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Autocalibration in hydrologic modeling: Using SWAT2005 in small-scale watersheds

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Abstract

SWAT is a physically based model that can simulate water quality and quantity at the watershed scale. Due to many of the processes involved in the manual- or autocalibration of model parameters and the knowledge of realistic input values, calibration can become difficult. An autocalibration-sensitivity analysis procedure was embedded in SWAT version 2005 (SWAT2005) to optimize parameter processing. This embedded procedure is applied to six small-scale watersheds (subwatersheds) in the central Texas Blackland Prairie. The objective of this study is to evaluate the effectiveness of the autocalibration-sensitivity analysis procedures at small-scale watersheds (4.0–8.4 ha). Model simulations are completed using two data scenarios: (1) 1 year used for parameter calibration; (2) 5 years used for parameter calibration. The impact of manual parameter calibration versus autocalibration with manual adjustment on model simulation results is tested. The combination of autocalibration tool parameter values and manually adjusted parameters for the 2000–2004 simulation period resulted in the highest E_{NS} and R^2 values for discharge; however, the same 5-year period yielded better overall E_{NS}, R^2 and P-values for the simulation values that were manually adjusted. The disparity is most likely due to the limited number of parameters that are included in this version of the autocalibration tool (i.e. Nperco, Pperco, and nitrate). Overall, SWAT2005 simulated the hydrology and the water quality constituents at the subwatershed-scale more adequately when all of the available observed data were used for model simulation as evidenced by statistical measure when both the autocalibration and manually adjusted parameters were used in the simulation.
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Keywords: SWAT; Hydrologic modeling; Autocalibration; Watershed; Nutrients; Sediment

1. Introduction

Public concern regarding the degradation of water quality due to nonpoint sources and point sources has driven policy regulators to scrutinize land management practices and examine how water quality conditions can be improved. Agricultural practices are commonly regarded as being sources of water and soil contamination (Sharpley, 1995; Abbozzo et al., 1996; Burkholder et al., 1997). Land application of manure provides nutrients and organic matter that enhance crop growth and can improve soil physical properties; however, when applied in excess, runoff from manured lands can result in the impairment of nearby water resources. Phosphorus (P) is a recognized contaminant that can cause adverse conditions in surface waters (Sharpley et al., 1994; Grobbelaar and House, 1995; Sims et al., 1998; Daniel et al., 1998).

Environmental regulation has expedited the necessity of agricultural producers to design and implement more environmentally suitable practices. There is a need to identify critical nutrient and their loss/transport potentials. Computer models can simulate multiple watershed management scenarios that can help environmental policy managers make decisions that could ultimately reduce P and N loss from agricultural lands. Models are inexpensive tools that can identify optimum watershed management practice scenarios for pollutant transport reduction.

Limited monitoring data exist at the watershed-scale for poultry litter application sites due to naturally inherent

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Notations

c threshold for a ‘‘good’’ parameter
$\theta*$ parameter set
p free parameters

complexities such as rainfall variation, the requirement for a large amount of land, and the equipment and personnel required for data collection (Harmel et al., 2003a,b; Gilley and Risse, 2000). Long-term watershed monitoring data are rare due to the expense involved (Santhi et al., 2006); however, long-term simulations are needed to account for the inherent environmental variability (Rao et al., 2007). The ability of water quality models to accurately estimate environmental impacts from manure application needs to be determined.

Grayson et al. (1992) provided guidelines for analyzing any model which included testing measured data against simulated data and for a model's hydrologic processes to be tested over a wide range of watersheds and conditions, with both positive and negative results reported (Arnold et al., 1999; Chu and Shirmohammadi, 2004; and Rosenthal et al., 1995). Small-scale watershed studies have been conducted by Fohrer et al. (2001) and Srinivasan et al. (2005) at 26 and 39.5 ha, respectively. Fohrer et al. (2001) successfully analyzed the SWAT model (Arnold et al., 1998; Arnold and Fohrer, 2005) model for sensitivity to crop parameters and land use change. These studies are considered ‘‘small-scale’’ due to the relative size of watersheds that have been simulated with SWAT.

Barlund et al. (2007) used the SWAT model in a Finnish catchment to assess its usefulness to evaluate management impacts, such as nutrient load reductions. While the model proved its worthiness, it also demonstrated the necessity to adequately parameterize, calibrate and validate the model. These authors identify the need to include a parameter sensitivity analysis to concentrate on the more influential parameters that impact calibration. Krysanova et al. (2007) and Rao et al. (2007) agree with the previous authors that there is a demonstrated need for powerful calibration and validation techniques for hydrological models. In addition, there is a need to identify the criteria to achieve an adequate validation, which is based on sensitivity and uncertainty analyses to determine the most influential parameters and evaluate the model's uncertainty in relation to input data. Miller et al. (2007) emphasize the importance of the process used for parameter estimation; the higher the degree of spatial variability, the greater the complexity of correctly estimating parameter values.

This study evaluates the SWAT model's autocalibration-sensitivity analysis embedded procedures to simulate the stream discharge, sediment, organic nitrogen (N) and P, soluble P, and nitrate-N (NO_3-N) loss after poultry litter application to small-scale agricultural land at a research site in central Texas. The periods of calibration and validation are also tested to emphasize the impact that the calibration time period has on model autocalibration results. The purpose of applying the SWAT model to these subwatersheds is to test if the autocalibration-sensitivity procedures embedded in SWAT2005 can be applied to small-scale watersheds (4.0–8.4 ha) resulting in realistic output.

2. SWAT model background

The SWAT model is a continuation of modeling efforts by the U.S. Department of Agriculture Agricultural Research Service (USDA ARS; Arnold et al., 1998; Arnold and Fohrer, 2005) and has become an effective means for evaluating nonpoint source water resource issues (flow, sediment, and nutrients) for a large variety of national and international water quality applications. The model is part of the U.S. Environmental Protection Agency (USEPA) Better Assessment Science Integrating Point & Nonpoint Sources (BASINS) software package (Di Luzio et al., 2002) and is being used by many U.S. federal and state agencies. For example, SWAT has been used to validate flow, sediment and nutrients in the Bosque River Watershed in Texas for Total Maximum Daily Load (TMDL) analyses (Srinivasan et al., 1998; Santhi et al., 2001a). The SWAT model is one of the models selected by the U.S. Department of Agriculture Conservation Effects Assessment Project (CEAP) established in 2003 by the Agricultural Research Service and the Natural Resources Conservation Service to measure environmental impacts of conservation efforts at the national and benchmark watershed scale (Mausbach and Dedrick, 2004).

SWAT is a continuous time watershed-scale model that operates on a daily time step. The model is physically based, uses readily available inputs, is computationally efficient for use in large watersheds, and is capable of simulating long-term yields for determining the impact of land management practices (Arnold and Allen, 1996). Components of SWAT include: hydrology, weather, sedimentation/erosion, soil temperature, plant growth, nutrients, pesticides, and agricultural management. SWAT simulates the organic and mineral N and P fractions by separating each nutrient into component pools, which can increase or decrease depending on the transformation and/or the additions/losses occurring within each pool. A mass balance is calculated on a daily time scale to capture the series of changes addressed through the respective processes' equations. Neitsch et al. (2002a,b) describe the details of the nutrient process equations.

SWAT contains several hydrologic components (surface runoff, ET, recharge, and stream flow) that have been developed and validated at smaller scales within the EPIC, GLEAMS and SWRRB models. Interactions between surface flow and subsurface flow in SWAT are based on a linked surface–subsurface flow model developed by Arnold et al. (1993). Characteristics of this flow model include non-empirical recharge estimates, accounting of percolation, and applicability to basin-wide management assessments with a multi-component basin water budget. Surface runoff volume and infiltration are computed with the curve number equations or Green and Ampt. The peak rate component uses Manning's formula to determine the watershed time of concentration and considers both overland and channel flow. Lateral subsurface flow can occur in the soil profile from 0–2 m, and groundwater flow contribution to total streamflow is generated by simulating shallow aquifer storage (Arnold et al., 1993). Flow from the aquifer to the stream is lagged via a recession constant derived from daily streamflow records (Arnold and Allen, 1996).