Journal of Hydrology 521 (2015) 18–33

Contents lists available at ScienceDirect

Journal of Hydrology

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

Climate change and water resources management in the Upper Santa Cruz River, Arizona

Eylon Shamir [a,*], Sharon B. Megdal [b], Carlos Carrillo [c], Christopher L. Castro [c], Hsin-I Chang [c], Karletta Chief [e], Frank E. Corkhill [d], Susanna Eden [b], Konstantine P. Georgakakos [a,f], Keith M. Nelson [d], Jacob Prietto [b]

[a] Hydrologic Research Center, San Diego, CA, United States
[b] Water Resources Research Center, The University of Arizona, Tucson, AZ, United States
[c] Atmospheric Science Department, The University of Arizona, Tucson, AZ, United States
[d] Arizona Department of Water Resources, Phoenix, AZ, United States
[e] Soil, Water and Environmental Sciences, The University of Arizona, Tucson, AZ, United States
[f] Scripps Institution of Oceanography, University of California, San Diego, United States

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form 21 November 2014
Accepted 22 November 2014
Available online 29 November 2014
This manuscript was handled by Geoff Syme, Editor-in-Chief, with the assistance of Konstantine P. Georgakakos, Associate Editor

Keywords:
Rainfall generator
Santa Cruz River
Ephemeral streams
Water resources management
Climate change

SUMMARY

Episodic streamflow events in the Upper Santa Cruz River recharge a shallow alluvial aquifer that is an essential water resource for the surrounding communities. The complex natural variability of the rainfall-driven streamflow events introduces a water resources management challenge for the region. In this study, we assessed the impact of projected climate change on regional water resources management. We analyzed climate change projections of precipitation for the Upper Santa Cruz River from eight dynamically downscaled Global Circulation Models (GCMs). Our analysis indicates an increase (decrease) in the frequency of occurrence of dry (wet) summers. The winter rainfall projections indicate an increased frequency of both dry and wet winter seasons, which implies lower chance for medium-precipitation winters. The climate analysis results were also compared with resampled coarse GCMs and bias adjusted and statistically downscaled CMIP3 and CMIP5 projections readily available for the contiguous U.S. The impact of the projected climatic change was assessed through a water resources management case study. The hydrologic framework utilized includes a rainfall generator of likely scenarios and a series of hydrologic models that estimate the groundwater recharge and the change in groundwater storage. We conclude that climatic change projections increase the uncertainty and further exacerbate the already complicated water resources management task. The ability to attain an annual water supply goal, the accrued annual water deficit and the potential for replenishment of the aquifer depend considerably on the selected management regime.

1. Introduction

Meeting water demands in semi-arid and arid regions is a particularly challenging task in communities that rely on local water resources and who also lack the infrastructure for multi-year storage. Precipitation variability in these regions often consists of long dry spells with episodic wet events that replenish their reservoirs. This study focuses on the Upper Santa Cruz River (USCR) north of the border shared by Arizona in the United States (U.S.) and Sonora, Mexico (Fig. 1). In this region, the city of Nogales, Arizona and surrounding water users extract their water supply from a relatively shallow and small alluvial aquifer beneath the ephemeral channel of the USCR (Erwin, 2007). The main source of recharge to this aquifer is the highly variable intermittent rainfall-driven streamflow events on the USCR (Erwin, 2007), which implies that the natural variability of the river flow and the groundwater recharge are tightly linked (Liu et al., 2012; Nelson, 2010; Shamir et al., 2007a,b).

In this study, we demonstrate the usability of a hydrological modeling framework for decision making regarding groundwater pumping and addressing regional statutory management goals as applied to arid and semi-arid area. The modeling framework, based on the approach of Shamir et al. (2005, 2007a), was enhanced in this work to enable impact assessment of projected future rainfall scenarios, as interpreted from dynamically downscaled regional

* Corresponding author.
E-mail address: eshamir@hrcwater.org (E. Shamir).

http://dx.doi.org/10.1016/j.jhydrol.2014.11.062
0022-1694/

climate models. In the core of the modeling framework there is a weather generator that produces synthetic likely rainfall realizations. These realizations are used as input to simulate streamflow, channel routing, groundwater recharge and groundwater levels and to assess the impact of projected future changes in precipitation under different groundwater management scenarios.

An extensive stakeholder involvement process was deployed to inform the technical modeling. Stakeholders were engaged to raise water management issues and provide feedback and comments on the hydrologic modeling framework. Reliability of water supply and impacts of over pumping on groundwater levels and riparian corridors were identified as their most significant concerns.

To date, studies of future climate analysis that include in their domain the study area were mainly focused on broad regional and seasonal perspectives and extreme events (review is provided in Section 3). As demonstrated in Section 1.1, the wide regional perspective is often inadequate for describing the hydrologic response in the area studied herein. In the study area that represents many other semiarid and arid ephemeral environments, it is the high spatiotemporal resolution and the detailed characteristics of the rainfall that dominate the intermittent streamflow and groundwater recharge events. In this study we address this information gap and present a modeling framework that connects the future climate projections to the scale that is needed for a meaningful hydrologic impact assessment.

Perhaps the most important contribution of the present study is the detailed analysis of the important contributors that provide useful management information for arid and semi-arid regions, when it is necessary to incorporate climatic variability and change on small scales. The details of such analysis are very different from approaches that have focused on wetter regions (e.g., Georgakakos et al., 2012) whereby long term averages dominate water management decisions and where intermittence of management-significant events maintains a more or less uniform distribution throughout the records.

In the remainder of this section we discuss the approach followed for the hydrologic impact assessment. In Section 2 we describe the study area and its observed climate influences. In Section 3 we present a discussion of climate projections of future rainfall for the study area from the results of analysis of eight carefully selected dynamically downscaled regional climate models. In addition, we compare the results of the eight downscaled models to CMIP3 and CMIP5 readily available projections of coarse GCMs and statistically downscaled GCMs. In Section 4 we describe the hydrologic modeling framework and the incorporation of the climate projection results into the framework. A water resources

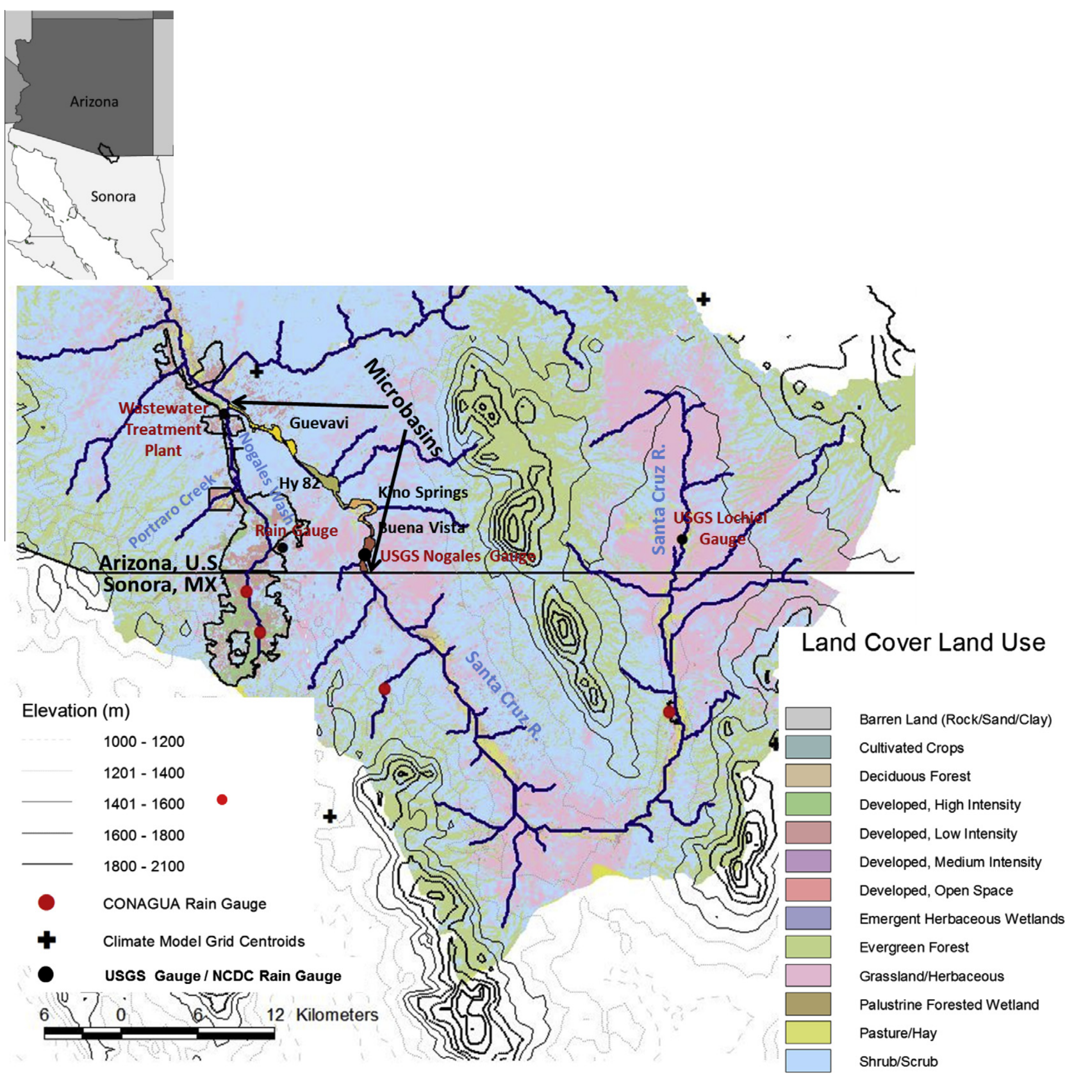

Fig. 1. Map of the study region.