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Modeling climate change impacts — and uncertainty — on the hydrology of a riparian system: The San Pedro Basin (Arizona/Sonora)

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Summary An assessment of climate change impacts in the water resources of a semi-arid basin in southeastern Arizona and northern Sonora is presented using results from an ensemble of 17 global circulation models (GCMs) and four different climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC). Annual GCM precipitation data for the region is spatially downscaled and used to derive spatially distributed recharge estimates in the San Pedro Basin. A three dimensional transient groundwater-surface water flow model is used to simulate the hydrology of the current century, from 2000 to 2100, under different climate scenarios and model estimates. Groundwater extraction in the basin was maintained constant and equal to current. The use of multiple climate model results provides a highest-likelihood mean estimate as well as a measure of its uncertainty and a range of less probable outcomes. Results suggest that recharge in the San Pedro basin will decrease, affecting the dynamics of the riparian area in the long term. It is shown that mean net stream gain, i.e. base flow, will decrease and the effects on the riparian area could be significant. The results of this work provide a basis for the

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inclusion of representative climate scenarios into the basin's existing decision support system model.

Introduction

In the last century, massive industrialization and the extended use of fossil fuels have lead to a great increase in the atmospheric concentrations of greenhouse gases. Population growth, industrial development, and agriculture are causing major societies to face serious challenges in allocating scarce water resources to increasing demands. Because human development is affecting global climate dynamics and changing land atmosphere interactions at unprecedented scales (IPCC, 2001), an assessment of the long term impacts of climate change on water resources is essential to plan for future management strategies. Current water resources management systems are relatively effective in handling inter-annual variability. However not enough consideration has been given to long term trends until climate change impacts began to be felt as a challenge with a significant immediacy.

This paper presents a methodology to quantify climate change impacts on the water budget and dynamics of a riparian stream-aquifer system in a semi-arid region, from years 2000 to 2100, providing a measure of the uncertainty in the results. Climate change estimates corresponding to emissions scenarios defined by the Intergovernmental Panel on Climate Change (IPCC) have been used. The methodology has been applied to the transboundary San Pedro Basin in Arizona/Sonora (US/Mexico) with aims of including the impacts of representative climate scenarios into the Decision Support System (DSS) developed for policy and decision making in the basin. This will allow the water managers in the basin to evaluate strategies to cope with a changing water balance under future scenarios.

While a broad range of literature exists regarding regional climate forecasting using global circulation models (GCM) and downscaling techniques to assess hydrologic impacts, these often focus on relatively short lead times and use daily time steps. A significant number of papers deal with particular events throughout the year, such as low flows, peak flows, extreme events, and changes or shifts in seasonal processes. However, few publications seem to focus on the long term evolution of a basin's water balance due to climate change impacts on regional hydrologic processes. Yet this may be the most beneficial application of hydro-climatology to support long term water resources management and planning. While short term forecasts of regional precipitation may be very useful to foresee availability constraints for the following seasons, predictions on the long term evolution of the water budget of a riparian system are the basis for strategic planning.

Loaiciga et al. (2000), assess climate change impacts in a regional karst aquifer using diverse historical time series — extreme shortage, near average and above average recharge — scaled for $2\times CO_2$ conditions. Climate scenarios generated using one GCM (GFDL R30) were used to simulate aquifer impacts with different pumping rates with a finite-difference groundwater model. Results are then compared to a lumped parameter groundwater model run with climate-forcing data from six other GCMs and using historical pumping rates. The study concludes by proposing reduced pumping rates for the future to minimize impacts on spring discharge and aquifer levels under $2\times CO_2$ climate conditions.

Jiang et al. (2007), compare the results of six hydrologic models simulating the hydrological impacts of climate change in the Dongjiang Basin in South China, which provides about 80% of Hong Kong's annual water supply. The hydrological models are first run using historical climate data to simulate current water balance components. Then, they are run using *hypothetical* climate change scenarios to simulate its impacts on hydrology and evaluate how diverse the results from each model are. While the models performed similarly when simulating the historical period, greater differences occurred in the simulated hydrologic impacts using future climate projections. The main differences in the six hydrological models lie in the conceptual representation of streamflow, evapotranspiration and soil moisture balance. While the approach by Jiang et al. (2007) is a very valid one to quantify sensitivity of results to hydrological model structure, some model's conceptual representations may be more appropriate than others for a particular region and climate.

Scibek and Allen (2006) model the impacts of future climate change on recharge and groundwater levels of the Grand Forks aquifer, attempting to evaluate the importance of the spatial distribution of recharge and identifying uncertainties in the modeling process from global climate predictions to local hydrologic impacts. Results from the Canadian Global Coupled Model (CGCM1) run for an IPCC climate change scenario (IS92a) are downscaled using SDSM (Wilby et al., 2002) and a principal component K- nearest neighbor algorithm (Zorita and von Storch, 1999; Yates et al., 2003). Change factors from the downscaling process were used to stochastically generate daily weather series with LARS-WG (Racsko et al., 1991; Semenov et al., 1998). Although precipitation was assumed to be uniform over the extent of the aquifer, *spatially distributed and temporally varying recharge zones* are modeled using EPA's Hydrologic Evaluation of Landfill Performance (HELP, Schroeder et al., 1994). Recharge was found to be most sensitive to the depth of the unsaturated zone and moderately sensitive to soil thickness and porosity. These recharge zones are then linked to a distributed MODFLOW hydrologic model of the aquifer. Groundwater levels were only influenced by recharge away from floodplain areas. Within floodplain areas, river levels are the main driver of water level fluctuations (Scibek et al., 2007). Sensitivity of recharge model results to spatially distributed recharge was higher compared to temporally varying recharge (variations of <10 cm). In general, it was found that water level differences between scenarios of recharge distribution were typically about 20 cm. A realistic representation of the spatial distribution has a more significant influence in the water balance than a temporal