Watershed Configuration and Simulation of Landscape Processes with the SWAT Model

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EXTENDED ABSTRACT

Recent and future river basin management requires a more spatially distributed description of basin hydrology and nutrient transport processes to enable land use management as a process controlling factor to realize sound river basin management. The spatial description of these processes in the Soil and Water Assessment Tool (SWAT) watershed model is presently realized by aggregating the flows from overlaid soil and land use patches in subbasins with averaged slope angles. Many concepts with different degrees of complexity have been developed in river basin modelling to aggregate units with similar hydrologic behavior (Hydrological Response Units). Watershed configuration for SWAT currently consists of: 1) subbasins defined by surface topography and 2) hydrologic response units in each subbasin to account for heterogeneity in soils and land use. The hydrologic response units do not account for landscape position within the subbasin. Until recently, many existing watershed models did not implicitly account for landscape processes within a subbasin. Other smaller scale models do account for hillslope transfer (e.g. WEPP, REMM, APEX, HYDRUS-2D).

In an attempt to account for landscape position and processes, SWAT was modified to simulate landscape units within subbasins. Surface, lateral vadose zone, and groundwater flows are routed between landscape units (while allowing for hydrologic response units within each landscape unit). Surface runoff can be overland or channelized when routed from one landscape unit to the next. The model is being tested on the USDA-ARS experimental Y-watershed at Riesel, Texas, USA, using soil moisture and groundwater data. Using GIS techniques, the watershed was divided into three landscape units - valley bottom, hillslope, and upland. Further development will include landscape unit routing of sediment and nutrients and stream interaction with the valley bottom (i.e.; riparian/flood plain landscape unit). Simulated daily stream flow at the watershed outlet after routing across the landscape units, compared well to measured flow (R^2 = 0.7). Mean annual lateral flows across landscape units were also realistically simulated. Soil moisture (upper 1 m) was compared to measured soil moisture at one monitoring site in each landscape unit with the model predicting drying early in the summer but following general wetting/drying cycles. The revised version of the model is also tested using data collected from a low-gradient watershed near Tifton, Georgia, USA which contains heavily vegetated riparian buffers. The modified model provided reasonable simulations of surface and subsurface flow across the landscape positions without calibration. The application demonstrates the applicability of the model to simulate filtering of surface runoff, enhanced infiltration, and water quality buffering typically associated with riparian buffer systems. Future validation will include comparison with: 1) the Riparian Ecosystem Management Model (REMM) and riparian data sets; 2) with data from larger basins with defined floodplains; and 3) watersheds having well defined variable source contributing areas. The concept assumes the controlling factors for hydrological processes and functions must be adequately described at different spatio-temporal scales to accurately delineate such response units. This requires a sound description of the characteristics by using physically based parameters and indicators, but also simplified solutions at larger scales. Presentation of the new model concept and first results of testing simulations of different aspects of catchment-related control of landscape processes, pattern hydrology, and spatially distributed modelling are discussed.

1. INTRODUCTION

Watershed models are valuable tools for examining the impact of land use on hydrology and water quality. While extensive research has been done to describe the impact of agricultural management practices on small scales (field and farm level, hillslopes or headwaters), less is known about how these changes are reflected at the watershed scale. While linkages are being developed between the micro- and meso-scale (Shaman *et al.* 2004), the lack of reliable field data limits testing to a few specific linkages such as stream chemistry or groundwater flow, but not the many other features which actually occur. However, the success of programs such as the Total Maximum Daily Load (TDML) in the United States and the European Water Framework Directive (WFD) will be based on water quality improvements that result at the watershed scale.

Recently, Wolock *et al.* (2004) have proposed a linkage between basin scales that is based on a fundamental hydrologic landscape unit. According to the authors, this unit is defined as an upland and lowland separated by a valley side slope. They assert that hydrological landscapes can be conceived as variations and multiples of this fundamental unit. Bogaart and Troch (2006) investigations into the flow processes follow a similar approach in that they indicate that an ideal catchment would be characterized into a fixed drainage network and a fixed hillslope that folds around the channel network.

The Soil and Water Assessment Tool (SWAT) has been applied to watersheds throughout the world (Arnold and Fohrer, 2005). In most cases, the prediction accuracy was satisfactory to obtain working knowledge of the hydrologic system and the processes occurring in the watersheds. One of the shortcomings of SWAT has been an inability to model flow and transport from one position in the landscape to a lower position prior to entry into the stream. The model utilizes a Hydrologic Response Unit (HRU) concept which combines a unique combination of land use and soil type within a defined subbasin. Transported water, sediment, and chemicals from the HRUs are routed directly into the stream channel. Due to the importance of the different hydrological processes and transport mechanisms related to specific landscape positions, the purpose of this study is to document a new modelling approach which links these watershed processes from the hillslope to the watershed scale using the concept of hydrological landscape units. The modification divides the catchment into three units, the upland divide, the hillslope, and the floodplain. The modified model routes surface runoff, lateral subsurface flow, and shallow ground water flow from the divide, through the hillslope, through the floodplain, and eventually to the stream. By linking these units within watersheds, processes at the micro scale can be more appropriately summed for assessment of impacts and flow regimes at the watershed scale within a reasonable programming architecture for rapid assessment of land use and management scenarios. The specific objectives of this study are: 1) to develop a simple yet realistic model for landscape processes that can be generally applied at the river basin scale, 2) incorporate the landscape model into SWAT, and 3) test it at the USDA-ARS experimental watersheds at Riesel, Texas. The revised model is also tested using data collected from a low-gradient watershed near Tifton, Georgia, USA, which contains heavily vegetated riparian buffers (Bosch *et al.* 2007).

2. CURRENT LANDSCAPE APPROACHES IN MODELS

There have been numerous attempts to simulate landscape processes at various scales with varying complexity. Merrit *et al.* (2003) and Drewry *et al.* (2006) provide excellent reviews of and references for the following and numerous other models with details on how they spatially represent the processes in a watershed. The WEPP model simulates flow and sediment transport across a hill slope using multiple overland flow elements. HYDRUS-2D uses a numerical model to route surface and subsurface flow across a hill slope. Riparian zones near a stream are simulated in REMM, which needs inputs from upland models such as GLEAMS or EPIC or observed data.

There are also several different approaches to simulating landscape processes when scaling up to watersheds. One common approach, used in TOPMODEL, AGNPS, ANSWERS, and several numerical models like MIKE SHE, is to divide the watershed into cells. This accommodates significant spatial detail but for larger watersheds does not preserve channel reaches. Another approach is to divide a watershed into subwatersheds defined by topography (typically using a DEM), ensuring all surface water within the subwatershed flows to the outlet and each subwatershed contains a channel reach for routing. Models differ on accounting for heterogeneity within each subwatershed. The WEPP watershed model assumes a representative hill slope within each subwatershed, while models like DWSM, PRMS and KINEROS use overland flow planes or segments. HSPF allows pervious and impervious areas within a subwatershed. The HRU approach of SWAT is described in sections 1 and 3.1.