# Spatially distributed assessment of short- and long-term impacts of multiple best management practices in agricultural watersheds

C.S. Renschler and T. Lee

**ABSTRACT:** Best management practices (BMPs) are a critical tool for preventing or mitigating the degradation of water quality caused by soil erosion. However, currently available assessment models are primarily designed for use over and, therefore, are only valid over these particular spatial and temporal scales. This study investigates the feasibility of combining three models that were designed for use at different spatial scale into a single assessment tool that allows for more detailed, spatially-explicit assessment of BMPs over both short (four to eight years) and longer (100 year) time scale. The three models evaluated were: 1) the Water Erosion Prediction Project (WEPP) model for hillslope and small watershed up to 260 ha (642 ac); 2) the Geospatial interface for WEPP (GeoWEPP), which utilizes geographic information system (GIS) or precision farming datasets of topography, soils, and landuse to automatically derive WEPP model input; and 3) a linked GeoWEPP-SWAT model, which injected WEPP model output as point sources into the Soil and Water Assessment Tool (SWAT). The linked GeoWEPP-SWAT model provides a mechanism for applying the WEPP model to larger watershed scales beyond the validity of its channel routing algorithms. This paper summarizes the challenges, validity, and opportunities of this modeling approach for BMP assessment in large watersheds.

**Keywords:** BMP, GeoWEPP, scale, SWAT, WEPP

**Best management practices (BMPs) have been widely recognized and as a critical tool for preventing or mitigating water quality degradation.** Although BMPs are often used in combination as part of an erosion reduction program, research efforts at the plot, hillslope, and small watershed scale are often limited to investigating the impact and efficiency of a single BMP (Lowrance et al., 2002). Sometimes soil erosion problems are so severe that it is not possible to wait for long-term studies to determine BMP effectiveness and valuable time is lost in developing recommendations for land managers.

Continuous, process-based models provide a rapid and cost-effective means for researchers and land managers to assess the long-term benefits and effectiveness of BMPs. Thus, model approaches that are capable of predicting the impacts of multiple BMPs at various spatial and temporal scales are potentially very useful assessment tools for policy makers and planners to test scenarios before implementing costly BMPs (Renschler and Harbor, 2002). In this paper, we suggest an approach for combining three different models to assess the effectiveness of BMPs across a range of spatial and temporal

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scales that a single model is unable to predict. The Water Erosion Prediction Project (WEPP), the Geospatial interface for WEPP (GeoWEPP), and the Soil and Water Assessment Tool (SWAT) are combined in a linkage to estimate the long-term impacts of BMPs on runoff, soil loss, and sediment yields in watershed setting. In order to take advantage of multiple model components we want to capitalize on the specific strength of each model component.

The objectives of this study are the validation of the WEPP Microsoft Windows version, the GeoWEPP interface, and the WEPP-SWAT linkage as well as the estimation for the impact of BMPs for a set of selected WEPP validation sites. This validation will form the foundation for using the GeoWEPP interface to prepare data for a WEPP-SWAT linkage for larger watersheds to estimate impacts of BMPs at various spatial and temporal scales. In this study, it is assumed that the original WEPP parameters for the sites are correct and used for linkage validation.

**Figure 1**
Locations of the selected Water Erosion Prediction Project (WEPP) watershed validation sites.


## Methods and Materials

***The WEPP model.*** WEPP (Laflen et al., 1991) is a process-based, continuous model, developed with new and improved erosion technology over the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1959). It predicts daily runoff, soil erosion, and sediment yield at various temporal and spatial scales from single storm events to long-term studies for a hillslope or small agricultural watersheds. WEPP takes into account the daily condition of weather, plants, soils, and sediment yield and deposition, and predicts spatially on representative hillslope profiles within small watersheds (Laflen at al., 1991; Laflen et al., 1997; Ascought II et al., 1997). WEPP requires four major inputs for hillslope (weather, management, slope, and soil) and additional channel information for watersheds (Liu et al., 1997). The model calculates inter-rill and rill erosion as the function of sediment detachment and delivery (Ascough II et al., 1997). Peak runoff rate and duration are determined by overland flow routing that is based on kinematic approximation for physical parameters such as slopes steepness and length, surface roughness, soil texture, and rainfall distribution. Erosion equations, normalized to the water discharge and flow shear stress, used to determine sediment detachment, transport, and deposition in each hillslope segment. The information of hydrology and sediment for only the last hillslope segment are used for routing to the outlet. The Window interface of WEPP, in contrast to its 1995 released version, is a useful and user-friendly tool to predict the effectiveness of BMPs by substituting different land management practices.

***The GeoWEPP interface.*** The need of a spatially distributed erosion prediction model capable of using larger and more detailed data sets—usually managed with geographic information systems (GIS) or precision farming software packages—has led to the development of the Geo-spatial interface for WEPP (GeoWEPP) (Renschler, 2003; Renschler et al., 2003). GeoWEPP easily identifies the degree of seriousness in soil erosion by user's criteria at each on-site location (e.g. specific target value such as tolerable soil loss) or at each off-site channel segment (e.g. total daily maximum loads (TMDL) of tolerable sediment yields); this helps establish a 'hot spot' analysis for planners and decision makers. GeoWEPP utilizes the Environmental Systems Research Institute (ESRI) ArcView GIS 3.x software consisting of multiple AVENUE, C++, and FORTRAN scripts (Renschler, 2003). GeoWEPP prepares WEPP model inputs automatically through a GIS-based wizard, runs the WEPP hillslope and watershed model, and analyzes the model output. While detailed topographic surveys were quite expensive in the past, today's precision farming global positioning systems (GPS) produce very accurate and multi-temporal digital elevation models that can be used as input for GeoWEPP (Renschler et al., 2003). However, the WEPP channel routing algorithms for the watershed simulation (Ascought II et al, 1997; Lui et al, 1997) were originally designed to simulate channel processes in watersheds smaller than 260 ha (642 ac) (Flanagan and Nearing, 1995), as a result, GeoWEPP also has this limitation.

***The SWAT model.*** While WEPP is smaller scale model (valid up to 260 ha), the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) allows a channel routing procedure for much larger watersheds and its channel networks (Di Luzio et al., 2002). SWAT has been used numerous times for basin-wide applications and BMP assessments to predict the impact of runoff and sediment transport (e.g. Bracmort et al., 2004; Inamdar et al., 2002). While SWAT does not offer the ability to simulate the details at the smaller hillslope scale, a combination of SWAT and WEPP has great potential representing the smaller hillslope scales as well as the larger watershed scales in a linked model approach. It is also more suitable for BMPs representation since most BMPs are implemented in a smaller hillslope scale and requires detailed parameterization to be properly represented.

***WEPP validation sites and validating WEPP Windows.*** The original DOS-based WEPP version was previously validated for several watersheds in the United States (Lui et al., 1997). The Windows-based version of the WEPP model was successfully validated for selected WEPP watershed sites by translating all DOS-based input data sets into WEPP

**Table 1. Characteristics of Water Erosion Prediciton Project (WEPP) watershed model validation sites (after Liu et al., 1997).***

| Watershed ID, State† | Size (ha) | No. of Years | No. of Events | Annual observed Runoff (mm $yr^{-1}$) | Annual observed Sediment (t $ha^{-1}$ $yr^{-1}$) | Management‡ | Soils |
|---|---|---|---|---|---|---|---|
| Cos 130, OH | 0.66 | 6 | 33 | 7.0 | 0.005 | Alfalfa | Coshocton (silt loam) |
| Wat P-1, GA | 2.69 | 8 | 40 | 54.2 | 4.90 | Sorghum - Barley - Soybean - Winter wheat- Clover | Watkinsville (sandy loam) |
| HSp 3, MS | 0.65 | 8 | 278 | 357.3 | 11.75 | Winter wheat - soybean - corn | Grenada (silt loam) |
| ChiC-5, OK | 5.11 | 4 | 51 | 80.0 | 1.07 | Winter wheat | McLain (silt loam) |

* **Note that the four watersheds were selected based on the availability of topographic data and the different orders of magnitudes in observed runoff and sediment yields. In contrast to Liu et al. (1997), all simulated events were taken into account.**

† **Note: Cos 130 - Coshocton 130, Ohio; Wat P-1 - Watkinson P-1, Georgia; HSp 3 - Holly Spring 3, Mississippi; Chi C-5 - Chickasha C-5, Oklahoma.**

‡ **Channel management for Watkinsville and Holly Springs is fescue, which is the same vegetation as grassed waterway.**

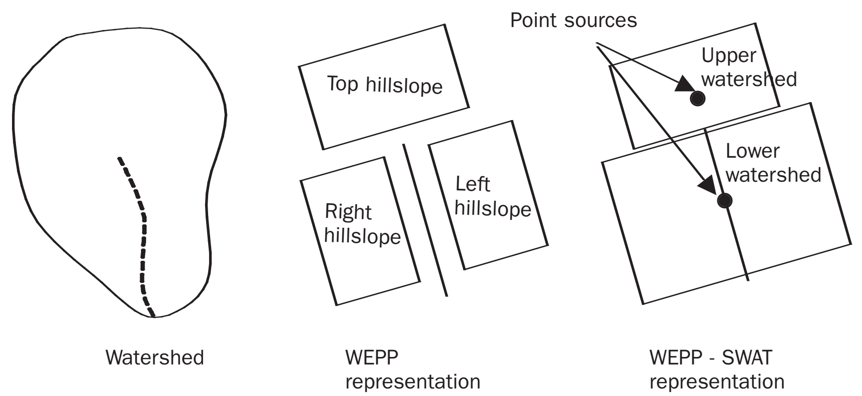
Windows parameter data sets (Renschler and Lee, 2003). We selected a total of four U.S. Department of Agriculture Agricultural Research Service experimental watersheds in four different agricultural regions with typical land management or crop rotations on soils with similar soil textures (Table 1 and Figure 1), and there were no BMPs initially implemented on the sites. The input data for the WEPP validation sites used in this study (Table 1) were surveyed or generated by one of the WEPP model components (Liu et al., 1997). For weather data, main parameters such as precipitation and duration were calculated from break point precipitation data, and the other parameters like solar radiation and wind velocity are generated by CLIGEN (Nicks et al., 1995), which is an embedded component in WEPP. Management information like tillage and the dates of plants and harvests were based on the field operation notes. Coshocton has perennial (alfalfa) on hillslope as well as channel while Watkinsville and Holly Spring have fescue on channel (Table 1), which are the similar or the same vegetation as BMPs used in this study. Slope and channel characteristics were extracted from topography map and soil characteristics are obtained from survey.

The yearly measured runoff and sediment yields of these four watersheds are at four different scales (Table 1) ranging from annual averages of about 7 mm (0.28 in) runoff and 0.005 t $ha^{-1}$ (0.002 t $ac^{-1}$) sediment yield (Coshocton, Ohio) to around 357.3 mm (14.07 in) and 11.75 t $ha^{-1}$ (5.25 t $ac^{-1}$) (Holly Spring, Mississippi). Most of the original WEPP watershed validation sites described in Liu et al. (1997) unfortunately had unsatisfactory spatially distributed topographic information.

***Short- and long-term BMP assessment with WEPP Windows.*** The validated WEPP Windows model input parameter sets for the four watersheds were then modified to represent a couple of non-structural BMPs such as grassed waterway and field border in the following ways: 1) a 5 m (16.4 ft) wide field border at the downhill end of a hillslope before entering the channel (on-site BMP); 2) a grassed waterway with various width depending on the original channel width in the channel area of each watershed (off-site BMP); or 3) a combination of the two. Both BMPs were implemented in a way that the managements of either lower hillslope, channel, or both were substituted with fescue. The fescue is widely used vegetation for field border and grassed waterways, and can be functional in various weather condition including dry weather, thus fescue is selected in this study (Laflen, 2005, personal communication). The climate time series observed at each location within the validation time periods were used as model input for the short-term BMP assessment (Table 1). For the long-term impact of BMPs, the CLIGEN stochastic climate generator (Nicks et al., 1995) in WEPP was used to create a 100-year climate input file for each specific location. CLIGEN produces time series of daily weather parameters from static monthly values observed at the site for the period of record, e.g., monthly mean, standard deviation, and skewness. This approach permits generation of representative weather patterns for user selectable time intervals, using a relatively small amount of input data.

***Spatially distributed off- and on-site BMP assessment with GeoWEPP***. GeoWEPP allows for utilization of the WEPP hillslope and watershed model algorithms in the WEPP Windows version with basically two simulation methods: 1) a relatively faster *Watershed Method* (off-site assessment) that allows one to simulate runoff and sediment yields from single representative hillslopes for each contributing area draining into a channel and a channel routing for the watershed outlet; and 2) a more time consuming *Flowpath Method* (on-site assessment) that allows one to simulate and merge soil loss results along all possible hillslope flowpaths within a watershed, but without channel routing for individual channel segments and the watershed outlet. For more information about how to derive representative hillslopes as well as how to merge the flowpath by weighting their results according to flowpath length and contributing area, refer to Cochrane and Flanagan (1999). GeoWEPP allows the user to map the spatially distributed on- and off-site results based on a relative value. This gives users the flexibility in assessing the BMP impact with a single threshold. A possible relative measure could be the tolerable soil loss (Schertz, 1983), soil loss tolerance factor or target value for on-site soil loss and off-site sediment yields or T. The Natural Resources Conservation Service (NRCS) publishes T values for each soil-mapping unit based on properties of root limiting subsurface soil layers, current climate regions, and an economic feasibility summarized for soils in defined land resource regions. T values usually range up to 11.2 t $ha^{-1}$ $yr^{-1}$ (5 t $ac^{-1}$ $yr^{-1}$). Geo-WEPP determined soil loss and sediment yield are classified relative to T-values and tolerable soil losses are displayed according to their intensity in green color shades, intolerable

**Figure 2**
Conceptual view of the hillslope and channel representation in the WEPP/GeoWEPP watershed model and the WEPP-SWAT model linkage.




ones are shown in red, and deposition areas are in yellow (Renschler, 2003). Since the application of GeoWEPP is limited to the maximum allowable watershed size for the WEPP model, the linkage to the SWAT model was tested for the selected WEPP validation watersheds.

***Optimization and validation of WEPP-SWAT linkage.*** The linkage of the WEPP and SWAT models is based on the combination of WEPP simulation runs for each representative WEPP hillslope, which will become a point source in each sub-watershed in SWAT, and SWAT channel routing (see Figure 2). The runoff and sediment yield from each WEPP hillslope (or first-order WEPP sub-watershed) are represented as a point source in the SWAT model. Runoff and sediment yield from the top hillslope is injected into the upper watershed in a linkage, and in the same way runoff and sediment yields from left and right hillslopes is injected as a SWAT point source into the lower watershed.

The WEPP hillslope simulations take into account all hydrologic and geomorphologic processes at the hillslope scale driven by climate, management, topography and soil as well as specific management and BMP conditions. In the SWAT modeling part of the linkage, the amount of rainfall was intentionally modified to zero and the SWAT channel is used only to route the water and sediment from WEPP simulation runs. If there is the need to obtain base flow at larger watershed scales, the SWAT model could be run independently to obtain the baseflow amount and the WEPP point source contributions would be added.

The WEPP-SWAT linkage was tested and validated for the selected WEPP watershed validation sites. Most of the parameter values for SWAT channel characteristics were transferred from WEPP parameters in order to represent the same channel condition. Manning's *n* and hydraulic conductivity were obtained from WEPP channel characteristics. However, some SWAT required parameters such as the channel erodibility and coverage factor were estimated based on optimizing the linkage model runs. The validation of the selected SWAT channel parameters was based on two consecutive optimization steps that compared WEPP Windows and WEPP-SWAT linkage simulation runs.

In the first step, the channel parameters were optimized by minimizing the differences of simulated runoff and sediment yields for three selected events at various scales (in order of priority: large, medium, and small) for each watershed site. The results were based on actually observed climate data and considered as a test for the short-term assessment of BMPs with the linkage. In a second optimization step, the channel parameters were then adjusted by optimizing the coefficient of variation ($r^2$) for event-based runoff and sediment yields for the first 10 years in a 100-year time period. After the optimization was satisfactory, the linkage performance was validated for the remaining 90 years of a 100-year simulation. The validation results based on generated climate data for this step were considered as a test for the long-term assessment performance of the linkage. In order to estimate the impacts of BMPs in the model linkage, the same BMPs as for WEPP were tested on three of the validation sites. The on-site field BMP (field border) was represented as WEPP hillslopes simulations (same parameters used as WEPP simulation only). The off-site BMP for the channel (grassed waterway) was represented as SWAT channels (related channel parameters were adjusted to achieve runoff and sediment yields at the same order of magnitude as with WEPP simulations only).

## Results and Discussion

***Validation of WEPP Windows.*** The translation of the model input parameters for the WEPP DOS version and the Windows version was successful (Table 2). There are minor differences in the average annual values for runoff and sediment yields. The comparison of the event-based runoff and sediment values indicated that the coefficient of variation ($r^2$) is at least 0.998 for the observation period at the four WEPP validation sites. As a result the WEPP Windows parameter sets for the soils and land use/rotation for hillslopes and channels can be used in both WEPP and GeoWEPP and as a basis to implement BMP assessment scenarios.

**Table 2. Runoff and sediment yield at the outlets of four Water Erosion Prediciton Project (WEPP) watershed validation sites predicted by WEPP DOS (DOS) and WEPP Windows (WIN) versions.**

| | Runoff ($m3\ yr^{-1}$) | | | Sediment yield ($t\ yr^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Sites** | **DOS** | **WIN** | $r^2$ | **DOS** | **WIN** | $r^2$ |
| Cos 130 | 71 | 71 | *1.0000* | 0.3 | 0.3 | *1.0000* |
| Wat P-1 | 1,103 | 1,107 | *0.9980* | 1.1 | 1.1 | *0.9998* |
| HSp 3 | 2,271 | 2,277 | *0.9998* | 8.7 | 8.7 | *0.9996* |
| Chi C-5 | 4,978 | 4,983 | *0.9999* | 11.3 | 10.8 | *0.9998* |

***Short- and long-term BMP assessment with WEPP Windows.*** The short-term and long-term assessment of BMP impacts in Table 3 demonstrates that the long-term results for runoff and sediment yields reductions by BMPs are more consistent throughout the model period. The short-term assessment results yield only an indication for the order of magnitude of the potential negative or positive impact of each BMP setting. However, the results may still be biased by the particular impact of a specific event during

Table 3. Short-term and long-term average annual runoff and sediment yield predictions with Water Erosion Prediciton Project (WEPP) Windows version for implementing best management practices (BMPs) grassed waterway (GW), field border (FB) and the combination of GW and FB at the original WEPP watershed validation sites.

| | Runoff ($m^3$ $yr^{-1}$) | | | Sediment yield (t $yr^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Sites** | **Pre-BMP** | **Post-BMP** | ***Difference (%)*** | **Pre-BMP** | **Post-BMP** | ***Difference (%)*** |
| **Short-term assessment (for each observation period in Table 1)** | | | | | | |
| Cos 130 | 71 | | | 0.3 | | |
| GW, 8m wide | | 70 | *- 1.0* | | 0.3 | *no* |
| FB, 5m wide | | 59 | *- 16.9* | | 0.3 | *no* |
| GW & FB | | 75 | *5.0* | | 0.3 | *no* |
| Wat P-1 | 1,107 | | | 1.1 | | |
| GW, 9m wide | | 1,127 | *1.0* | | 1.1 | *no* |
| FB, 5m wide | | 917 | *- 17.2* | | 0.8 | *- 19.6* |
| GW & FB | | 932 | *- 15.8* | | 0.9 | *- 18.0* |
| HSp 3 | 2,277 | | | 8.7 | | |
| GW, 6m wide | | 2,220 | *- 2.5* | | 8.6 | *- 1.1* |
| FB, 5m wide | | 2,007 | *- 11.8* | | 5.0 | *- 42.5* |
| GW & FB | | 1,965 | *- 13.7* | | 4.9 | *- 43.7* |
| Chi C-5 | 4,983 | | | 10.8 | | |
| GW, 5m wide | | 4,365 | *- 12.4* | | 7.0 | *- 35.2* |
| FB, 5m wide | | 4,399 | *- 11.7* | | 5.2 | *- 51.8* |
| GW & FB | | 3,557 | *- 28.6* | | 4.7 | *- 56.1* |
| **Long-term assessment (100 years of generated weather)** | | | | | | |
| Cos 130 | 162 | | | 0.7 | | |
| GW, 8m wide | | 161 | *no* | | 0.7 | *no* |
| FB, 5m wide | | 162 | *no* | | 0.8 | *12.0* |
| GW & FB | | 162 | *no* | | 0.8 | *12.0* |
| Wat P-1 | 2,323 | | | 2.8 | | |
| GW, 9m wide | | 2,320 | *no* | | 2.8 | *no* |
| FB, 5m wide | | 1,922 | *- 17.2* | | 2.4 | *- 14.2* |
| GW & FB | | 1,917 | *- 17.4* | | 2.3 | *- 17.8* |
| HSp 3 | 3,038 | | | 13.4 | | |
| GW, 6m wide | | 3,010 | *- 0.9* | | 13.3 | *- 0.7* |
| FB, 5m wide | | 2,648 | *- 12.8* | | 9.2 | *- 31.3* |
| GW & FB | | 2,625 | *- 13.6* | | 9.1 | *- 32.1* |
| Chi C-5 | 5,945 | | | 11.9 | | |
| GW, 5m wide | | 5,288 | *- 11.1* | | 8.0 | *- 32.8* |
| FB, 5m wide | | 5,347 | *- 10.1* | | 6.9 | *- 42.0* |
| GW & FB | | 4,402 | *- 26.0* | | 5.0 | *- 58.0* |

the relative short test period of not more than eight years (see Table 1). As compared to short- vs. long-term field studies, long-term simulation studies eliminate the impact of significant events and give a better basis to analyze long-term trends.

The implementation of a fescue field border at the Coshocton site (alfalfa) suggested a reduction of runoff in the short-term analysis, while the long-term analysis clearly indicates that there is no significant reduction. The increase in sediment yield totals in the long run at that order of magnitude is acceptable taking into account the expected model algorithm uncertainty and rounding of values caused by inserting an additional overland flow element in the WEPP model run. That is, increases of 0.1 t $yr^{-1}$ (0.15 t $ha^{-1}$ $yr^{-1}$) of sediment yields for Coshocton are within the uncertainty of the model and do not indicate a significant increase in sediment yield. A 5 m (16.4 ft) field border implementation at the Holly Springs and Chickasha site showed a potentially long-term large reduction of runoff by 10 percent to almost 13 percent. The reduction for the Watkinsville site with more than 17 percent is even higher, while the reduction in sediment yields with about 14 percent is relatively small in contrast to the 31 percent and 42 percent at the Watkinsville and Holly Springs site, respectively. The long-term analysis for the field border at Chickasha and Holly Springs showed less reduction in runoff and sediment yield than short-term since short-term climate has less precipitation but much larger rainfall intensity. This means the field border is much more effective in trapping runoff and sediment at hillslopes when there are events with larger rainfall intensity. Moore et al. (1992) also verified that intensity plays a bigger role in soil erosion than the amount of rainfall.

The addition of a grassed waterway to the field border seems to have a significant impact only at Chickasha by reducing runoff and

**Table 4. Surveyed and GeoWEPP derived watershed sizes for Water Erosion Prediciton Project (WEPP) watershed validation sites in Coshocton, Ohio, and Holly Springs, Mississippi.**

| | Watershed size (ha) | | |
|---|---|---|---|
| **Site** | **Surveyed** | **GeoWEPP delineated** | **Difference (%)** |
| Cos 130 | 0.66 | 0.61 | - 7 |
| HSp 3* | 0.65 | 0.55 | - 15 |
| HSp 2* | 0.59 | 0.47 | - 20 |

* **Note that Holly Spring 2 (HSp 2) and Holly Spring 3 (HSp 3) have the same soil and land use. Wat P-1 and Chi C-5 topographic data had insufficient detail.**

sediment by an additional 16 percent. Grassed waterways at Coshocton, Watkinsville, and Holly Springs did not show noticeable reduction because the channel management was originally alfalfa or fescue, which is the same vegetation as the implemented BMP grassed waterway (see Table 1). While the conventional WEPP model application requires us to manually assemble model input data sets and design representative hillslope profiles and channels, it also produces results only at the outlet of these representative modeling units.

***Spatially distributed off- and on-site BMP assessment with GeoWEPP.*** GeoWEPP derives representative modeling units automatically based on the spatially distributed topography, drainage pattern, soils, and land management units. However, the topographic surveys for the Watkinsville and Chickasha site were insufficient to produce reliable digital elevation models. The automatically delineated watershed areas turned out to be somewhat smaller than the surveyed WEPP validation data sets (Table 4). This is due to the fact that the boundary of the experimental watersheds needed to be artificially raised to prevent surface runoff around the watershed from entering the experimental area. The topographic analysis algorithms in GeoWEPP are based on the Topographic Parameterization software TOPAZ (Garbrecht and Martz, 2000) that are specifically designed to remove such artificial features in landscapes to create digital elevation models with a clearly defined converging drainage pattern (i.e. no diversion of flow allowed). Because the area of watersheds is different each other, average annual value per hectare is used for the unit consistency.

As mentioned above and shown in Table 3, the long-term assessment of simulation results shows a much more consistent assessment than the short-term assessment (Table 5). In the long-term, the GeoWEPP watershed method only slightly underestimates the average annual runoff by less than one percent,

**Table 5. Off- and on-site assessment for field border best management practices predicted by Water Erosion Prediciton Project (WEPP) Windows version and by GeoWEPP watershed and flowpath methods for experimental watersheds in Coshocton, Ohio, and Holly Springs, Mississippi.**

| | Off-site assessment (Watershed method) | | | | | | On-site assessment (Flowpath method) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sites** | Runoff ($m^3$ $ha^{-1}$ $yr^{-1}$) | | | Sediment yield (t $ha^{-1}$ $yr^{-1}$) | | | Soil loss (t $ha^{-1}$ $yr^{-1}$) | | |
| | **WEPP** | **Geo-WEPP** | ***Diff. (%)*** | **WEPP** | **Geo-WEPP** | ***Diff. (%)*** | **WEPP** | **Geo-WEPP** | ***Diff. (%)*** |
| **Short-term assessment (for each observation period)** | | | | | | | | | |
| Cos 130 | 108 | 126 | *16.7* | 0.45 | 0.49 | *8.9* | 0.36 | 0.49 | *36.1* |
| FB, 5m | 89 | 116 | *30.3* | 0.45 | 0.49 | *8.9* | 0.37 | 0.49 | *32.4* |
| ***Diff.*** | ***-17.6%*** | ***-7.9%*** | | ***no*** | ***no*** | | ***2.8%*** | ***no*** | |
| HSp 3 | 3,503 | 3,626 | *3.5* | 13.4 | 12.5 | *-6.7* | 22.15 | 19.64 | *-11.3* |
| FB, 5m | 3,088 | 3,450 | *11.7* | 7.69 | 9.10 | *18.3* | 17.58 | 13.09 | *-25.5* |
| ***Diff.*** | ***-11.8%*** | ***-4.9%*** | | ***-42.6%*** | ***-27.2%*** | | ***-20.6%*** | ***-33.4%*** | |
| HSp 2 | 3,322* | 3,860 | *16.2* | 15.2* | 14.5 | *-4.6* | n.a. | 18.72 | |
| FB, 5m | n.a. | 3,890 | | n.a. | 10.0 | | n.a. | 13.83 | |
| ***Diff.*** | | ***0.8%*** | | | ***-31.0%*** | | | ***-26.1%*** | |
| **Long-term assessment (100 years of generated weather)** | | | | | | | | | |
| Cos 130 | 245 | 243 | *-0.8* | 1.06 | 1.15 | *8.5* | 0.96 | 0.98 | *2.1* |
| FB, 5m | 245 | 243 | *-0.8* | 1.21 | 1.15 | *-5.0* | 1.04 | 0.98 | *-5.8* |
| ***Diff.*** | ***no*** | ***no*** | | ***14.2%*** | ***no*** | | ***8.3%*** | ***no*** | |
| HSp 3 | 4,674 | 4,633 | *-0.9* | 20.62 | 19.10 | *-7.4* | 31.65 | 27.75 | *-12.3* |
| FB, 5m | 4,074 | 4,058 | *-0.4* | 14.15 | 12.90 | *-8.8* | 25.01 | 23.24 | *-7.1* |
| ***Diff.*** | ***-12.8%*** | ***-12.4%*** | | ***-31.4%*** | ***-32.5%*** | | ***-21.0%*** | ***-16.3%*** | |
| HSp 2 | n.a. | 4,777 | | n.a. | 23.60 | | n.a. | 27.36 | |
| FB, 5m | n.a. | 4,032 | | n.a. | 14.90 | | n.a. | 20.94 | |
| ***Diff.*** | | ***-15.6%*** | | | ***-36.9%*** | | | ***-23.5%*** | |

* **Note that WEPP results for HSp 2 were taken from Liu et al. (1997) and represented only 241 events of the 278 observed events; n.a. = not applicable; Diff. = difference.**

while the sediment yields for the same watershed outlets are consistently underestimated by about five to nine percent. The comparison of on-site and off-site assessment (soil loss predicted by *GeoWEPP flowpath method* and sediment yields by *GeoWEPP watershed method* respectively) indicates that the channels of all three watersheds are in a deposition mode. That means that a part of the soil that was eroded on the hillslopes is deposited in the channels within the small watersheds.

The BMP assessment demonstrates that the long-term assessment is also much more consistent. The GeoWEPP results for the off-site assessment indicate that there is a negligible difference from the WEPP simulations (Table 5). The field border implementation would reduce the runoff at the Holly Springs watersheds 2 and 3 by about -12.5 and -15.5 percent, while the sediments are predicted to be lowered by about -32 and -37 percent, respectively.

The GeoWEPP maps for the on-site BMP assessment for the Holly Springs experimental watersheds demonstrate the spatially-distributed effect of the 5 m-wide (16.4 ft) field border along the channels (Figure 3; note that the results for Holly Springs watershed number 1 are only included for illustrative purpose of the BMP effect). The soil loss maps in Figure 3 are classified with a tolerable target T-value for soil loss of 5 t $ha^{-1}$ $yr^{-1}$ (2.23 t $ac^{-1}$ $yr^{-1}$). While soil erosion only occurs on the hillslopes without a field border around the channels, an implemented field border would lower the erosion rates and create deposition areas before the sediments would reach the channel. GeoWEPP also creates off-site assessment maps such as runoff and sediment yields per channel-contributing area.

**Table 6. Constant, best management practices adjusted (grassed waterway), and optimized values for SWAT model channel parameters in WEPP-SWAT model linkage at three selected study sites.**

| | Constant | | Adjusted for BMPs | | After optimization | |
|---|---|---|---|---|---|---|
| Site | Hydraulic conductivity | Channel erodibility | Coverage factor | Manning's n | Stream power coefficient* | Peak rate adjustment factor* |
| Cos 130 | 3.50 | 0.1 | 0.2 | 0.30 | 0.009 | 1.5 |
| GW, 8m | 3.50 | 0.1 | 0.0 | 0.30 | n.a. | n.a. |
| HSp 3 | 0.47 | 0.1 | 0.2 | 0.30 | 0.01 | 6.5 |
| GW, 6m | 0.47 | 0.1 | 0.0 | 0.30 | n.a. | n.a. |
| Chi C-5 | 1.20 | 0.4 | 0.5 | 0.15 | 0.01 | 2.3 |
| GW, 5m | 1.20 | 0.4 | 0.0 | 0.20 | n.a. | n.a. |

* Note that, stream power coefficient is more sensitive and was optimized prior to peak rate adjustment factor.

***Optimization and Validation of WEPP-SWAT linkage.*** In order to apply the WEPP model to a larger watershed, the WEPP-SWAT linkage was tested at three watershed locations. Some of the WEPP channel parameters could be directly taken as SWAT model parameters (Table 6). Coshocton, Watkinsville, and Holly Springs have perennial coverage on the channel (alfalfa and fescue), which are almost the same for both BMPs tested. Thus, the SWAT channel parameters for erodibility and coverage factor can be set relatively small (0.1 and 0.2, respectively) while there is heavy agricultural activity in Chickasha such as tillage, planting, and harvest (channel erodibility and coverage factor were estimated as 0.4 and 0.5, respectively).

The optimization of the SWAT channel parameters in the WEPP-SWAT linkage for short-term assessment was performed based on three different sizes of events (Table 7). A return period analyses with a 100-year simulation run showed that small events at each site have a return period of less than one year, medium events about one year, and large events about two years. The parameters optimized in SWAT channel were stream power coefficient (SPCON) and peak rate adjustment factor for sediment routing in main channel (PRF). The optimization results show that runoff values match relatively well with WEPP-only results for all sites. Sediment yields of the SWAT-WEPP linkage for the Chickasha watershed did not match well especially on 5/31/71 and 9/24/71.

Table 8 shows the model validation for entire observed period at each site, not including the three events used for optimization. Runoff and sediment yields at all site showed $r^2$ values larger than 0.979, except the sediments at Holly Springs. This is due to a

**Table 7. Three selected events to estimate SWAT channel parameter values to optimize runoff and sediment yield output for WEPP-SWAT linkage.**

| | | After optimization of SWAT channel parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | Runoff ($m^3$) | | | Sediment yield (t) | | |
| Sites | Events* | WEPP | Linkage | *Difference (%)* | WEPP | Linkage | *Difference (%)* |
| | 7/19/88 (L) | 86.6 | 82.5 | *-4.7* | 0.64 | 0.62 | *-3.1* |
| Cos 130 | 4/3/88 (M) | 26.0 | 23.7 | *-8.8* | 0.07 | 0.08 | *14.3* |
| | 5/14/87 (S) | 14.2 | 12.2 | -14.1 | 0.03 | 0.03 | *no* |
| | 3/3/70 (L) | 264.7 | 234.1 | *-11.6* | 0.40 | 0.39 | *-2.5* |
| HSp 3 | 4/1/70 (M) | 129.9 | 117.3 | *-9.7* | 0.23 | 0.27 | *17.4* |
| | 3/19/70 (S) | 11.4 | 13.7 | *20.2* | 0.01 | 0.01 | *no* |
| | 9/17/71 (L) | 1,723.3 | 1,675.3 | *-2.8* | 3.78 | 3.79 | *0.3* |
| Chi C-5 | 9/24/71 (M) | 882.1 | 860.5 | *-2.4* | 2.19 | 1.46 | *-33.3* |
| | 5/31/71 (S) | 130.8 | 159.1 | *21.6* | 0.05 | 0.11 | *120.0* |

* L = large event, M = medium event, S = small event (in order of priority for optimization).

**Figure 3**
GeoWEPP on-site, short-term assessment of best management practice (field border) impact on soil loss for Holly Springs watershed 2 and 3, Mississippi (tolerable target value T = 5 t $ha^{-1}$ $yr^{-1}$).

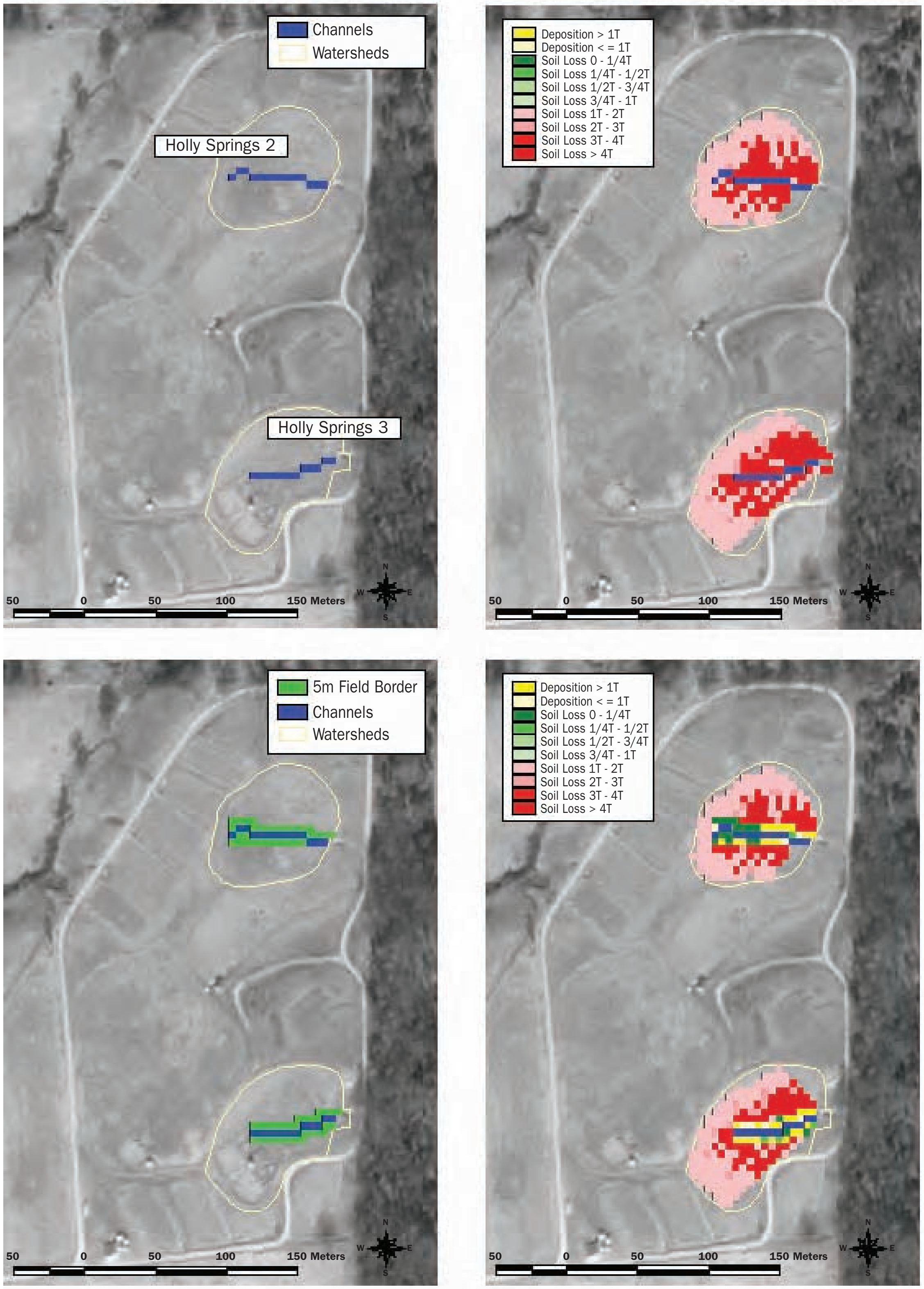


**Table 8. Validation for short-term and long-term assessment WEPP-SWAT linkage. This includes the optimization of SWAT channel parameters based on a comparison of all events in the first 10 years of 100 years generated climate for each site. The following 90 years of the 100 years climate was used for validation.**

| | Runoff ($m^3\ yr^{-1}$) | | | Sediment yield ($t\ yr^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Sites** | **WEPP** | **Linkage** | $r^2$ | **WEPP** | **Linkage** | $r^2$ |
| | | | **Validation for short-term assessment (observation periods)** | | | |
| Cos 130 | 71 | 68 | *0.993* | 0.3 | 0.3 | *0.993* |
| HSp 3 | 2,277 | 2,313 | *0.979* | 8.7 | 4.4 | *0.594* |
| Chi C-5 | 4,983 | 4,986 | *0.999* | 10.8 | 10.4 | *0.996* |
| | | | **After optimization of SWAT channel parameters (first 10 of 100 years)** | | | |
| Cos 130 | 156 | 149 | *0.995* | 0.7 | 0.7 | *0.993* |
| HSp 3 | 3,050 | 2,906 | *0.967* | 11.6 | 15.6 | *0.942* |
| Chi C-5 | 5,703 | 5,682 | *0.998* | 10.6 | 10.4 | *0.995* |
| | | | **Validation for long-term assessment (last 90 of 100 years)** | | | |
| Cos 130 | 162 | 158 | *0.991* | 0.7 | 0.7 | *0.992* |
| HSp 3 | 3,038 | 2,905 | *0.998* | 13.4 | 17.1 | *0.811* |
| Chi C-5 | 5,945 | 5,965 | *0.996* | 11.9 | 11.5 | *0.993* |

number of large events that occurred in the eighth year when the model did not perform well. When the eighth year was excluded, $r^2$ was 0.772. When optimizing the SWAT channel parameters for the long-term assessment based on a CLIGEN generated 100-year climate model input, $r^2$ was 0.811 (Table 8). Long-term simulation for the linkage shows better agreement with WEPP output than short-term. As Nearing (1998) discussed, this is probably because the model does not predict well for the large events in short-term estimation but it is averaged out for the long-term simulation. All other sites showed $r^2$-values larger than 0.99 for either runoff or sediment yields.

As with the individual models, long-term assessment results for the linked models were more consistent than the short-term ones (Table 9). However, the results after BMP implementation for long-term simulation generally showed similar reduction rates as in the short-term simulation. The reduction of sediment yield at Holly Spring by grassed waterway was 39.8 percent, a much larger reduction than in the short-term simulation. This is because the linked model estimated sediment yield slightly higher than WEPP in

**Table 9. Short-term and long-term assessment of runoff and sediment yield predictions by Water Erosion Prediciton Project (WEPP)-SWAT linkage for implementing best management practices (BMPs), grassed waterway (GW), and field border (FB) at the original WEPP watershed validation sites.**

| | Runoff ($m^3\ yr^{-1}$) | | | Sediment yield ($t\ yr^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Sites** | **Pre-BMP** | **Post-BMP** | ***Difference (%)*** | **Pre-BMP** | **Post-BMP** | ***Difference (%)*** |
| | | | **Short-term assessment (for observation periods)** | | | |
| Cos 130 | 68 | | | 0.3 | | |
| GW, 8m wide | | 69 | *1.4* | | 0.3 | *no* |
| FB, 5m wide | | 70 | *2.9* | | 0.3 | *no* |
| GW & FB | | 71 | *4.4* | | 0.3 | *no* |
| HSp 3 | 2,313 | | | 4.4 | | |
| GW, 6m wide | | 2,213 | *- 4.3* | | 4.4 | *no* |
| FB, 5m wide | | 1,916 | *- 17.2* | | 4.0 | *- 9.1* |
| GW & FB | | 1,916 | *- 17.2* | | 4.0 | *- 9.1* |
| Chi C-5 | 4,986 | | | 10.4 | | |
| GW, 5m wide | | 4,972 | *- 0.2* | | 5.0 | *- 51.9* |
| FB, 5m wide | | 4,409 | *- 11.6* | | 5.6 | *- 46.2* |
| GW & FB | | 4,399 | *- 11.8* | | 3.2 | *- 69.2* |
| | | | **Long-term assessment (100 years scenario)** | | | |
| Cos 130 | 158 | | | 0.7 | | |
| GW, 8m wide | | 160 | *1.2* | | 0.7 | *0.0* |
| FB, 5m wide | | 163 | *3.2* | | 0.6 | *- 14.2* |
| GW & FB | | 161 | *1.9* | | 0.7 | *0.0* |
| HSp 3 | 2,905 | | | 17.1 | | |
| GW, 6m wide | | 2,868 | *- 1.3* | | 10.3 | *- 39.8* |
| FB, 5m wide | | 2,384 | *- 17.9* | | 10.6 | *- 38.0* |
| GW & FB | | 2,365 | *- 18.6* | | 9.2 | *- 46.2* |
| Chi C-5 | 5,965 | | | 11.5 | | |
| GW, 5m wide | | 5,897 | *- 1.1* | | 5.9 | *- 48.7* |
| FB, 5m wide | | 5,235 | *- 12.2* | | 6.3 | *- 45.2* |
| GW & FB | | 5,223 | *- 12.4* | | 4.2 | *- 63.5* |

the long-term and sediment yield estimations were not correct in the short-term simulation as mentioned earlier.

The results for conditions after a BMP implementation showed that the reduction in runoff by grassed waterway is much smaller than predicted by WEPP simulation only while the reduction of sediment yield is relatively higher. This can be explained by the fact that the SWAT channel has a very limited number of adjustable parameters to represent BMPs. In fact, Manning's *n* and channel cover factor are the only major parameters sensitive to this model and those parameters should not be adjusted beyond the typical range for those values. When Manning's *n* is increased, runoff is decreased but the sediment yield is decreased even more.

Sediment yield at Holly Springs did not show much reduction because the linkage did not estimate the correct amount in the earlier step (Table 7). At the Coshocton site, BMPs resulted in no reduction or even increased runoff and sediment yield because the site is managed in alfalfa on both the hillslopes and channel. The total amounts of runoff and sediment are anyhow extremely small and rounding of results in the model or in the post-processing can cause amplified percent differences.

There are several other assumptions one has to account for in the proposed WEPP-SWAT-linkage. Currently, point sources are the only sources for water flow and sediment, and it does not take into account other hydrologic cycles, such as ground water. However, as mentioned above, the base flow can be obtained by SWAT simulation itself. Second, hillslope contributes runoff and sediment yield to the channel evenly along the channel in WEPP. On the other hand, runoff and sediment yield from point sources (originally from WEPP hillslopes) in the linkage have no geographical location in each sub-watershed and they are simply added with input of the sub-watershed. This, however, is the way that the SWAT model accounts for a point source input in a sub-watershed. Third, left and right hillslope from WEPP representation is represented as a single sub-watershed in the linkage. Thus, as a consequence characteristics of both hillslopes are either averaged or combined. These trade-offs need to be further investigated to establish a consistent and reliable integrated model parameter estimation and linkage of WEPP and SWAT. In the future GeoWEPP could be potentially the platform to derive these parameter values from spatially distributed maps of larger watersheds for both models.

## Summary and Conclusion

Best management practices can be effective methods to prevent water quality degradation. Model approaches need to be tested in order to investigate their combined and spatially distributed impact at the watershed level for various spatial and temporal scales. The validated WEPP Windows version was used for the short- and long-term impact assessment of multiple BMP settings at four of the original WEPP validation watersheds. The more consistent long-term assessment with the WEPP model demonstrated that field borders potentially reduce runoff and sediment yield up to 17.2 and 42.0 percent, respectively. Grassed waterways reduce runoff by up to 11.1 percent, and sediment yields by up 32.8 percent. The combination of field border and grassed waterway seems to work better than either one used alone. The effectiveness of this combination appeared to work most effectively at the dryer Chickasha location where more extreme rainfall intensity events occur.

The automated methods to derive WEPP input parameters in GeoWEPP show long-term, off-site assessment results that clearly indicate that there is a negligible difference from the manually derived WEPP Windows simulation runs. However, one has to keep in mind that appropriate spatially distributed information about topography, soils and land management is available in a GIS format. GeoWEPP creates on- and off-site assessment maps such as soil loss, runoff, and sediment yields within a watershed. This allows precision farmers and other land managers to build land management scenarios and a hot spot detection of areas for preferred management option, such as spatially distributed BMPs along channels or in pattern (e.g. contour farming, buffer-strips, or others).

The linkage of WEPP and SWAT builds on the unique benefits from each model and generates similar results in runoff and sediment yield as the WEPP-only simulations. The long-term impact assessment of BMPs in the linked model predicted similar results for field borders as the WEPP model. On the other hand, it was difficult to represent the grassed waterway in the linkage for both the short-term and the long-term due to the limitation of adjustable parameters in SWAT. The optimization procedure of short-and long-term assessment parameter estimation demonstrated that the Manning's *n* and channel cover factor were the only parameters sensitive to the linked model approach.

The WEPP-SWAT linkage results show promise for the potential application of the model larger watersheds that are beyond the validity of WEPP channel algorithms. Sub-watersheds of less than 260 ha (642 ac), which is currently the limitation for WEPP and GeoWEPP, can be prepared with GeoWEPP and simulated with WEPP. Model output may be imported into SWAT to represent the more detailed, smaller sub-watersheds. The GeoWEPP interface and modeling approach provide a potential platform for effectively deriving model input parameters from spatially distributed maps of larger watersheds for the WEPP-SWAT model linkage.

## Endnote

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