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Effects of soil data resolution on SWAT model stream flow and water quality predictions

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Abstract

The prediction accuracy of agricultural nonpoint source pollution models such as Soil and Water Assessment Tool (SWAT) depends on how well model input spatial parameters describe the characteristics of the watershed. The objective of this study was to assess the effects of different soil data resolutions on stream flow, sediment and nutrient predictions when used as input for SWAT. SWAT model predictions were compared for the two US Department of Agriculture soil databases with different resolution, namely the State Soil Geographic database (STATSGO) and the Soil Survey Geographic database (SSURGO). Same number of sub-basins was used in the watershed delineation. However, the number of HRUs generated when STATSGO and SSURGO soil data were used is 261 and 1301, respectively. SSURGO, with the highest spatial resolution, has 51 unique soil types in the watershed distributed in 1301 HRUs, while STATSGO has only three distributed in 261 HRUS. As a result of low resolution STATSGO assigns a single classification to areas that may have different soil types if SSURGO were used. SSURGO included Hydrologic Response Units (HRUs) with soil types that were generalized to one soil group in STATSGO. The difference in the number and size of HRUs also has an effect on sediment yield parameters (slope and slope length). Thus, as a result of the discrepancies in soil type and size of HRUs stream flow predicted was higher when SSURGO was used compared to STATSGO. SSURGO predicted less stream loading than STATSGO in terms of sediment and sediment-attached nutrients components, and vice versa for dissolved nutrients. When compared to mean daily measured flow, STATSGO performed better relative to SSURGO before calibration. SSURGO provided better results after calibration as evaluated by R^2 value (0.74 compared to 0.61 for STATSGO) and the Nash-Sutcliffe coefficient of Efficiency (NSE) values (0.70 and 0.61 for SSURGO and STATSGO, respectively) although both are in the same satisfactory range. Modelers need to weigh the benefits before selecting the type of data resolution they are going to use depending on the watershed size and level of accuracy required because more effort is required to prepare and calibrate the model when a fine resolution soil data is used.

Keywords: SWAT model; STATSGO; SSURGO; Water quality; Stream flow; Sediment; Nutrients

1. Introduction

Soil physicochemical information is one of the crucial inputs needed to assess the impacts of existing and alternative agricultural management practices on water quality. Assuming that there are no significant impacts from other factors that control soil hydrodynamics such as crusting in sandy soils and micro-aggregation in clay soils, sandy soils allow a high rate of water infiltration and produce less runoff while soils consisting of poorly drained clay soils allow a low infiltration and produce more runoff (Haan et al., 1994). Soil properties also influence sediment and nutrient loading to streams. Thus, it is important to evaluate the effects of the spatial scale at which the soil database is developed. In the United States, State Soil Geographic database (STATSGO) and Soil Survey Geographic database (SSURGO) are the most commonly available soil databases. Because soil data sets may yield different results in water-quality predictions, it is important to consider this important issue when developing Total

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Maximum Daily Loads (TMDLs) for impaired watersheds where conflicting interests of stakeholders may opt for different soil data sets. STATSGO and SSURGO developed by the Natural Resources Conservation Agency (NRCS) are digital soil databases that are used in most water-quality simulation models to derive soil input data. The STATSGO maps are compiled by the NRCS through generalizing more detailed soil survey maps, often county level soil maps that are at the scale of SSURGO (USDA-NRCS, 1995). Where SSURGO-level maps are not available, data on geology, topography, vegetation, climate, and Landsat images of the area are used to generate STATSGO maps.

The mapping scale for STATSGO is 1:250,000 (USDA, 1994). The base map used is the US Geological Survey 1:250,000 topographic quadrangles. The number of soil polygons per quadrangle map is between 100 and 400. SSURGO is the most detailed level of soil mapping. Maps are made at scales ranging from 1: 15,840 to 1: 31,680 (Kroner and Cozzie, 1999). The smallest soil map unit represented in STATSGO is about 6.25 km^2 (625 ha), whereas it is about 0.02 km^2 (2 ha) in the SSURGO database. In this study, the two spatially different soil databases (STATSGO and SSURGO) have been used to determine the effect of scale on stream flow and water quality.

STATSGO soil data is available throughout the United States. However, not all areas have SSURGO data in digital format. NRCS expects completion of the SSURGO data digitizing by 2008 (USDA, 2006). For this reason, very few studies have considered the effect of spatial scale on water quality when soil input is derived at different spatial resolution. Besides, not all hydrology and water-quality models are compatible with SSURGO data. For instance, the SSURGO in its standard format is incompatible for use within Soil and Water Assessment Tool (SWAT) especially with ArcView SWAT (AVSWAT) version 2000 (Peschel et al., 2003). A pre-processor extension for the AVSWAT model (SSURGO SWAT 2.0) was developed by Peschel et al. (2003). SSURGO database is included in the current version of SWAT (AVSWATX 2003) although digital SSURGO data is limited especially in western United States. In addition, because there may be thousands of SSURGO units in a watershed, using SSURGO data that is not digitized is not usually practical for watershed modeling studies.

Soil surveys use map unit boundaries across which observed differences are significant and within which the soil is relatively homogeneous. However, there is heterogeneity within soil map units. Thus, map unit in all soil surveys includes other soil components that are not identified in the map unit either because they are too small to be delineated separately at a given soil survey scale or deliberately included in delineations of another map unit to avoid excessive detail in the map (Soil Survey Division Staff, 1993). These inclusions reduce the homogeneity or purity of map units and often affect interpretation or modeling. Lin et al. (2005) assessed soil spatial variability at multiple scales. They demonstrated that soil spatial variability is a function of map scale, spatial location, and specific soil property. They used a measure of spatial of soil variability within a map unit termed map unit purity. In general, area weighted map unit purity decreased with decreasing map scale.

Modeling studies have been conducted to evaluate the effect of soil data resolutions on stream flow and water-quality predictions. Chaplot (2005) evaluated the impact of DEM mesh size and soil map scale on SWAT runoff, sediment, and NO_3 predictions. The study indicated that there might be no significant increase in the accuracy of models, as a result of more precise topographic or soil information, which increases the input data collection and preparation. The study used different map scales (1/25,000; 1/250,000, and 1/500,000 scale) within the SWAT to simulate runoff, sediment, and NO_3 load. For runoff, few differences existed between the map scales. In contrast, the scale of the soil input maps greatly affected nitrogen as well as sediment loads. The 1/250,000 and 1/500,000 maps significantly decreased the mean monthly N load. For all DEM mesh sizes, the finest soil information enhanced the prediction quality for runoff, nitrogen and sediment loads.

Another study on DEM grid resolution by Zhang and Montgomery (1994) showed that DEM grid size significantly affects topographic parameters. The finest resolution DEM (10 m) provided better results than a 30 m and 90 m data. Brown et al. (1993) investigated response of Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS) to variations in soil, terrain, and land cover data aggregation levels. Soils, land cover, slope angle data were generalized by assigning a class value occupying the majority of the area with in an aggregation unit to all cells within the unit. The study concluded that the magnitude of change in the model out puts due to aggregation depends on the spatial dependence of the input variables. The degree of spatial dependence within the input variables had an influence in the results.

Levick et al. (2004) compared Food and Agricultural Organization (FAO) soils with STATSGO and SSURGO at the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Walnut Gulch Experimental Watershed in Arizona using the Kinematic Runoff and Erosion Model (KINEROS2). The study showed that runoff using STATSGO soils were generally higher than with SSURGO. In most cases, FAO soils data produced less runoff than STATSGO soils, although it produced more runoff than SSURGO soils about half the time. The differences in runoff and soil properties were attributed to the difference in data resolution.

Peschel et al. (2003) developed and applied SSURGO SWAT 2.0 extension to Leon Creek Watershed in Texas to compare the effect of soil data resolution on stream flow. In this study, unlike the finding by Levick et al. (2004) total flow obtained using SSURGO soil data was higher than flow obtained using STATSGO data. It was determined