Summary of the Modification for Subsurface Flow

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The following is a summary of the modifications to a number of subroutines in the WEPP model that are related to subsurface flow. Changes were primarily made in the approach to, and algorithms for modeling the deep percolation of soil water and subsequent subsurface lateral flow. The modification was based on the v2004.601 of WEPP. v2004.601 includes changes to the ET and water balance routines.

In the original WEPP model, the subsurface runoff calculated in the WEPP hillslope component is not included in the hillslope and watershed pass files, meaning that subsurface runoff is not incorporated in the channel flow that ultimately discharges at the watershed outlet. On the other hand, WEPP's hillslope component tends to substantially overestimate deep percolation and underestimate subsurface runoff for several reasons. First, WEPP allows the saturated hydraulic conductivity (K_{sat}) to be input for the surface soil layer only. The model estimates K_{sat} for the remaining layer(s) using empirical functions of soil properties, in particular, the percentages of clay and sand. All these empirical equations lead to a minimum K_{sat} no less than 2.1×10^{-8} m s^{-1} even under extreme conditions, e.g., zero percent of sand content or a clay content of 100 percent, and a CEC (cation exchange capacity) value as high as 50. The method of assigning and determining K_{sat} in the WEPP model may be reasonable for agricultural lands with relatively uniform and deep soils or with subsurface drainage systems, but is invalid for most forest settings where soils are shallow and have low-permeability bedrock underneath. Without subsurface drain pipes installed to intercept percolated soil water, an overestimated K_{sat} value for the deeper soil layers will simply lead to an overestimated deep percolation.

In the WEPP model, the evaluation of individual components (e.g., surface runoff, ET, change in soil moisture) of the water balance is made sequentially. Prior to calculating deep percolation, WEPP estimates and adjusts for soil water content. If soil water content is greater than the water content at field capacity (θ_{fc}), deep percolation starts and is removed from the soil profile. Afterwards, if the soil water content is still greater than θ_{fc}, WEPP calculates the lateral flow following Darcy's law using the internally estimated K_{sat} adjusted for the present soil water content. In reality, deep percolation and lateral flow take place simultaneously. Therefore, if the two processes are simulated separately and if the deep percolation is incorrectly overestimated, the subsurface lateral flow would then be underestimated as a consequence.

Second, WEPP assumes that the modeled soil profile is isotropic, i.e., the horizontal and vertical K_{sat} values are equal. This assumption, again, may be adequate for many agricultural fields but inadequate for forestland where the layered structure of porous soil lying on top of low-permeability bedrock tends to create higher horizontal hydraulic conductivity and greater amount of lateral flow. In fact, this is also the case for typical stratified soils (Maasland, 1957) for which the value of horizontal hydraulic conductivity is always higher than that of vertical hydraulic conductivity.

To correct WEPP's problem of overestimation of deep percolation, we added three additional parameters in the soil input file providing information for a "restricting" layer at the bottom of a soil profile. These are a flag variable, the name or the vertical saturated hydraulic conductivity of the bedrock, and the anisotropy ratio of the soil profile. The modified code allows a user to choose whether or not to use the restricting layer with the character flag variable (slflag) in the soil input file. When slflag = 0, no restricting layer is assumed and WEPP uses the original algorithms to estimate K_{sat} for deeper soil layers; otherwise, the restricting layer is assumed and the following methods are used to determine the K_{sat} value for this restricting layer. If an *in situ* field measurement or a reliable estimation of K_{sat} is available, the user may provide the value. An anisotropy ratio variable for the soil profile allows the user to describe the relative predominance of lateral versus vertical flow. When information about the anisotropy ratio is available, the user directly includes this value in the soil input file. When this information is not available, the user should indicates this condition by giving a negative value. Subsequently, a default value of 25 would be used internally by the program. Domenico and Schwartz (1997) suggest a range of anisotropy of 1–1,000 for most geological materials. The value of K_{sat} in the horizontal direction for each soil layer will be in turn altered by multiplying the K_{sat} values with the anisotropy ratio. Currently, a single anisotropy ratio is assigned for all soil layers. In the future, the user may be given the option to input the anisotropy ratio for each individual soil layer. The general types of bedrock included in the modified WEPP Windows interface code are those given by Domenico and Schwartz (1997), representing the most commonly occurring sedimentary and crystalline rocks. For these rocks, the vertical K_{sat} values range from 3×10^{-14} m s^{-1} for unfractured igneous and metamorphic rocks to 3×10^{-2} m s^{-1} for gravel. For each individual bedrock, Domenico and Schwartz (1997) provide a range of the K_{sat} values. Included in the WEPP Windows interface were the average K_{sat} values.

In the original WEPP code, only surface runoff information, labeled as “EVENT”, is stored and passed to the watershed master pass file. To include the subsurface runoff information in the hillslope and watershed pass files, two different methods are used, and for both it was assumed that, due to its slow rate and after undergoing natural filtration, subsurface runoff is essentially clear and contains no sediment. In the first method, when both surface runoff and subsurface runoff occur on a certain day, the surface runoff is assumed to dominate the water flow and sediment transport processes, and the subsurface runoff is simply added to the surface runoff (by volume) without changing the sediment amount in it and without altering the event duration. This approach is valid under those field conditions where the stream bank slope is relatively gentle and well vegetated. Additionally, a preliminary analysis of WEPP simulation results indicated that surface runoff occurs much less frequently than subsurface runoff but it typically produces much greater amount of flow than subsurface runoff on an event basis. Therefore, the neglect of erosion caused by subsurface runoff may be adequate. The second method of including subsurface runoff in the pass files is used in situations when only subsurface runoff occurs on a hillslope. In the new WEPP code, a subsurface runoff event is assumed to last 24 hours (one day) and the event is recorded in the hillslope pass file, with a label “SUBEVENT”. This information is then transferred to the watershed master pass file by a WEPP subroutine (WSHPAS), which has been modified to subsurface events in addition to surface events. Accordingly, another subroutine (WSHRED) was modified such that it can properly read the information stored in the watershed master pass file, and then pass the information to the channel or impoundment model component for subsequent calculations.

Another important change made was for routing subsurface flow events when there is no surface runoff event. In the original WEPP, the channel or impoundment component cannot route flow when there is no storm, irrigation, or surface runoff event. Modifications were made to route subsurface runoff when no such water input or runoff is existent. Generally, the total volume of subsurface runoff generated by an upstream hillslope was assumed to be evenly distributed along the channel and water balance is calculated by the existing WEPP channel hydrologic routines. As mentioned earlier, compared to surface runoff that often occurs within a relatively short duration and at a high intensity, subsurface runoff tends to last much longer and at a much lower rate. Therefore, the subsurface runoff generally does not carry with it sediment and does not cause bank erosion upon entering the stream from the hillslope. After entering a channel, however, the subsurface runoff adds to the channel flow, increasing the transport capacity of the channel and potential channel erosion as well. Hence, the modified WEPP would generally be expected to predict higher channel erosion than the original model.

Presently, the total amount of subsurface runoff from hillslopes is added to the channel flow. However, depending on the position of a specific channel relative to the hillslopes, subsurface flow may or may not enter the channel in its entirety. Future efforts may be devoted to refine the relevant algorithms in order to properly represent the channel and hillslope interaction.

Finally, modifications were made to add new output variables to record subsurface runoff from individual hillslopes to channel segments. This modification allows easy comparison of WEPP-predicted and field-observed total runoff from hillslopes, which in turn helps such comparisons made at the watershed level for future studies.

References

Maasland, M., 1957. Soil anisotropy and land drainage. In James N. Luthin (Ed.), Drainage of Agricultural Lands. Am. Soc. Agron., Madison, WI. pp. 216–285.