Vanoni (1975) and USDA (1972) are similar, compared with the SDR curve by Boyce (1975). For the accurate estimation of the sediment yield for a given watershed, use of a watershed specific SDR curve is desirable, although it is not easy to obtain watershed specific SDR curves.

The USLE has been linked with GIS because of advantages of using GIS for large quantities of spatial data. Hession and Shanholtz (1988) used GIS for non-point source agricultural pollution modeling with USLE for the computation of sediment loading to streams. Spanner et al. (1983) and Blaszczynski (1992) used RUSLE with GIS to extract slope length and steepness from Digital Elevation Models (DEM). Yitayew et al. (1999) developed the Arc/Info RUSLE system to compute the combined slope length and steepness factor from DEM using two algorithms, one is with Spanner's algorithm (1983) and the other with Moore's algorithm (1992). It was found that the LS factor using Moore's algorithm is nearly double compared with that using Spanner's algorithm with the same source of data (Yitayew et al., 1999). The comparison of the RUSLE GIS estimated soil erosion with the measured sediment yield data indicates the sediment delivery ratio depending on watershed size needs to be considered in the comparison as a possible explanation for the difference in RUSLE GIS estimated erosion and measured sediment yield (Yitayew et al., 1999). Ouyang and Bartholic (2001) developed a Web-based GIS interface to the RUSLE model. It provides a soil erosion index map to the client web browser with the input information provided by the users. However, this system does not consider the SDR for sediment yield estimation. Lin et al. (2002) developed the WinGrid system to extract the slope length factor for each cell to estimate the soil loss and sediment yield from a watershed. In the WinGrid system, the sediment delivery ratio is computed based on the ratio of receiving drainage length to the total drainage length. The WinGrid estimated sediment yield at five outlets was somewhat similar to the measured sediment data (Lin et al., 2002). However, this system was developed for research purposes, thus it is not readily available to soil erosion decision makers.

2.2. Prototype version of the SATEEC GIS system

The prototype version of the SATEEC GIS system was developed to provide an easy-to-use sediment assessment tool for soil erosion decision makers with Avenue programming within the ArcView GIS software (Lim et al., 2003). Fig. 1 provides an overview of the prototype version of the SATEEC GIS system. Soil loss is estimated with RUSLE, and a spatially distributed sediment yield map is generated with RUSLE estimated soil loss multiplied by the spatially distributed sediment delivery ratio map.

To compute soil loss from rill and interrill erosion, RUSLE was first integrated with the GIS system. In the prototype version of the SATEEC GIS system, the method developed by Moore and Burch (1986a,b) was used to calculate the LS factor from the Digital Elevation Model (DEM). All DEM pre-processing and map algebra were automated with Avenue programming. According to the RUSLE User's Guide (Foster et al., 1996), the length of hill slopes in the USLE experimental plots ranged from 10.7 m (35 ft) to 91.4 m (300 ft). Thus, it was recommended that the use of slope lengths less than 122 m (400 ft) are desired because overland flow becomes concentrated into the rills in less than 122 m (400 ft) under natural condition (Foster et al., 1996). Thus, SATEEC computes the LS factor using the method developed by Moore and Burch (1986a,b) (Eq. (7)) and an upper bound of slope length is provided by users, such as 122 m (400 ft).

$$LS = \left(\frac{A}{22.13}\right)^{0.4} * \left(\frac{\sin\Theta}{0.0896}\right)^{1.3} \tag{7}$$

where

A is flow accumulation * cell size,
Θ is slope angle in degrees.

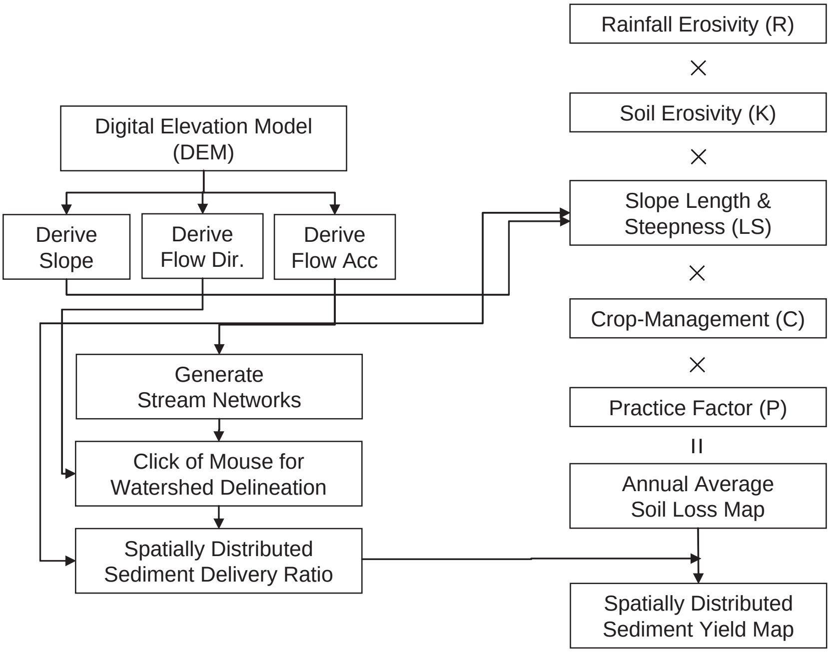


Fig. 1. Overview of prototype version of the SATEEC GIS system (Lim et al., 2003).

The SATEEC GIS system estimates annual average soil loss by multiplying all USLE input parameter maps (e.g. *R*, *K*, LS, *C*, and *P* maps). The SATEEC estimated soil loss can be used to identify spatial locations vulnerable to soil erosion within the study area. The total soil loss for a given area is not the same as the sediment yield measured at a point of interest, such as a watershed outlet. To explain the possible deposition of eroded materials while they travel to the channel networks and eventually to the watershed outlet, the spatially distributed SDR is computed in the SATEEC GIS system. The SDR is related with physical characteristics of the watershed, such as size and shape of watershed, rainfall patterns, direct runoff, peak runoff, land use, cover crop, slope, particle size, and channel density (Ouyang and Bartholic, 1997). Area based methods were used to estimate the SDR in the SATEEC GIS system because watershed area at any point within a watershed can be easily computed from the flow accumulation map, which is one of the by-product maps from DEM preprocessing to compute the LS factor. Three area based methods (USDA, 1972; Boyce, 1975; Vanoni, 1975) are used in SATEEC to compute the spatially distributed SDR map. The SDR curve developed by Vanoni (1975) is a generalized curve because it was derived from 300 watersheds. Thus, it is recommended that the users select the default SDR curve by Vanoni if they are not familiar with different SDR curves. The SDR values for a very small watershed using the power functions by Vanoni (1975), Boyce (1975), and USDA (1972) exceed 1.0. SATEEC computes the SDR value for every cell within the watershed. Thus, the SDR value for a single cell watershed, usually a cell at the watershed boundary, can exceed 1.0. The SATEEC users can set the upper limit of allowable SDR value when generating a sediment delivery ratio map. The input data for the SATEEC GIS system are *R*, *K*, DEM, *C*, and *P* maps, which are the basic input maps to RUSLE. Thus, one of advantages of using the SATEEC GIS system is that no additional input data, other than those for RUSLE, are needed to operate the SATEEC GIS system. Also, all of the functions shown in Fig. 1 are fully integrated and automated within the ArcView GIS system. Thus, with several clicks of the mouse button with SATEEC menus, users can estimate the sediment yield for every cell within a watershed (Lim et al., 2003).

A sediment retention basin is a pond to hold storm water and filter out the sediment. It can remove the majority of the sediment within the storm water by settling out the sediment. Sediment basins are often 70–80% effective in filtering out sediment, 50–55% effective for phosphorus filtering, 45–55% effective for nitrogen filtering, 75–80% effective for trace metal filtering (Schueler, 1987). With the prototype version of SATEEC, users could not simulate the impact of sediment retention basins on the sediment yield of downstream areas. It would be helpful to include this function in the SATEEC GIS system for effective soil erosion and sediment management.

2.3. Web-based decision support system for erosion control design planning

A WWW-based decision support system, Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (SEDSPEC), was developed for the estimation of peak runoff from small-scale watersheds, and for designing hydrologic, sediment, and erosion control structures (Tang et al., 2004). The Web-based SEDSPEC is available at http://pasture.ecn.purdue.edu/~sedspec. It can simulate the short-term peak runoff from watersheds using hydrologic soil group, land use data, and design storm data in the SEDSPEC relational database. Also, it calculates dimensions and costs of hydrologic, sediment and erosion control structures based on user's specifications while planning conservation in a watershed (Tang et al., 2004). Widely used hydrologic models are used in the SEDSPEC for peak runoff estimation. One is the Rational Method (Chow et al., 1988), and the other is TR-55 (NRCS, 1986). The Rational Method is good for small watersheds up to 2.59 km^2, while the TR-55 is good for watersheds up to 51.8 km^2 (NRCS, 1986). Although these two models have inherent limitations, these models were employed in SEDSPEC because the input data for these models are readily available, and these are widely used methods in storm sewer system design (Pilgrim, 1986). SEDSPEC can be used to design seven possible engineering practices: channels, culverts, sediment basins, level terraces, storm water detention basins, runoff diversions, and lower water crossing. SEDSPEC also provides design, cost, and maintenance information for hydrologic and erosion control structures depending on site characteristics and user's responses about the location, size, slope, land use, vegetation, and erosion level of the site (Tang et al., 2004). The Web GIS interface for SEDSPEC was developed to automate input data preparation for the Rational Method. More details can be found at the studies by Tang et al.

(2004). SEDSPEC is an easy to use, interactive web tool to help prevent runoff and erosion problems and eventually achieve sustainable development of the environment.

3. Enhancement of the SATEEC GIS system

As stated previously, the prototype version of the SATEEC GIS system is an easy-to-use sediment assessment tool. However, there is a need to enhance the SATEEC GIS system and to add new modules to the prototype to facilitate creation of better soil erosion management plans. The enhancements include such capabilities as assessment of the effects on the receiving water bodies of sediment retention basins within the watershed, estimation of the sediment yield from a single storm event, and development of a GIS interface for the Web-based sediment decision support system for sediment retention basin design.

3.1. Assessment of effects of sediment retention basin on downstream water bodies

A new module to assess the effects of sediment retention basins on downstream sediment yield was developed and added to the SATEEC GIS system with Avenue programming. Fig. 2 shows how the enhanced SATEEC system estimates the effects of sediment retention basins on downstream water bodies. First the SATEEC system estimates soil loss by multiplying R, K, LS that was calculated from the DEM, C, and P factor maps together (Map 1 in Fig. 2). The SATEEC estimated soil loss map shows the soil loss potentials in kg/ha/year. SATEEC provides a “Generate Stream with User Specified Threshold Value” option to allow users to generate stream maps within the study area (Map 2 in Fig. 2). This stream map, as well as the soil loss map generated in previous step, can complement the selection of potential locations for the sediment retention basin within the study area to estimate the effects of sediment retention basins on downstream water bodies. Once users select the potential location for a sediment retention basin, the SATEEC system requests the sediment reduction ratio for the retention basin. Then, the SATEEC system delineates the subwatershed for the retention basin to quantify the sediment load contribution (Map 3 in Fig. 2). With the sediment reduction ratio value, the SATEEC GIS system computes the sediment reduction with the retention basin for the subwatershed (Map 4 in Fig. 2). SATEEC also estimates soil loss for the entire study area (Map 5 in Fig. 2). SATEEC then combines maps generated in steps 4 and 5 (Maps 4 and 5 in Fig. 2) and runs the SDR module to compute the spatially distributed sediment yield map (Map 6 in Fig. 2). The Map 6 in Fig. 2 shows the sediment yield map for the entire study area after installing a sediment retention basin. The difference in the sediment yields before the sediment retention basin (Map 2 in Fig. 2) and after the sediment retention basin (Map 6 in Fig. 2) is computed to provide the spatial impacts of the sediment retention basin on downstream water bodies (Map 7 in Fig. 2). It is worth noting that there is no difference in the sediment yield of the tributaries (white cells on the tributaries, Map 7 in Fig. 2). Thus, the module developed in this study is useful as a screening tool to locate potential sediment retention basins and estimate their impacts on downstream water bodies.

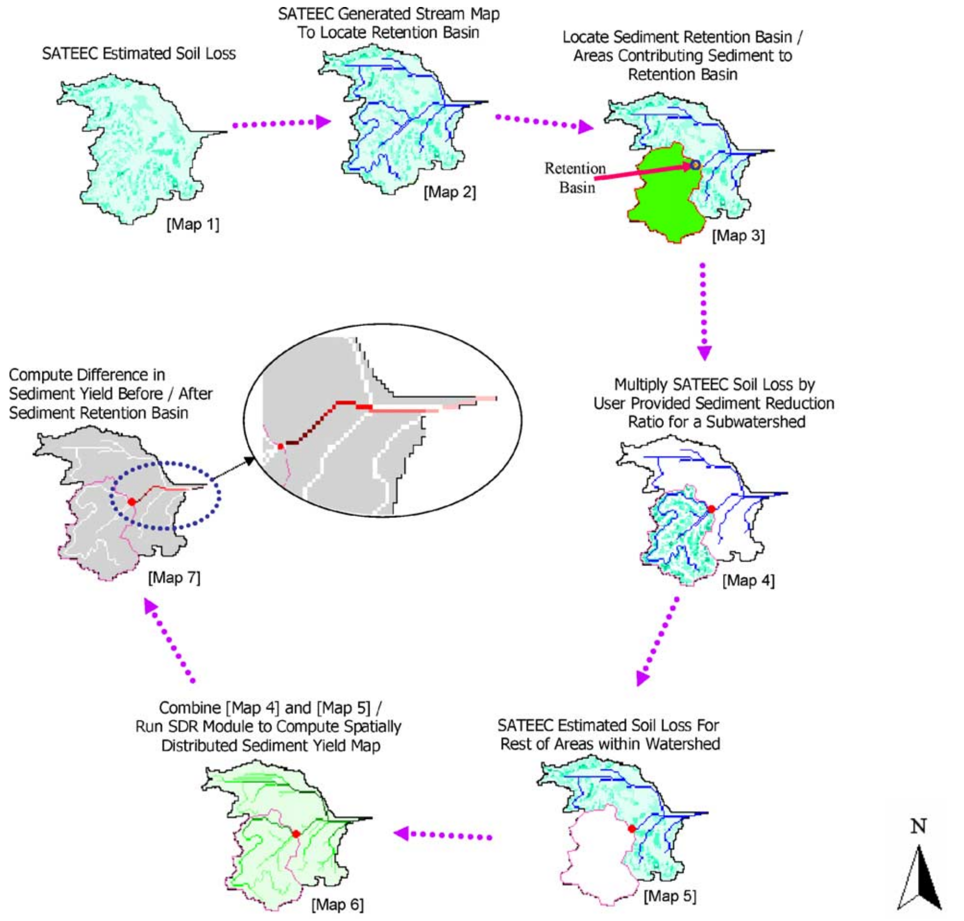


Fig. 2. How SATEEC estimates the effects of sediment retention basins on downstream water bodies.

3.2. Estimation of the sediment yield from a single storm event

In the prototype version of the SATEEC GIS system (Lim et al., 2003), the long-term annual average soil loss is estimated using the USLE. Thus, it cannot be used to compute the sediment yield from a single storm event. In this study, a new module was developed to compute the sediment yield for a given rainfall event using the MUSLE equation. The MUSLE equation estimates the sediment yield with runoff volume, peak rate of runoff, and the USLE K, LS, C, and P factors (Eq. (2)). The land use, hydrologic soil group, and Curve Number (CN) lookup table are used to compute the CN values for all land use and hydrologic soil group combinations within a GIS (Engel, 1997), and the runoff volume for each CN value is computed for a given rainfall event. The peak runoff rate is computed using the Rational Method. The runoff coefficient is estimated by the ratio of the estimated runoff depth to the rainfall depth within a GIS. The cell value in the runoff coefficient map represents the runoff coefficient for a watershed having that cell as a watershed outlet. The new module first delineates the subwatershed boundary at a user identified point, and computes sediment yield using the runoff volume map and peak runoff rate map with K, LS, C, and P factor maps for the subwatershed.

3.3. Development of GIS interface to the web-based SEDSPEC system

The Web-based SEDSPEC system (http://pasture.ecn.purdue.edu/~sedspec; Tang et al., 2004) can be used to design hydrologic and erosion control structures. Thus, the GIS interface to the Web-based SEDSPEC system was developed and integrated with the SATEEC GIS system to facilitate the input data preparation for sediment retention basin design with Avenue, Perl CGI, and SQL programming and spatial GIS datasets. This module allows the user to define the point of interest as a watershed outlet, and it computes input parameter values for the SEDSPEC system, such as flow length and average slope of the watershed, unique combination of land use and hydrologic soil group, and area for each combination for the design of sediment retention basins. Then, it builds the Uniform Resource Locator (URL) to transfer the input parameter values for the sediment retention basin to the Web-based SEDSPEC system from the SATEEC GIS system. The input parameter values from the URL are parsed, and are used to construct the input data for the Web-based SEDSPEC retention basin module. The SEDSPEC module customized for the

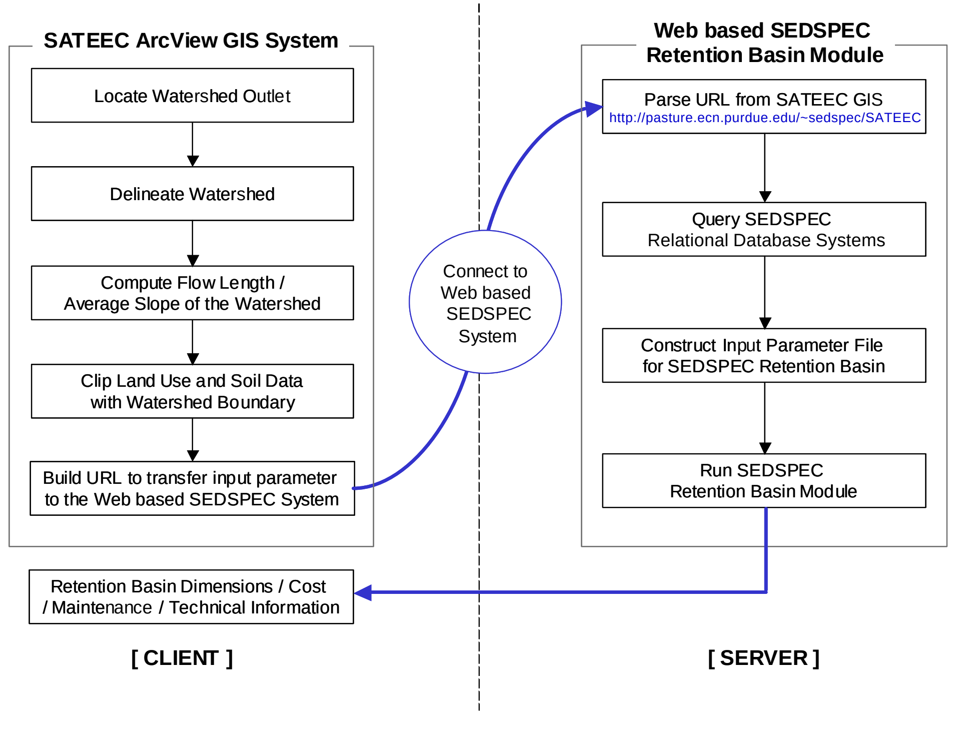


Fig. 3. Interface to the Web-based SEDSPEC from the SATEEC GIS system.

SATEEC (http://pasture.ecn.purdue.edu/~sedspec/SATEEC) computes all possible sediment retention basin dimensions, and displays adequate storage of runoff and sediment, cost, maintenance, and technical information in the output interface. Fig. 3 shows how the SATEEC GIS system can be used to design the sediment retention basin using the Web-based SEDSPEC system.

4. Results

4.1. Enhanced SATEEC GIS system

The SATEEC GIS system was enhanced with additional functions incorporated in the SATEEC menus to simulate the effects of sediment retention basins in the watershed, estimate the sediment yield from a single storm event, and provide a GIS interface to the Web-based SEDSPEC retention basin module. With the enhanced SATEEC GIS system, users are able to use a watershed specific SDR power function for improved sediment estimation. The SATEEC ArcView GIS interface is shown in Fig. 4. All functionalities described in Section 3 were fully automated with ArcView Avenue, Perl CGI, and Oracle SQL programming. SATEEC Version 1.5 is available in the ArcView GIS project file

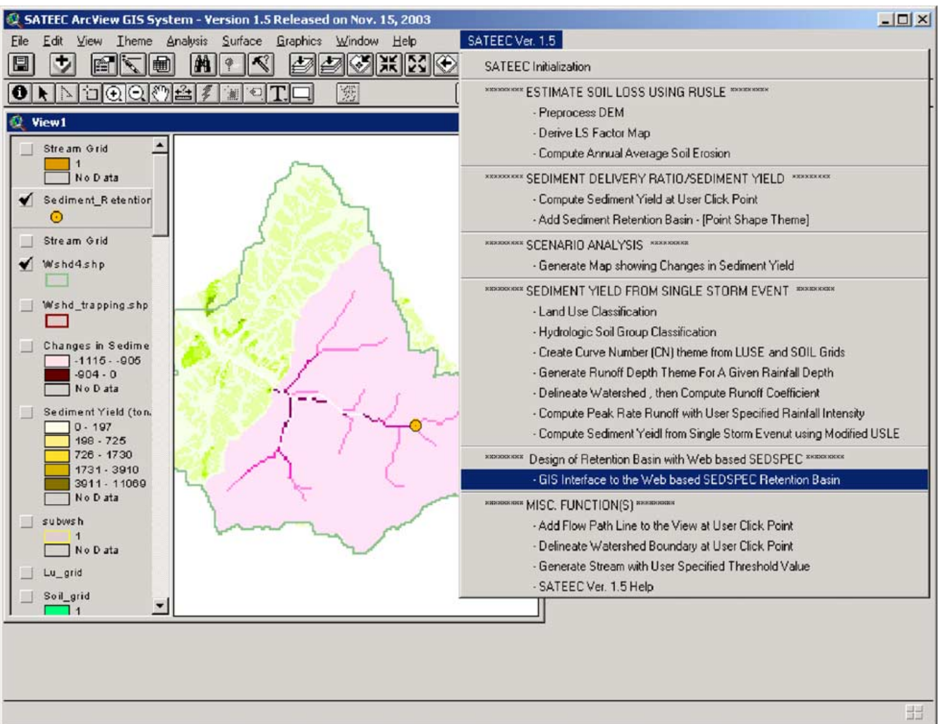


Fig. 4. Enhanced SATEEC ArcView GIS interface.

format; however, efforts are underway to create an ArcView Extension to facilitate installation on desktop computers.

4.2. Application of the enhanced SATEEC GIS system

The enhanced SATEEC GIS system was not compared with measured data for validation purposes in this study because the USLE has been widely used and validated in many countries (Lal, 1990; Mati et al., 2000; Moehansyah et al., 2004). Also, the sediment delivery ratio equation incorporated in the SATEEC system was derived from measured data from hundreds of watersheds (USDA, 1972; Boyce, 1975; Vanoni, 1975). Instead, the enhanced SATEEC GIS system was applied to the Sudong watershed, located in Chuncheon, Korea (Fig. 5), to demonstrate how the new module in SATEEC can be easily used for effective soil erosion management. The area of the Sudong watershed is 11.2 km^2 and the primary land uses are forest, pasture, agricultural land, and residential areas. Additional details on the watershed are provided by Koo (2002). First, SATEEC is applied to the study watershed to estimate the effects of a sediment retention basin on the receiving water bodies. Second, the sediment yield from a single storm event is estimated using the newly developed module. Third, the enhanced SATEEC GIS system and the Web-based SEDSPEC system are used to design a sediment basin.

4.2.1. Estimation of soil loss and sediment yield and effects of sediment retention basin on the receiving water bodies

The SATEEC GIS system was used to calculate the LS factor from the DEM using the method by Moore and Burch (1986a,b) (Eq. (7)) with the upper bound of slope

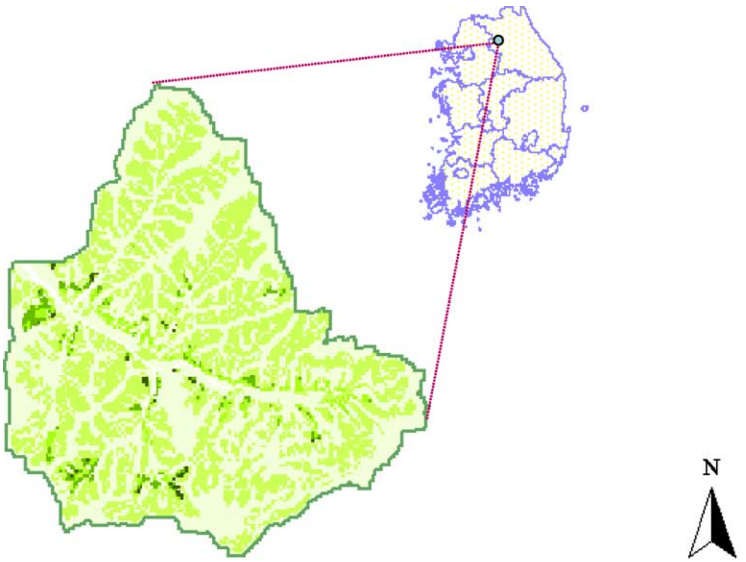


Fig. 5. Location of Sudong Watershed, Chuncheon, Korea.

length provided by users. The value of 464 for Chuncheon is used as a representative *R* factor for this area (Koo, 2002). The *K* factor for each soil type was computed based on the ratio of sand, silt, and clay content using MUSLE. The *C* and *P* factors for the Sudong watershed were prepared based on land use classifications (Koo, 2002). Detailed information about these input parameters is discussed in the study by Koo (2002). The sediment yield maps using three area-based SDR estimation methods (Eqs. (4)–(6)) were computed for subwatersheds in the study watershed (Fig. 6). The SDR values for the subwatersheds range from 0.24 to 0.45, and the total sediment yields at the outlet of the watershed range from 7713 ton/year to 14740 ton/year as shown in Fig. 6. The sediment yield using the USDA SDR method is almost double the amount obtained using the Boyce SDR method with the same USLE input parameter data sets. As shown here, it is highly recommended that SATEEC users use the watershed specific SDR method when comparing the estimated sediment yield with the measured sediment data. The cell values in the sediment yield map (Fig. 6) represent the total amount of sediment delivered to each cell. Thus, the SATEEC estimated sediment yield map can be used to find the most vulnerable reach to sediment loading. Based on the sediment yield map, erosion control

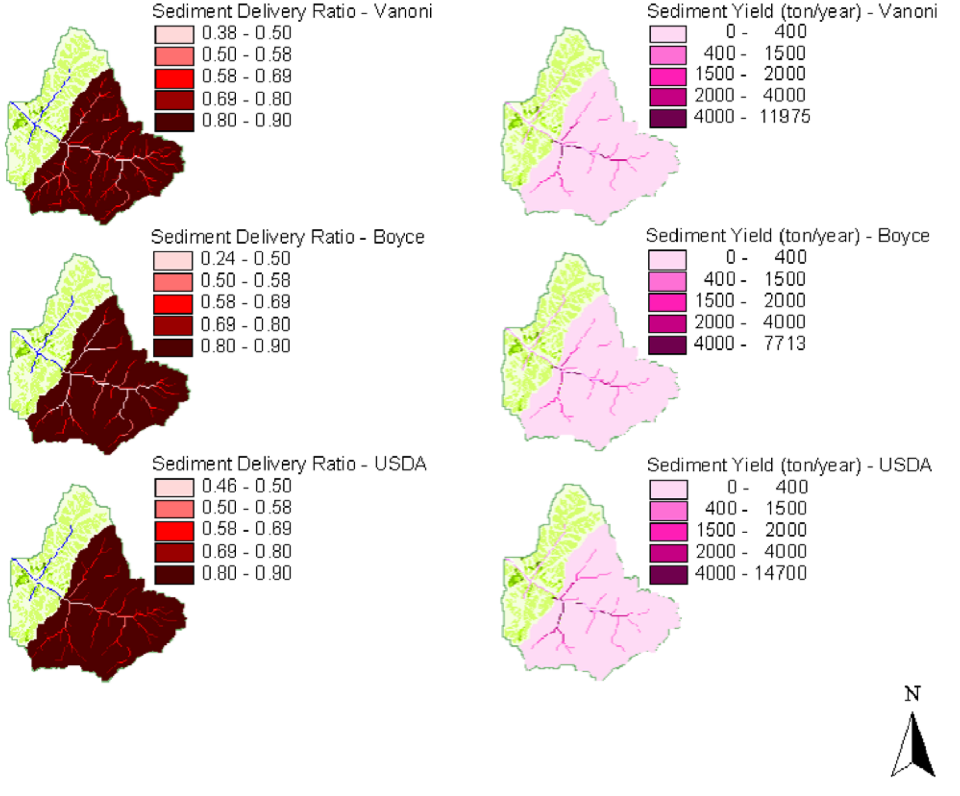


Fig. 6. SATEEC estimated spatially distributed sediment delivery ratio and sediment yield maps (cell values represent the SDR and sediment yield for watershed having that cell as an outlet).

decision makers can prioritize the most vulnerable upstream areas for effective erosion control management.

To demonstrate how the sediment retention basin module in the enhanced SATEEC GIS system can be used to assess the effects of a sediment retention basin installed in an upstream area of the Sudong watershed, a hypothetical location (marked ‘B’ in Fig. 7) for the sediment retention basin was selected. A sediment reduction ratio of 50%, indicating that half of the sediment loading contributed from the upper areas are deposited in the sediment retention basin and the rest of the sediment leaves the sediment retention basin to downstream areas, was used for demonstration purposes. The SATEEC estimated sediment yield with the sediment retention basin is 11,069 ton/year; representing a 906 ton/year decrease in the sediment yield at the outlet (marked ‘A’ in Fig. 7). As shown in this example, the SATEEC sediment retention module can be used as a screening tool to estimate the effects of sediment retention basins on receiving water bodies with only a few clicks of the mouse, because all the procedures, including location of the sediment retention basin and sediment reduction ratio, are fully automated in the SATEEC GIS system. Soil, other auxiliary spatial data, and relational data can be used to assist users in locating sediment retention basins.

4.2.2. Estimation of sediment yield from a single storm event

To demonstrate how the newly developed SATEEC module can be used to estimate the sediment yield from a single storm event, one subwatershed within the Sudong watershed was delineated and its area is 1.14 km^2. It was assumed that 127 mm (5 in) of torrential rainfall lasted for an hour. The spatially distributed runoff coefficient map was computed from the runoff depth generated using a GIS-based CN method (Engel, 1997) and rainfall depth. The peak runoff map was computed using the Rational Method, and the sediment yield map was computed using the new module in the SATEEC GIS

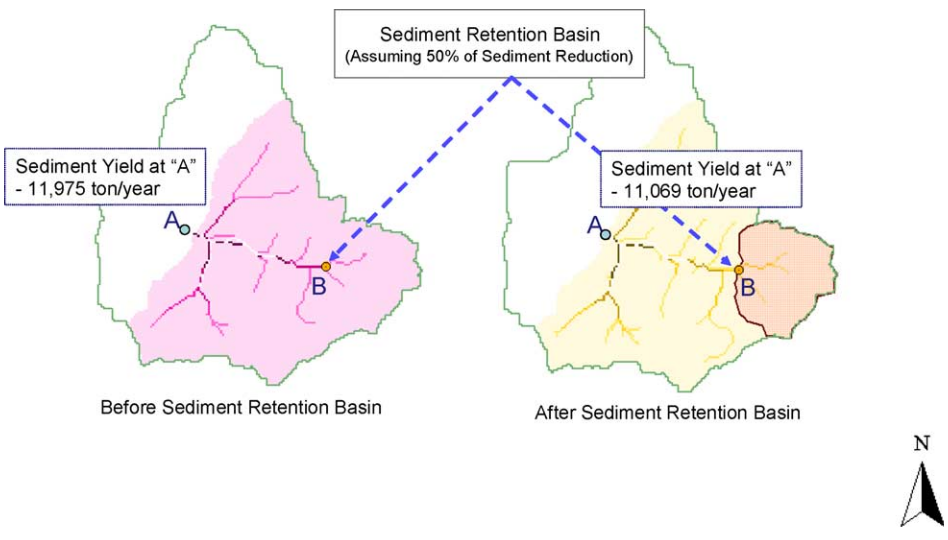


Fig. 7. Effect on downstream water bodies of the sediment retention basin.

system. Instead of using a lumped runoff coefficient for the Rational Method, the spatially distributed runoff coefficient was computed (Fig. 8). The spatial variations in the runoff coefficient map are due to the differences in the land uses and hydrologic soil group. The cell values in the sediment yield map represent the sediment yield for a watershed having each cell as an outlet. The sediment yield map from the single storm event can be used to design the dimensions of the sediment retention basin and to establish sediment management plans.

4.2.3. Design of sediment retention basin using web based SEDSPEC system

To demonstrate how the enhanced SATEEC GIS system can be used to derive the input parameter data for the Web-based SEDSPEC system, one hypothetical watershed, 0.49 km^2 in size, was chosen. The new module determines the total number and area of unique land use and soil combinations. It also computes the flow length and average slope for a watershed of interest. The enhanced SATEEC GIS system estimated flow length is 855 m and the average slope is 49.19% for this watershed. There are two unique land use and soil combinations in this watershed. In this example, a 10 year return period is selected as suggested by the SEDSPEC system (Tang et al., 2004). With these data, the SATEEC module in the SEDSPEC system (http://pasture.ecn.purdue.edu/~sedspec/SATEEC) computes retention basin dimension as shown in Fig. 9. With several clicks of the mouse button using the enhanced SATEEC GIS system, users can design the width, length, and depth of a sediment retention basin, and spillway barrel and riser size.

5. Summary and conclusions

The prototype version of the SATEEC GIS system was enhanced in this study by adding three new modules. New modules were developed to: 1) simulate the effects of

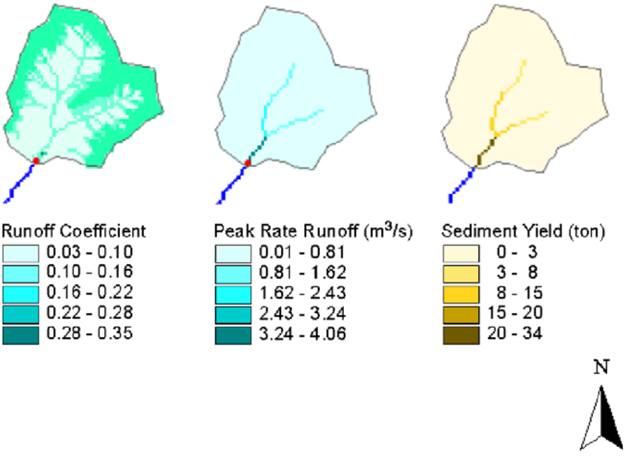
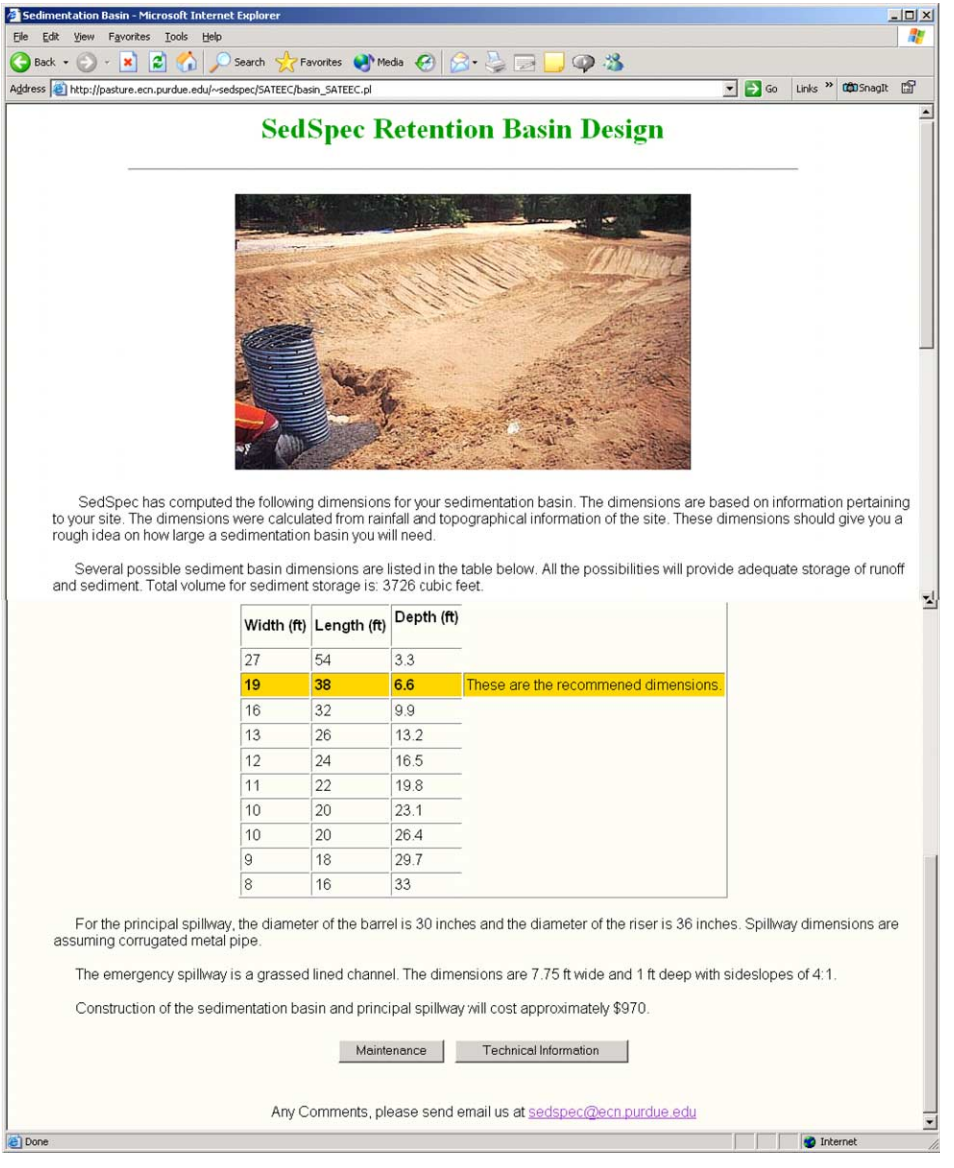


Fig. 8. Spatially distributed sediment yield from a single storm event (cell values in each map represent the runoff coefficient, peak rate of runoff and sediment yield for a watershed having that cell as an outlet).


Sedimentation Basin - Microsoft Internet Explorer

Address http://pasture.ecn.purdue.edu/~sedspec/SATEEC/basin_SATEEC.pl

SedSpec Retention Basin Design

SedSpec has computed the following dimensions for your sedimentation basin. The dimensions are based on information pertaining to your site. The dimensions were calculated from rainfall and topographical information of the site. These dimensions should give you a rough idea on how large a sedimentation basin you will need.

Several possible sediment basin dimensions are listed in the table below. All the possibilities will provide adequate storage of runoff and sediment. Total volume for sediment storage is: 3726 cubic feet.

Width (ft)	Length (ft)	Depth (ft)	
27	54	3.3	
19	38	6.6	These are the recommened dimensions.
16	32	9.9	
13	26	13.2	
12	24	16.5	
11	22	19.8	
10	20	23.1	
10	20	26.4	
9	18	29.7	
8	16	33	

For the principal spillway, the diameter of the barrel is 30 inches and the diameter of the riser is 36 inches. Spillway dimensions are assuming corrugated metal pipe.

The emergency spillway is a grassed lined channel. The dimensions are 7.75 ft wide and 1 ft deep with sideslopes of 4:1.

Construction of the sedimentation basin and principal spillway will cost approximately $970.

Maintenance Technical Information

Any Comments, please send email us at sedspec@ecn.purdue.edu

Fig. 9. Retention basin design using SEDSPEC sediment decision support system.

sediment retention basins on the downstream sediment loading, 2) estimate the sediment yield from a single storm event, and 3) provide a GIS interface to the Web-based SEDSPEC system for the design of sediment retention basins. These three modules are fully automated through ArcView Avenue, Perl CGI, Java Script, and SQL programming. Thus, the SATEEC GIS system does not require experienced GIS users to operate the system. Soil erosion management plans need to be targeted to the major problem areas rather than to the entire region of interest. Thus, this easy-to-use SATEEC GIS system can be used by soil erosion decision makers to estimate soil loss and sediment yield, to identify areas vulnerable to soil loss, and to establish efficient erosion control plans with a fully automated menu driven system.

Although the enhanced SATEEC is an efficient tool for soil erosion management, SATEEC does not estimate soil loss from gully and channel erosion processes. Thus, it should not be used for large watersheds if the soil loss from gullies and channels is dominant. Also only area-based SDR estimation methods are utilized in the enhanced SATEEC GIS system. Thus, other SDR estimation methods, considering watershed shape, rainfall pattern, direct runoff, peak runoff, land use, cover crop, particle size, and channel density, need to be incorporated into the SATEEC GIS system.

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