Journal of Hydrology (2007) **332**, 456–466

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

Sensitivity analysis and identification of the best evapotranspiration and runoff options for hydrological modelling in SWAT-2000

N. Kannan [a,*], S.M. White [b], F. Worrall [c], M.J. Whelan [d]

[a] *Blackland Research and Extension Centre, Texas A&M University, 720, East Blackland Road, Temple, TX 76502, USA*
[b] *Institute of Water and Environment, Cranfield University, Silsoe, MK45 4DT Bedfordshire, UK*
[c] *Department of Earth Sciences, University of Durham, DH1 3LE County Durham, UK*
[d] *Safety and Environmental Assurance Centre, Unilever Colworth Laboratory, Sharnbrook MK44 1LQ, Bedfordshire, UK*

Received 18 December 2005; received in revised form 1 August 2006; accepted 2 August 2006

KEYWORDS
SWAT;
Hydrological modelling;
Colworth;
Curve number (CN);
Sensitivity;
Stream flow

Summary Distributed models used in hydrological modelling, have many parameters. To get useful results from the model, every parameter is required to have a sensible value. Usually a calibration is undertaken to reduce the uncertainties associated with the estimation of model parameters. To ensure efficient calibration, a sensitivity analysis is conducted to identify the most sensitive parameters. This paper describes simple and efficient approaches for sensitivity analysis, calibration and identification of the best methodology within a modelling framework. For this study, the SWAT-2000 model was used on a small catchment of 141.5 ha in the Unilever Colworth estate, in Bedfordshire, England. Acceptable performance in hydrological modelling, and correct simulation of the processes driving the water balance were essential requirements for subsequent pesticide modelling. SWAT gives various options for both evapotranspiration and runoff modelling. Identification of the best modelling option for these processes is a pre-requisite to achieve these requirements. As a first step, a sensitivity analysis was conducted to identify the sensitive parameters affecting stream flow for subsequent application in stream flow calibration. Hydrological modelling has been carried out for the catchment for the period September 1999 to May 2002 inclusive using both daily and sub-daily rainfall data. The Hargreaves and Penman-Montieth methods of evapotranspiration estimation and the NRCS curve number (CN) and Green and Ampt infiltration methods for runoff estimation techniques were used, in four different combinations, to identify the combination of methodologies that best reproduced

* Corresponding author. Tel.: +1 254 774 6122; fax: +1 254 774 6001.
E-mail address: kannan@brc.tamus.edu (N. Kannan).

doi:10.1016/j.jhydrol.2006.08.001

the observed data. In addition, as the initial calibration period, starting in September 1999, was substantially wetter than the following corresponding validation period, the calibration and validation periods are interchanged to test the impact of calibration using wet or dry periods.

Introduction

Use of physically based or conceptual, distributed parameter models has become increasingly popular to address catchment and higher level water resource management problems. These models use many different parameters whose values vary widely in space and time. To reduce the uncertainties posed by the variation of model parameters, a calibration process becomes necessary. In addition, access difficulties for measurement of parameters and budget constraints for the project increase the difficulty of working with models (Lenhart et al., 2002). Hence a modeller relies heavily on calibration of the model selected for addressing a problem. For models with several parameters, such as the 'Soil and Water Assessment Tool (SWAT)' (Arnold et al., 1993; Gassman et al., 2006), the catchment modelling tool used in this study, a successful and efficient trial and error calibration is practically impossible. In recent years, complex automated calibration procedures have been successfully used for hydrological modelling with SWAT (Van Griensven and Bauwens, 2003; Van Griensven and Meixner, 2003; Van Griensven et al., 2002; Eckhardt and Arnold, 2001). However, due to the number of simulations required, time taken and computational requirements, the use of such automated calibration procedures is not widespread. Addressing this problem, a trade-off between simplicity and automation of calibration is attempted and described in this paper.

Vandenberghe et al. (2001) highlighted ''the complementarity of the sensitivity analysis and the parameter calibration''. Thus, a sensitivity analysis is usually the first step towards model calibration because it answers several questions such as; (a) where data collection efforts should focus; (b) what degree of care should be taken for parameter estimation; and (c) the relative importance of various parameters (Cho and Lee, 2001). A sensitivity analysis also identifies the most sensitive parameters, which ultimately dictates the set of parameters to be used in the subsequent calibration process. There are different methods available for carrying out sensitivity analyses and expressing their results (e.g. Van Griensven et al., 2006; Van Griensven and Meixner, 2003; Van Griensven et al., 2002; Lenhart et al., 2002). Some methods use a percentage change in input and report a corresponding change in output variables. This is not always suitable for parameters such as saturated hydraulic conductivity and curve number (CN). Hydraulic conductivity can vary over several orders of magnitude and a 10% variation of a CN value in hydrologic soil group C can lead to a CN value in soil group B or D (Neitsch et al., 2001a). Therefore increasing all the parameter values by a certain percentage for a sensitivity analysis is undesirable. Some other methods use an increase or decrease in a certain proportion and record the changes observed. This is also unsuitable because the parameters such as available water capacity (expressed as depth of water available/unit depth of soil) normally assume very small values, and a small change in that parameter will result in a considerable change in output variables. Therefore the variation of values for a particular parameter for sensitivity analysis has to be in accordance with the range appropriate for that parameter. This concept is emphasized in the study described here. The primary focus of this paper is the development of a simple, minimal-effort semi-automated approach for sensitivity analysis and calibration with the SWAT modelling tool.

Study area

The study area (Fig. 1) is located at Sharnbrook, Bedfordshire, UK (in an area bounded by National Grid References SP 495000, SP 263000 SP 499000, and SP 263000). The total catchment area is 141.5 ha. The predominant soil series is Hanslope, consisting of clay loam soil over stony, calcareous clay (1:25000 outline soil map R112 TL14; http://www.silsoe.cranfield.ac.uk/nsri/services/publicationslist.pdf (Last accessed: April 24, 2006); http://www.silsoe.cranfield.ac.uk/nsri/services/cf/gateway/pdf/bibliography.pdf (Last accessed: December 16, 2005). A group of eight fields forming approximately half of the catchment area is directly controlled by Unilever under their ''sustainable agriculture programme''. A rotation of wheat, oil seed rape, grass, beans and pea crops is implemented. Different pesticides and cropping patterns are being tested in these fields with the objective of reducing pesticide loss to the outlet stream whilst maintaining crop yield. All eight fields have extensive drainage systems, mostly installed during the 1960s, using clay tile drains at an approximate spacing of 40 m with gravel backfill. Secondary drainage treatments are a mixture of mole drainage and sub-soiling. All field drains eventually discharge into the main stream, which runs through the centre of the study area. The remaining part of the catchment consists of a mixture of arable fields, woodland, grass and concrete areas.

Data availability

Soil horizon data with key physical and chemical properties such as land-use group, depth of horizon, percentage of sand, silt, clay, organic carbon, bulk density, saturated hydraulic conductivity and water content at different tension values for each horizon were obtained from the National Soil Resources Institute database (http://