Review of Uncertainties in Applying GIS Data and Hydrological Models to Evaluate the Effectiveness of Best Management Practices

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수리모델과 GIS 데이터를 이용한 최적관리방안의 평가에 대한 불확실성의 재고

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Abstract : Best management practices (BMPs) are widely accepted and implemented as a mitigation method for soil erosion and non-point source problems. Estimating the amount of soil erosion and the effectiveness of BMPs using hydrological models help to understand the condition, identify the problems, and make plans for conservation practices in an area, typically a watershed. However, the accuracy and reliability of assessment of BMP impacts estimated by hydrological models can be often questionable due to the uncertainties from various sources including GIS(Geographic Information System) data, scale, and model. This study reviewed the development and the background of hydrological models, and the modeling issues such as the selection of models, scale, and uncertainties of data and models. This study also discussed the advantage of a small scale and spatially distributed model to estimate the impacts of BMPs.
Key Words : BMP (Best Management Practice), GIS (Geographic Information System), Hydrological models, Scale, Uncertainty

요약 : 최적관리방안 (Best Management Practices)은 토양 침식과 비점오염원으로 인한 수질악화를 개선하는 방안으로 널리 이용된다. 모델을 이용하여 토양침식이나 최적관리관행의 잠재적 효과를 추정하는 것은 해당 지역의 전반적인 조건과 문제점을 식별하고 이에 대한 보전계획을 수립하는 데 도움이 된다. 그러나 데이터, 특히 GIS (Geographic Information System) 데이터, 데이터 스케일의 문제, 혹은 모델의 선택 등에서 오는 불확실성은 최적관리방안의 효과를 예측하는데 있어서 정확성과 신뢰성을 떨어뜨리고 있다. 따라서 이 논문에서는 수리모델의 발전과 배경, 데이터의 불확실성, 모델의 선택, 그리고 데이터의 스케일 등을 참고문헌을 통하여 전반적으로 정리하고 살펴봄으로서 불확실성의 전반적인 이해를 돕고자 하였다. 또한 모델을 이용한 최적관리방안의 효과를 예측함에 있어서 소규모(small scale) 모델과 분포형(spatially distributed) 모델의 장점에 대해서도 논의 하였다.
주요어 : 최적관리방안 (BMP), 지리정보시스템 (GIS), 수리모델, 스케일, 불확실성

1. Introduction

The condition and quality of land was brought to the attention of people and policy makers after catastrophic events like the Dust Bowl in 1930s (Renschler and Harbor, 2002). Laws, regulations, and concerns of land management practices since then have been continuously developed including the Soil Conservation Act and the creation of the SCS (Soil Conservation Service). Non-point pollution has been identified as significant contributor to water quality degradation as well as a threatening factor to human and aquatic health. Government regulations, such as the Clean Water Act and the TMDL (Total Maximum Daily Load) plan, are placing growing emphasis on non-point source pollution control.

The important roles and necessities of BMPs (Best Management Practices) as a mitigation methodology for water degradation have become apparent after non-point source pollutants were

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separated from point sources by the Federal Water Pollution Control Act Amendments in 1972 (Novotny and Olem, 1994). While point source pollutants are controlled and permitted by the National Pollution Discharge Elimination System (NPDES), the reduction of non-point source pollutions depends on BMPs (Ice, 2004).

The assessment of the impacts of BMPs is very important in order to define methods that may be used to mitigate the problems. It helps to regulate water quality and make a comprehensive watershed protection plan. For more reliable and accurate assessment using hydrological models, their scales and uncertainties should be considered and understood beforehand.

A BMP is defined as the practice or combination of practices used to prevent or reduce non-point sources of pollution in order to meet water quality goals (Novotny and Olem, 1994). Design and installation should be based on technological and economic criteria, institutional consideration, appropriate assessments, and public participation (USEPA, 2001). BMPs are designed mainly for reducing runoff and deliveries of sediments and nutrients by the runoff as non-point sources. Vegetative BMPs are usually perennial vegetation located at critical points where prevention and reduction of sediment and pollutant delivery to the waterbody is maximized (Dabney, 2003).

BMPs have been widely accepted and played an important role to mitigate the degradation of water quality in any types of waterbody. The benefits of BMPs are not limited to a mitigation of water degradation. They also keep soils and nutrients from leaving fields and the vegetation of certain BMPs provides habitat for wildlife. The implementation of BMPs has been dramatically increased after the National Conservation Buffer Initiative by the USDA-NRCS (United States Department of Agriculture - Natural Resources Conservation Service) (USDA-NRCS, 2002). Compensation to the land owner was successful in encouraging them to install buffer strips. Although it mainly focused on buffer strips along drainage channels in agricultural fields, this program was successful with a number of supporting funds and programs such as the Conservation Reserve Program (CRP).

There are a number of models that have been developed and used for years to estimate soil loss, the effectiveness of BMPs and the associated on- and off-site impacts. A hillslope scale soil erosion was described by Ellison (1947) in 1940s and then, represented with an equation by Wischmeier and Smith (1959). After the 1970s, water quality degradation due to non-point source pollutants and the impacts of agricultural practices at off-site have been major concerns (Lane *et al.*, 1995), and consequently the focus of models covered a wide range of technologies, targets, and scales. A small scale model, defined as a model validated in a relatively small watershed, provides simulation in a detail level with more intensive dataset while a large scale model, defined as a model validated in a relatively large watershed, offers the overview of hydrological condition in the watershed but aggregates detail condition within the watershed. More recent trend of erosion models is toward the process-based model emphasizing physical process (Jetten *et al.*, 2003) rather than simple empirical based model in terms of modeling technique, and toward the spatially distributed model rather than lumped model in terms of the level of detail.

Lumped models such as the USLE (Universal Soil Loss Equation, (Wischmeier and Smith, 1959)) and EPIC (Erosion-Productivity Impact Calculator, (Williams *et al.*, 1983)) represent parameters in space in a simplified way. On the other hand, more complicated spatially distributed models take into account the spatial distribution of each parameter and the level of detail that depends

Table 1. The classification of hydrological model.

Classification	Type	Note
Spatial Scale	Lumped	One representative value in a hydrological unit. (e.g. single soil type in a watershed)
	Spatially distributed	Detail level of spatial variation (e.g. multiple soil type in a watershed)
Temporal Scale	Event based	Estimation for a event (short-term) (e.g. estimation for a single storm)
	Continuous	Estimation for a continuous long-term (e.g. estimation for years including dry season)
Methodology	Empirical	Equations are based on observation (e.g. statistical dataset for a region)
	Physically based	Equations are based on experiments and validation (e.g. physically validated equation based on experiment.

on the resolution of data. An empirical based model is simple to use but does not represent the process of nature while a process based (physically based) model takes into account the natural process although it requires a larger amount of data and time. 〈Table 1〉 lists the classification of hydrological model. The hydrological models can be categorized by spatial scale, temporal scale, and modeling methodology. A lumped model sums up or averages the parameter values in a watershed to represent them as a single value for each parameter while a spatially distributed model can have multiple values for parameters. Based on temporal scale, an event based model simulates only an event but continuous model estimates long-term periods. An empirical based model uses empirical equation obtained from observation or statistical analyses. On the other hand, a physically based model consists of equations from experiments and validation.

The limitations of modeling performance in empirically based models (e.g. USLE) includes the representation of varied crops, application of the model to other area, and various spatial and temporal scale issues, has lead to development of a revised model (e.g. Revised USLE), an alternative process-based model such as WEPP (Water Erosion Prediction Project (Laflen *et al.*, 1991)), and comprehensive watershed model such as SWAT (Soil and Water Assessment Tool (Arnold *et al.*, 1998)). However, success in the usage of soil erosion prediction models depends heavily on many factors such as data accuracy, selection of proper model, scale, and the user's ability to analyze the output (Renschler and Harbor, 2002).

Therefore, the objectives of this study is 1) to review the uncertainty in hydrological models and data used for the models, 2) to review the issues to estimate the effectiveness of BMPs using the models, and 3) to discuss the advantages of using a small scale and spatially distributed model to perform the assessment of the BMP impacts.

2. Uncertainty in model and data

1) Scale issues

The spatial scale issue in hydrologic models starts with the discrepancy between the field test and the application to the larger watershed. The equations and laws in hydrology have been developed in small experimental flumes or plots. When these equations are applied to larger watersheds, they often introduce discrepancies in the results due to the unknown factors which did not exist in the plots (Brezonik *et al.*, 2001). Another important issue is that the scale of data and the selection of a model among a number of available models largely influences the model results (Renschler *et al.*, 2000). The heterogeneity existed in the real world is simply aggregated and eliminated in a large scale model (Turner, 1989). Therefore, determining the modeling scale, data, and size of sub-watersheds or hydrologic units in models has a considerable effect on model results.

The problem with the size of the watershed is shown in a widely used 'point-based' model. A 'point-based' model generates and calibrates hydrological outputs such as flow, sediment yield, and nutrients discharging in watersheds based on the data at the watershed outlet. A watershed outlet is used for a point of concern in monitoring, measuring, managing, and modeling water quality. Point outlets are useful and economical because it is easier to measure and control what comes from the source area within the watershed that the outlet belongs to. However, it does not take into account the spatial pattern and the distribution of those inputs and outputs within the watershed (Grayson *et al.*, 1992). Furthermore, the model might even lead to a completely wrong pattern (Favis-Mortlock *et al.*, 2001; Takken *et al.*, 1999), even though it estimates an acceptable result at the outlet. Therefore, variations within a watershed can be important parameters for hydrological modeling and good reasons for the necessity of spatially distributed data and models.

The spatially distributed models divide a watershed into a number of homogeneous units that have individual characteristics and properties, whereas lumped models take into account all properties in a watershed unit as one representative value. They offer a more detailed representation of the watershed than the lumped model. Therefore they provide better understanding and estimation of the processes in a watershed. However, a more complex model does not always promise better or more accurate results (Jetten *et al.*, 2003), and may have limitations in representing the real world (Grayson *et al.*, 1992).

The temporal scale of climate data is probably the most important in a hydrological model. Bronstert and Bardossy (2003) compared daily and minute scale rainfall data in their erosion simulation and they found out that the peak of rainfall is a dominant factor in soil erosion. Since daily data shows only total amount of rainfall throughout a day, it does not capture or represent the peak and intensity of rainfall. Some extreme events with high intensity result in a large portion of the total soil erosion (Moore *et al.*, 1992), although highly frequent events with low intensity can be considerable in long-term perspective (Renschler and Harbor, 2002). In that perspective, the current trend of considering and implementing sub-daily precipitation data in models (Jeong *et al.*, 2010; McMillan *et al.*, 2011) is important and valuable.

Short term modeling with a particular period of time may not include some large and intensive rains. On the other hand, estimation with data in long time segments, such as yearly or monthly estimation may hide variations within those periods compared to daily or hourly simulation. Therefore, the modeling period and temporal scale of data should be carefully considered depending on the purpose of model.

2) Data issues

Uncertainty is a critical issue in modeling especially when secondary data representing complex processes are involved, such as GIS (Geographic Information System) data. An error on input data, which is the first stage of modeling process, is one of the largest sources of errors (Frankenberger *et al.*, 1999) and can propagate through the entire modeling process. Natural variation in available data and non-linear relationship of parameters that models do not account for can easily introduce bias to the results and become a problem (Eagleson, 1982; Nearing, 1998). Non-linearity and spatial heterogeneity in relationships between parameters, which correspond to scale problems as mentioned earlier, are the major problems in 'linear' models (Beven, 2001). Averaged parameter values produce incorrect results, misleading the users that rely upon them. Jetten *et al.* (2003) argued that the errors in input data cause the physical based models to be no more effective or accurate than simpler empirical based models.

Jetten *et al.* (2003) compared widely used models in various ways, summarizing the research by Ingram *et al.* (1996). In their study, they found that each model has strong and weak points with regards to runoff and sediment prediction. Sometimes an empirical based model estimates the runoff and the soil erosion better than a physical based model. Most models performed poorly when estimating small events, this was also discussed by Nearing (1998) who explained the under-estimation for large events and the over-estimation for small events. Many models showed a problem in erosion prediction when there were some variations within watersheds; for example, flattened and condensed surfaces after large events, changes in topsoil structure by rain drop impacts, or the failure of runoff barriers (Jetten *et al.*, 2003). These variations within a watershed can be important parameters for hydrological modeling and good reasons for using spatially distributed data and models.

Another very important issue in uncertainty in hydrological modeling is using DEM (Digital Elevation Model). DEM is widely discussed for its uncertainty but the uncertainty during the interpolation process is not well known (Desmet, 1997). Uncertainty of the DEM depends on the accuracy of the measured or known elevation data, the distance between the interpolated location and the nearest known data, and the variation of the terrain between known elevation values (Isaaks and Srivastava, 1989). The degree to which a DEM represents the true surface depends mainly on the resolution and the surface roughness. However, finer DEM do not necessarily represent topography more accurately.

Most spatially distributed models use DEM and the model results are strongly dependent on the resolution of DEM. DEM resolution is important in distributed models and impacts a large portion of model results (Jetten *et al.*, 2003) and often determines the resolution of other data such as soil, and land use data. Jetten *et al.* (2003) also pointed out that when DEM size was larger, the watershed area represented by the DEM may have been larger and slope may have become less steep, thus runoff and sediment yield were decreased. There is a high possibility of error within soil erosion models due to the resolution of DEM (Desmet, 1997) because the impact of slope steepness is very large in soil erosion modeling. The selection of the cell size is sometimes arbitrary in modeling and there is no principle or consensus for better resolution of data (Jetten *et al.*, 2003). The data resolution should be based on the scale, the purpose of model, and the condition. Relatively recent usage of DEM with finer resolution such as 10m NED (National Elevation Dataset) or LIDAR (Light Detection And Ranging) have the same limitation although they represent landscape with more detail level. 〈Figure 1〉 illustrates an example of slope variation depending on the resolution of DEM. The example shows re-sampling of DEM from 10 meters (A) to 20 (B) and to 40 meters (C), then calculate slopes for

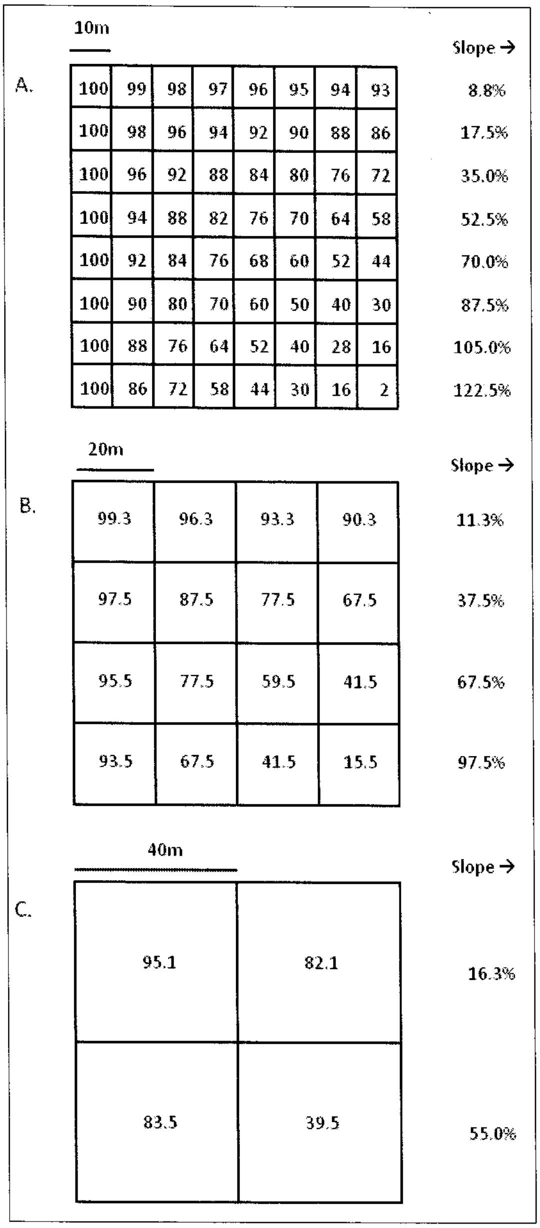

Figure 1. Misleading of slope by various resolution of DEM.

each row from left to right. The slope ranges from 8.8% to 122.5% with 10 meter resolution, from 11.3% to 97.5 with 20 meter resolution, and from 16.3 to 55.0% with 40 meter resolution, respectively. Therefore, the lower resolution smoothen the surface and the average slope is lower than higher resolution, which can mislead soil erosion estimation in models depending on the resolution of DEM.

3. Best Management Practices

1) Hydrologic and hydraulic aspect of vegetative BMPs

The most important hydrologic components related to reducing runoff and sediment yield by BMPs are flow velocity, infiltration, and soil erodibility. Vegetation reduces raindrop impact energy, flow velocity, soil erodibility, and increases surface storage and infiltration rate. Vegetation on BMPs is to reduce flow velocity by resistance of vegetation to flow. Vegetation increases the hydraulic roughness of the surface, thus decreasing flow velocity (Foster, 1982). Thompson *et al.* (2004) experimented and quantified how increased vegetation density is more effective in decreasing flow velocity and thus contributes to the settlement of sediment and nutrients.

Soluble pollutants can also be partly removed by interaction with vegetation and infiltration that is increased by the vegetation (Gharabaghi *et al.*, 2001). The development of rill and concentrated flow can be slowed down when peak runoff and runoff velocity are reduced by vegetation (Dabney, 1998). Concentrated flow and flow with high depth submerges and bends vegetation and decreases roughness and resistance (Syversen *et al.*, 2001). Therefore, vegetative BMPs are most effective in shallow water (Flanagan *et al.*, 1989) or with stiff grass (Dabney *et al.*, 1999).

Another major role of vegetation cover, alive or dead, on either fields or BMPs is to reduce the impacts of the kinetic energy of rain drops. If the vegetation cover is denser, there is a reduction of rain drop impact energy, and generally less soil erosion (Dunne and Leopold, 1978). Other roles of vegetation in reducing the detachment of soil particles by rain drop impacts are 1) providing high organic matter that helps development of soil aggregation (Dunne and Leopold, 1978), 2) binding those aggregated soils with vegetation roots (Dabney, 2003).

Vegetation on fields or BMPs increases infiltration in three ways (Dabney, 1998; Dabney, 2003). First, it reduces surface seal on soil by reducing rearrangement of soil particles (Römkens *et al.*, 1990) and makes water infiltrate quickly. Secondly it aids the growth of micro-organism and worms living in the soil, which increases soil porosity (Tomlin *et al.*, 1995). This increase in porosity allows greater water storage in the soil. Third, vegetation consumes water through evapotranspiration.

Sediment can be deposited by vegetation on BMPs by a back water effect or ponding (Blanco-Canqui *et al.*, 2004; Dabney, 2003; Rose *et al.*, 2003) rather than filtration by vegetation (McGregor *et al.*, 1999). The deeper water depth caused by the ponding effect decreases flow velocity because the volumetric flow rate is the product of flow velocity and flow depth. Dabney (2003) discussed the relative location of sediment deposition around the vegetative BMPs and inferred that the greatest amount of sediment is deposited right before the flow reaches where the flow depth is highest. Ghadiri *et al.* (2001) found that the length of backwater is proportional to vegetation density and inversely to slope. They also concluded that the sediment deposition occurred at the starting point of the backwater prism. Rose *et al.* (2003) found that the hydraulic jump and sediment deposition upslope of the vegetation became deeper and moved steadily upslope corresponding to accumulated sediments. Ghadiri *et al.* (2002) conducted similar test and found the same result and they also found that floating debris accumulated upslope of vegetation increasing hydraulic resistance. Syversen *et al.* (2001) tracked the movement of sediment particles from upslope to a buffer zone using Cesium-134 and found that the largest amount of soil was deposited in the upper area of the buffer. Thompson *et al.* (2004) divided the total shear in vegetative BMPs into particle shear from soil particles and form shear from vegetation to understand the roles of vegetation. Particle shear is responsible for particle detachment and transport while form shear plays a major role on resistance (90%) against flow (Prosser *et al.*, 1995). Sediment deposition upslope of vegetation increases bed roughness and flow depth, and changes surface slope, all of which increase sediment deposition upslope (Rose *et al.*, 2003). A number of studies (Blanco-Canqui *et al.*, 2004; Inamdar *et al.*, 2001; McGregor *et al.*, 1999; Shukla *et al.*, 2001) have been conducted to determine the effectiveness of BMPs using either pre- or post BMP scenarios on comparable multiple plots. These studies all agree that the significant reduction of sediments and nutrients by the BMPs is valid.

2) Assessment of BMP impacts in current modeling research

BMP effectiveness, optimization analysis, and cost effectiveness have been researched using many available modeling tools (Abu-Zreig, 2001; Bracmort *et al.*, 2004; Lee *et al.*, 2010; Niu *et al.*, 2001; Veith, 2002; Vennix and Northcott, 2002). Empirical models such as the USLE (Wischmeier and Smith, 1959) are dependent just on a statistical estimation to assess the impacts of BMPs and generate only the annual amount of erosion while relatively recent physical based models and spatial distributed models, such as ANSWERS (Bouraoui and Dillaha, 1996), WEPP (Laflen *et al.*, 1991), and SWAT (Arnold *et al.*, 1998) take into account physical and spatial process in much detail and account for spatial and temporal scales.

The BMPs in the studies above were represented by converting the landuse to grass from cropland, conservation tillage by adjusting management factors and the detention pond by adding a new pond in the model. Vennix and Northcott (2002) simulated the impacts of a buffer using the AGNPS model and they represented the buffer by changing parameters such as the SCS CN (Soil Conservation Service Curve Number), C-factor in USLE, and Manning's n. A study of BMP simulation with changing slope steepness after sediment deposition by the BMP was conducted by Zhu *et al.* (2001) using the WEPP model, and they concluded that the change and the redistribution of slope steepness during the simulation period is important for the long term effectiveness of BMPs. Bracmort *et al.* (2004) investigated the long-term effectiveness of the BMPs as well as the cost effectiveness by revisiting previous research studied 30 years ago. They evaluated the physical conditions of each BMP and estimated their future effectiveness in different scenarios with the physical condition of various BMPs. Lee *et al.* (2010) conducted a comprehensive watershed protection study by selecting cost effective BMP to establish a watershed protection plan.

4. Discussion - Issues on current BMP modeling

Although the watershed models discussed above have been used and helped in assessing the impacts of BMPs and making environmental plans and decisions, there are other important issues to be considered. 〈Table 2〉 summarizes the uncertainty issues in estimation of BMP effectiveness in hydrological models. For the uncertainty in spatial aspect, data resolution as discussed earlier, the scale of model (whether small scale or large scale model), and the location of BMP validation are important to be considered. For temporal aspect, data scale (how long the data represents?) and the design life of BMP are the factors to be considered before a particular model is selected to use.

There are limited data available in order to observe the impacts of BMPs at the BMP scale. In many cases, collecting and measuring data is conducted at the watershed outlet to evaluate the function of BMPs that are located in only a part of the watershed. This can be one of the problems in a 'point-based model' discussed earlier. Many BMPs are small in size (e.g. 5m wide filter strip) compared to the commonly available dataset (e.g. 10m or 30m DEM) that many watershed models use today. It may be necessary to use data with the size of a particular BMP in order to represent those management practices efficiently. 〈Figure 2〉 shows an example of representing a BMP using 5 meter DEM and WEPP model (Renschler and Lee, 2005). The 5 meter DEM, which is not commonly available, was extracted from 1 foot (0.3 meter) contour line and 5 meter field border was represented on 5 meter landuse (left). The model results showed the effectiveness of field border in green or yellow color on the right figure. The red and

Table 2. Uncertainty issues of modeling BMPs in a watershed model

	Type	Note
Spatial	Data resolution	GIS data resolution
	Model resolution	Small or large scale model
	BMP validation location	Where are BMPs validated, at BMPs or watershed outlet?
Temporal	Data scale	Length of data, unit of data
	BMP effectiveness	Design life of BMPs

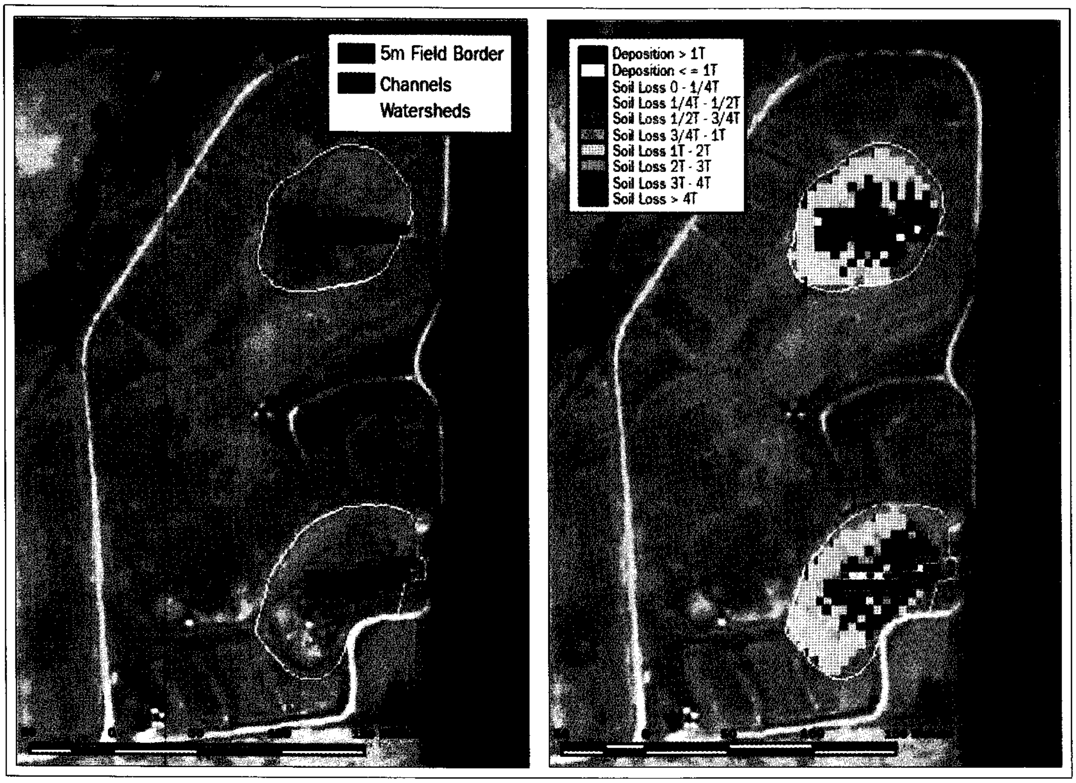

Figure 2. Representation of a BMP using 5 meter DEM (Holly Spring, Mississippi, USA) (Renschler and Lee, 2005). T in the legend on the left indicates Target Value by USDA-NRCS, which is defined as the maximum rate of annual soil loss that permits the high level of crop productivity.

pink cells indicate soil erosion with more severe soil erosion in darker red. T in the legend of the left image indicates Target Value by USDA-NRCS, which is defined as the maximum rate of annual soil loss that permits the high level of crop productivity.

Model selection in proper scale can be important since BMPs are represented in different ways in models usually depending on the scale of model (either small or large scale). ⟨Table 3⟩ shows an example of the methodologies that models represent filter strips and grassed waterways. SWAT as a large scale model represents them using a number between minimum and maximum values that the model suggests. For example, grassed waterways are represented with parameters such as channel erodibility and channel cover factor with a number between 0 and 1 (0 indicates no vegetation) as used in the studies by Bracmort *et al.* (2004) and Lee *et al*, (2010). This method may be beneficial to assess BMPs without intensive information and to estimate the overall effectiveness of multiple BMPs in a large watershed but it may not be the physical representation of those BMPs because a number between 0 and 1 may not represent the reality. Also, it brings the previously discussed 'point based' model issue. On the other hand, WEPP as a small scale model represent grassed waterways by replacing landuse to grassland at user defined width, soil, and slope in the area of grassed waterways as used in the studies by Zhu *et al.* (2001) and Renschler and Lee (2005), which involves and

Table 3. An example of methodologies to represent BMPs in a large scale and a small scale model

BMPs	Model	Representation
Filter strips	SWAT	FILTERW: Filter width between 0 and 100m
	WEPP	Change of landuse, soil, and slope at the end of hillslope
Grassed waterways	SWAT	CH_EROD: Channel erodibility between 0 and 1 CH_COV: Channel cover factor between 0 and 1
	WEPP	Change of landuse, soil, and slope at channel

requires more complicating parameter settings and detail physical properties. To represent and estimate the BMPs, a small scale model that is capable of representing the physical aspects of BMPs may have more advantages. Those small scale models that allow multiple managements in a hillslope or a watershed provide a platform to represent those small BMPs. A spatially distributed model has advantages in that it is often necessary to point out where the impacts take place.

Parameter settings with BMP representation in a model need to be measured, tested and validated at the individual BMP location, not only at the watershed outlet. It is often not clear and sufficient to estimate and validate the impacts of an individual BMP based on measurement at the outlet. Therefore, measurement data at the BMPs level as well as pre- and post BMPs scenarios are necessary since this would be necessary to provide a good comparison between scenarios and to validate model settings.

Assessing the short and long-term effectiveness of BMPs using a model provides advantages for estimating the efficiency of BMPs at the early stage in conservation planning. This allows decision makers and land owners to design and install management plans to solve problems and estimate future impacts after the implementation. A vegetative BMP, for example, can be damaged or fail over the years after it is implemented. Appropriate management and maintenance of BMPs keeps their functioning up or beyond their design life. Major failures found in vegetative practices are concentrated flow development and vegetation density decrease. Concentrated flow occurs where flow resistance is low and it lowers vegetation density. It finally develops rills and gullies and the practices no longer functions as planned. Therefore, long-term assessment of the BMP impacts may be more efficient by taking those maintenance practices and failures into account.

In addition to the spatial and temporal scale discussed above, the parameterization for the representation of BMPs is the key point in many studies. In most studies on modeling, BMPs have been represented by substituting land management and/or adjusting values of some parameters that are related or not directly related with the function of BMPs. The BMPs in models, however, need to be more representative in terms of physical, hydraulic, and hydrological aspects as discussed earlier. For example, changing land covers from cropland to grassland to represent BMPs in a model means changing a whole complex of natural processes and the BMP may not be represented just by adjusting some model parameters. Therefore, the selection of the proper model that offers to represent those natural processes in detail is important in the assessment of BMPs.

Therefore, several points should be addressed before the impacts of BMPs are estimated in models. First, more detailed and representative parameter settings can be helpful for a more accurate assessment of BMPs in models. Second, those representative parameter settings need to be validated at the BMPs, not at the watershed outlet. Third, a spatially distributed model with an appropriate scale of data may offer advantages to locate and understand the impacts of BMPs, and the last, estimating long-term impacts of BMPs including their failure and maintenance provides future assessment for designing and planning of the conservation plan.

5. Conclusion

Many different types of hydrological models have been developed to assess runoff, sediment, and nutrient yields in a watershed. A spatially distributed and physically based model is a recent trend to represent the detail level of physical condition in a watershed. The selection of model to be used should depend on spatial and temporal scale of a study.

Best management practices reduce the velocity of runoff and provide time for sediment and nutrients to settle down. Many researches have proved that BMPs are effective to prevent and mitigate non-point source problems. There have been a number of researches to assess the impacts of BMPs using hydrological models that which heavily depends on the scale of models and their inherent uncertainties. Because most BMPs are in small scale in size, estimation and evaluation of BMP performance may have disadvantages with a large scale watershed model and data when the detail impacts of BMPs need to be analyzed. Unknown conditions and properties within a watershed are also challenges in modeling the practices. As discussed earlier, the estimation of sediment and nutrient reduction by BMPs may not be shown correctly in the model results. In addition, calibration and validation at the BMP level can be critical to estimate more reliable benefits of the BMP.

A small scale model with spatially distributed parameters, on the other hand, may have advantages in representing the BMPs as well as estimating the impacts although it may require more cost and time. A small scale model takes into account the alteration of landuse (land cover), soil and slope in the representation of BMPs while a large scale model represents BMPs by changing one or two representing number although a large scale model can be more appropriate to assess overall impacts in the entire watershed. A small scale and spatially distributed model offers an opportunity to implement smaller size of BMPs directly in the places where BMPs are located and to represent with more realistic approach though the results at the watershed outlet by both small and large scale model may be the similar. Therefore, it helps provide more accurate estimation if represented properly and the model results can be more reliable and supportive to establish a cost effectiveness watershed protection plan. In conclusion, a large scale model helps to estimate and evaluate the overall performance of BMPs and their impacts in a large watershed although the representation of BMP may not be realistic or accurate. On the other hand, a small scale model offers more detail representation of BMPs in a small watershed and helps to estimate the on-site performance of BMPs although it requires more time and cost. Therefore, it is important for model users to understand the limitation or strength of each model and data and to select a model based on their scope and purpose of study.

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