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Simulation modeling for water governance in basins based on surface water and groundwater

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ABSTRACT

Accelerating future water shortages in the world require a development of operational water governance models as illustrated by the case studies. Conversion process and its coupling simulation of surface water and groundwater are the foundation of water resources development, utilization, and scientific evaluation. In order to simulate the impact of climate change on the water cycle in basins, the quasi-distributed watershed Surface Water (SW) model was coupled with the fully-distributed Ground Water (GW) model in the simulation. The Hydrologic Response Units (HRU) in the SW model were exchanged with cells in the GW model. By using the HRU–CELL conversion interface, the distributed groundwater recharge rate (RCH) and the groundwater evapotranspiration (EVT) calculated by the SW model were imported into the RCH and EVT modules of the GW model. The application of groundwater simulation in the Heihe River basin demonstrated that the correlation coefficient between the simulation results and the measured values was 0.89, the deterministic coefficient of the simulation results was 0.86. Under future predictions the discharge from the Heihe River will decrease in the first 20 years (2020–2039). In the later 20 years (2040–2059) the discharge will increase. The simulation groundwater along with the recharge value showed the same change trend of the measured groundwater level. The coupled SW–GW model was capable of predicting the future water cycle.

1. Introduction

Water-related problems are location-specific and diverse. The ideal condition of having the appropriate amount of good-quality water at the desired place and time is most often not satisfied. The broad concept of integrated water resources management has been advocated over a long time, because so many different problems need to be solved (Droogers and Bouma, 2014). Recently, integrated water resources management has been expanded by integrating all water resources, including surface water (SW) and ground water (GW).

A substantial number of studies has been undertaken during the last two decades related to integrated SW and GW management. Due to various conditions, many previous simulation studies separated the SW and GW. With technological development and social progress, coupling of SW and GW is feasible. In the hydrological system, SW and GW are not independent of each other (Yu and Rui, 2007). The coupled-modeling concepts and theoretical framework of watershed scale hydrological response were first proposed by Freeze and Harlan (1969). Pikul et al. (1974) found that the coupled one-dimensional Richards equation could accurately simulate the groundwater level. Li et al. (2008b) used the HydroGeoSphere model to analyze the coupling simulation of GW and SW systems in Toronto, Canada. Hu et al. (2007) summarized and analyzed the domestic and international SW–GW coupling models in China. However, due to their different simulation mechanisms and scope, there are significant differences between the various models. In general, model structure is very complex, and requires many parameters and input data. Model building and calibration are also very time-consuming, which limits their application.

Relevant basin information from reliable data is essential to assess not only the current condition of water resources but also past trends and future possibilities in a given basin. To explore

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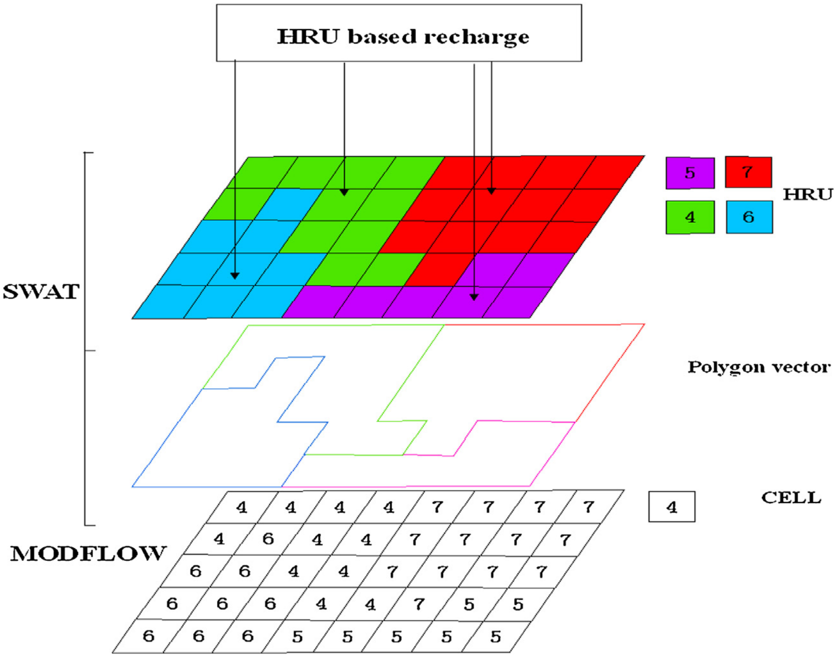

Fig. 1. Schematic diagram of recharge computation in SWAT–MODFLOW.

options for the future, Simulation models are needed to predict future water cycles that can explore the impact of future trends and possible ways for sustainable adaptation.

Because water shortages have adverse effects on eco-environmental quality, it is necessary to develop operational water governance practices. This can not only contribute towards improving existing practices, but to also develop innovative new practices which can increase water productivity. This needs to be expanded to make modeling a central and indispensable tool in decision-making processes of policy makers and stakeholders.

Current hydrological studies tend to focus too much on theoretical aspects and do not adequately address questions raised by policy makers and stakeholders. Policy makers need reliable simulation models so that decisions can be made based on realistic predictions. The objectives of this study are to (1) analyze the model selection process for given applications; and (2) predict the water cycle and future water resource dynamic change in Xi'an Heihe River basin using Ground Penetrating Radar (GPR) technology within the coupled SW–GW modeling system. The study is crucial for 8,000,000 citizens' water supply in Xi'an City Shaanxi province, China. It is also the key for effective regional water resources conservation and sustainable use. To our knowledge, this is the first attempt to combine the SW–GW model for the urban water resources area in northwest China to assess the effects of future climate change on river runoff. This paper will argue that the SW–GW model should be added to the methods to achieve successful water governance. The scientific community can help to define policy for the stakeholder and policy makers. This would result in more effective use of water regulating agencies. Better communication is needed with water regulating agencies so that their needs can be better met. In addition, this study will help to provide useful information for all of the Heihe River basin.

2. Materials and methods

2.1. Simulation models

The Soil and Water Assessment Tool (SWAT) model is a quasi distributed watershed hydrological model that is based upon well defined physical mechanisms (Li et al., 2013). In the SWAT model, a watershed is divided into multiple sub-basins. In each sub-basin, according to the different land use, soil type and slope, each sub-basin is then divided into one or more Hydrological Response Units (HRUs) with the same surface features. As HRUs are the basic computing unit of the model, each HRU calculation results are accumulated within the basin area, and routed to tributaries; finally, results at the river exit are obtained by river confluence calculations.

MODFLOW is a physically based and widely used model for layered aquifer systems, combining Darcy's law and the mass balance for subsurface flow. It can simulate confined, unconfined, leaky, delayed yield, and variably confined/unconfined conditions, MODFLOW is able to represent a number of aquifer conditions. Both transient conditions and steady state can be simulated. The model can account for all the common boundary conditions generally encountered in practice. These include pressured or fixed heads, groundwater recharge/discharge, variable or constant fluxes, point withdrawals, and drain (Osman and Bruen, 2002).

Recharge and evaporation parameters directly affect results of the groundwater dynamic simulation, and it is often difficult to accurately calculate these parameters. According to the characteristics of the distributed SWAT model, through HRU corresponding to the difference MODFLOW grid (CELL), building the interactive interface of SWAT–MODFLOW, recharge and evaporation parameters can be transmitted directly from SWAT to MODFLOW model. This is a very good method to deal with the problems of the parameter values transmitting between two different models. ArcGIS software can be used to import the value of recharge and evaporation from SWAT model to the sub-modules of groundwater recharge (RCH) and groundwater evapotranspiration (EVT) in MODFLOW. GPR technology was used to gain the measured data for testing the simulation results in Xi'an Heihe River basin.

The application of GPR measuring groundwater depth was one of the hot issues and difficult problems of non-destructive testing theory and technology research; it is not only related to the electromagnetic wave propagation in inhomogeneous media, and also closely related to the modern signal processing technology. A versatile full-range GPR System (A MALÅ ProEx) based on cutting-edge