SWAT-WB Theoretical Documentation

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To improve SWAT performance in areas dominated by saturation-excess runoff processes, a new runoff routine was added to SWAT. A daily soil water balance was used to determine the saturation deficit of each hydrologic response unit (HRU) in SWAT, which was then used, instead of the CN method, to determine daily runoff volume. What follows is a brief discussion of the methods used by the original SWAT model, SWAT2005, and the routine that we developed for use in modeling saturation-excess derived surface runoff in SWAT-WB.

Summarized SWAT Description

SWAT is a basin-scale model designed to simulate hydrologic processes, nutrient cycling, and sediment transport throughout a watershed. Catchment area varies widely throughout the peer-reviewed literature, with SWAT being used on watersheds as small as 0.15 $km^2$and as large as 491,700 km^2 (Gassman et al., 2007). From a digital elevation model (DEM), the watershed will be divided into subbasins that are assigned a stream channel, or reach in SWAT terminology. If the locations of stream gauges are known, the user can choose to have the subbasin outlets correspond to these gauges. Similarly, if a stream network has been previously mapped, this network can be used. If no such data is available, SWAT will determine the stream network from the DEM. All of these processes can be performed via a geographical information system (GIS) interface for SWAT. The ArcSWAT 2.0 interface for ArcGIS 9.2 was used for this project.

For each day of simulation, SWAT models processes such as: rainfall, runoff, infiltration, plant dynamics (including uptake of water and nutrients, biomass, etc.), erosion, nutrient cycling, leaching of pesticides and nutrients, and many others. In addition to the physical processes, users can model scheduled crop rotations, irrigation, fertilizer application, tillage, and harvesting. To increase computing efficiency, SWAT does not distribute these processes throughout the entire watershed. Instead, SWAT models these processes only once for each unique portion of the watershed. To determine these unique areas, SWAT utilizes hydrologic response units (HRUs). Each subbasin of a watershed is divided into HRUs, which are traditionally defined as the coincidence of soil type and landuse. The HRU is the smallest unit in the SWAT model and is used to simulate all of the processes mentioned above. These HRU simulation results are combined for each subbasin, and then routed through the watershed's stream network.

Curve Number Approach Used by SWAT2005

To model surface runoff for any given day, the first step that SWAT2005 takes is to assign an initial NRCS Curve Number (CN) is assigned for each specific landuse/soil combination in the watershed, and these values are read into the SWAT program. SWAT then calculates upper and lower limits for each CN following a probability function described by the NRCS to account for varying antecedent moisture conditions (CN-AMC) (USDA-NRCS, 2004). SWAT determines an appropriate CN for each simulated day by using this CN-AMC distribution in conjunction with daily soil moisture values determined by the model. This daily CN is then used to determine a theoretical storage capacity, *S,* of the watershed for each day the model is run. The storage is then indirectly used to calculate runoff volume, *Q*:

$$CN = \frac{1000}{10 + S/25.4} \qquad \textbf{eq. 1}$$

$$Q = \frac{\left(P - I_a\right)^2}{\left(P - I_a\right) + S} \qquad \textbf{eq. 2}$$

where S is watershed storage, P is precipitation, and I_a is initial abstraction. All terms are in mm of water, and by convention I_a is assumed to be equal to 0.2*S.

Water Balance Approach Used by SWAT-WB

To replace the CN, a simple soil profile water balance was calculated for each day of simulation. While SWAT's soil moisture routine greatly simplifies processes that govern water movement through porous media (in particular, partly-saturated regions), for a daily model the approach can be shown to be acceptable (Guswa et al., 2002). These inherent soil moisture routines are then used by SWAT-WB to determine the degree of saturation-deficit for each soil profile for each day of simulation. This saturation-deficit (in mm H_2O) is termed the available soil storage, τ:

$$\tau = EDC\left(\varepsilon - \theta\right) \qquad \textbf{eq. 3}$$

where *EDC* is the effective depth of the soil profile (unitless), ε is the total soil porosity (mm), and θ is the volumetric soil moisture for each day (mm). The porosity is a constant value for each soil type, whereas θ varies by the day and is determined by SWAT's soil moisture routines. The effective depth, *EDC,* a calibration parameter ranging from zero to one, is used to represent the portion of the soil profile used in calculating the saturation deficit. By including this adjustment to the available storage, the amount of water able to infiltrate each day will be controlled by the *EDC*. *EDC* will then be spatially varied in such a way that low values are assigned to areas with a high likelihood of saturation, and higher *EDC*s will be used for areas where not much surface runoff is generated via saturation excess. This spatially adjusted available storage is then used to determine what portion of rainfall events will infiltrate and what portion will runoff:

$$Q = \begin{cases} 0, & \text{if } P < \tau \\ P - \tau, & \text{if } P \geq \tau \end{cases} \qquad \textbf{eq. 4}$$

where Q is surface runoff (mm) and P is precipitation (mm).

The available storage, τ, is calculated each day prior to the start of any rain event. Once precipitation starts, a portion of the rain, equal in volume to τ, will infiltrate the soil. If the rain event is larger in volume than τ, the soil profile will be saturated and surface runoff will occur. If the rain event is less than τ, the soil will not be saturated and there will be no surface runoff. By using this simple saturation-deficit term, SWAT-WB represents saturation-excess process and is no longer reliant upon the CN method.

This theoretical documentation was adapted from the SWAT-WB article available from the SWAT-WB website and is meant to provide a brief overview of the changes made to the original version of SWAT. The official SWAT-WB paper should be referred to for a full discussion of the model and its successful application in two test watersheds. For a full description of the original SWAT program please refer to either the official SWAT website (www.brc.tamus.edu/swat) or to the comprehensive article by Gassman et al. (2007). Similarly, a full description of the Curve Number approach utilized by SWAT2005 is available in the NRCS's National Engineering Handbook.

These references are available from:

Gassman, P.W., Reyes, M.R., Green, C.H., & Arnold, J.G. (2007). The Soil and Water Assessment Tool: Historical development, applications, and future research directions. Transactions of the American Society of Agricultural and Biological Engineers. 50(4), 1211-1250

USDA-NRCS. (2004). Estimation of direct runoff from storm rainfall. In National Engineering Handbook, Part 630: Hydrology. Retrieved January 15, 2008, from http://policy.nrcs.usda.gov/viewerFS.aspx? hid=21422.