Assessing Surface Water Availability in the Upper Santa Cruz Watershed

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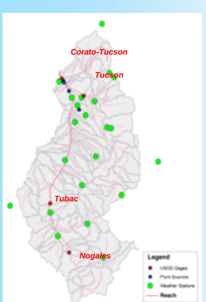
ABSTRACT

Given the growing demand for water and the likelihood of decreasing precipitation due to climate change, water availability has become a dominant issue in the semi-arid southwestern USA. In the upper Santa Cruz watershed (Arizona, USA and Sonora, Mexico), water availability has become a major concern due to a high population growth rate. In this study, the physically based distributed hydrological model, Soil and Water Assessment Tool (SWAT), was applied to assess surface water availability for this watershed. The model was calibrated and validated using twenty-two weather stations and four USGS gauging stations; the model was then applied to simulate spatial distribution of runoff for two landuse scenarios in year 1992 and 2001. Results indicate that urban expansion from 1992 to 2001 leads to the decrease of evapotranspiration and increase of surface runoff and water yield. In addition, calibration results suggest that simulation uncertainties may have been generated due to the application of non-representative metrological data. To address this issue, an ongoing study is being conducted to construct 4km x 4km gridded daily precipitation and temperature. Furthermore, to predict future water availability, the calibrated model will be applied to simulate runoff in subsequent decades using downscaled precipitation data derived from various climate scenarios and model estimates.

INTRODUCTION

In the southwest USA, future climate trends project a decrease in annual mean precipitation, an increase in annual mean temperature, and an increase in summer warming during the 21st century (Solomon et al. 2007). The low precipitation and high ET demand associated with hot-wet summers will dramatically decrease water supply in this region (Weiss et al. 2009). More specifically, continuous aridity trends will generate even more watershed issues where increased urban expansion and population growth are occurring, such as in the upper Santa Cruz watershed (Norman et al. 2009). To sustain water in this region, a study was performed to evaluate the surface water availability in the upper Santa Cruz watershed using a hydrological modeling approach. This study includes two steps: 1) simulate the spatial distribution of hydrological processes in the past; and 2) simulate runoff in subsequent decades using projected future climate scenarios.

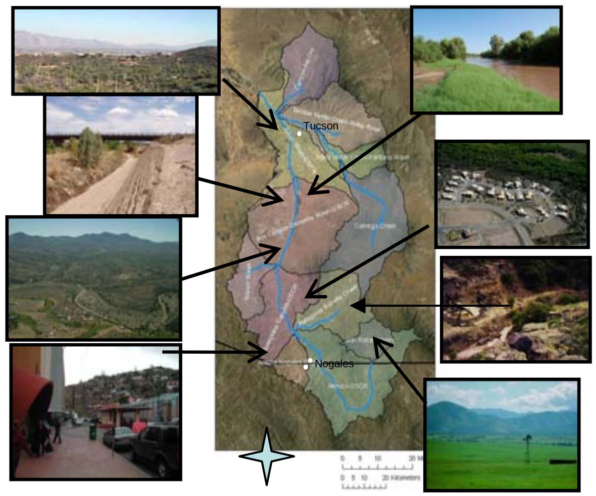
METHODS



The Soil and Water Assessment Tool (SWAT), a continuous, long-term, physically based distributed model, was used to assess impacts of land management and climate on hydrological processes for the upper Santa Cruz Watershed. The model was calibrated and validated at monthly time step for four USGS gages using 22 weather stations (Figure 1). Then, the calibrated model was used to simulate long-term (1960-2008) hydrological processes for two landuse scenarios at year 1992 and 2001derived from the U.S. - Mexico Border Environmental Health Initiative (BEHI) project (USGS). The only changes for the runs are land use, while DEM and soil were kept constant.

Figure 1. Location of weather stations, point sources, and USGS gages.

STUDY SITES



The Santa Cruz river originates in Arizona, flows south into Sonora , Mexico, and then flows north back into southeastern Arizona, USA (Figure 1). The upper Santa Cruz watershed has an area of about 9,073 km^2, and lies between latitude 31°02′ and 32°40′ N and longitude -111°18′ to -110°20′ W. Elevations in the watershed range from 496 to 2883 m, and annual rainfall ranges from 280 to 860 mm (valley to mountain). The dominant vegetation in the upper Santa Cruz watershed is desert shrub, the proportional extent of which is over 70% (USGS, BEHI). Other vegetation types include forest, grassland/pasture, agriculture, riparian and wetland (USGS, BEHI).

Urban lands use occupies over 5% of the watershed since 1992 (USGS, BEHI). The largest urban area in the watershed is Tucson with over a million people live in the metropolitan area and half million live within the city limits. The second largest city is Nogales, Sonora with over 300,000 people (Norman et al., 2009).

RESULTS -- CALIBRATION/VALIDATION

Table 1. Criteria for examing the accuracy of calibration and validation.

Index	Calibration (01/1988 - 12/1997)				Validation (01/1998 - 12/2007)			
	Outlet	Tucson	Tubac	Nogales	Outlet	Tucson	Tubac	Nogales
NS Coefficient	0.65	0.75	n.a.	0.53	0.55	0.30	0.69	0.59
R^2	0.79	0.82	n.a.	0.56	0.62	0.35	0.74	0.60

The calibration performance for SWAT model is considered satisfactory when NS>0.5 and R^2>0.5 (Moriasi et al., 2007). As shown in Table 1, all R^2 and NS values are above 0.50, except Tucson (0.35), indicating acceptable calibration. The low NS and R^2 values at the Tucson gage may be due to non-representative rainfall distributed in the drainage area for this gage. In addition, the simulated monthly streamflow largely matches the observation (Figure 3), suggesting that monthly streamflow can be described by the calibrated model. Thus, the SWAT model, set up with the optimal parameters, can be applied to evaluate spatial distribution of hydrological components.

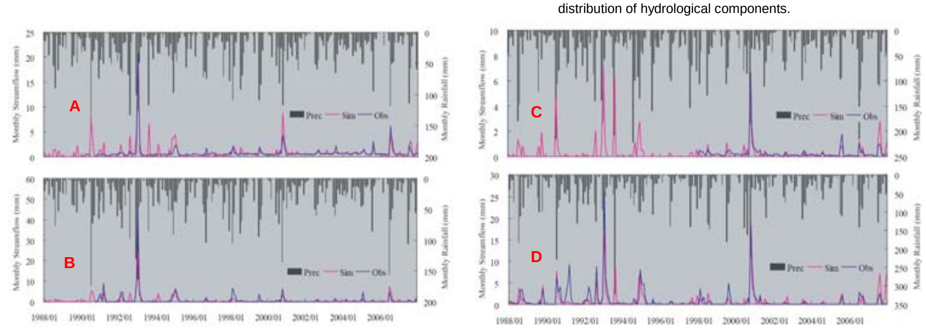


Figure 3. Monthly rainfall, and simulated and observed streamflow at four USGS gages.
A: Corato-Tucson gage ; B: Tucson gage; C: Tubac gage; and D: Nogales gage.

RESULTS -- SIMULATION

Table 2. Simulated annual average values, and relative changes for landuse scenarios in 1992 and 2001.

Hydrologic Process	mm 1992	mm 2001	mm 2001-1992	Percent 2001-1992
Evapotranspiration	379.8	378.7	***-1.10***	***-0.29***
Percolation	38.45	38.45	0.00	0.00
Surface Runoff	7.54	8.05	***0.51***	***6.76***
Baseflow	1.37	1.35	-0.02	-1.46
Water Yield	8.71	9.15	***0.44***	***5.05***

Cruz watershed from 1992 to 2001 (estimated from USGS, BEHI).

Landuse	Area (Hectare) 1992	Area (Hectare) 2001	Area (Hectare) 2001-1992	Percent 2001-1992
Developed	45782	66528	***20746***	***45.31***
Agriculture	8552	4657	-3895	-45.55
Forest	102297	98079	-4218	-4.12
Shrub	655382	652377	-3004	-0.46
Water	613	245	-368	-59.99
Barren	13007	14429	1422	10.93
Grassland/Pasture	67875	56284	***-11591***	***-17.08***
Wetland	42	951	909	2165.36

The average annual basin values of five hydrological processes are shown in Table 2. Compared to landuse scenario in 1992, the average evapotranspiration (ET) is 1.10 mm lower in 2001, decreased 0.29%. On contrary, the surface runoff and water yield in 2001 is 0.51 and 0.44 mm higher than 1992, enhanced 6.67% and 5.05%, respectively.

The decreased ET and increased surface runoff and water yield is due to landuse change. As shown in Table 3, the developed area increased 20746 hectare from 1992 to 2001, expanded 45.31% by replacing grassland, agriculture, forest, and shrub (USGS, BEHI). Urban expansion leads to the increase of impervious surfaces and consequently enhances the surface runoff and reduces plant transpiration (Franczy and Chang 2009).

According to the landuse dataset that were used from BEHI (USGS), the most significant landuse changes from 1992 to 2001 in the upper Santa Cruz Watershed was urbanization. Increase of surface runoff was simulated with urban expansion. The increased runoff is always considered as negative impacts in the watershed, because more sediment and erosion will be generated with higher runoff volume and velocity (Kepner et al., 2004).

In addition, model calibration results shows that the simulated streamflow peaks were not fully matched with observations. It may suggest that the high heterogeneity of rainfall may not be fully represented by weather stations applied in this study. To address this issue, an ongoing study is being conducted to construct gridded daily precipitation and minimum-maximum temperatures with 4km x 4km resolution using the methodology proposed by Di Luzio et al. (2008). In addition, USGS scientists are currently developing high-resolution land use maps for the watershed in a decadal time series starting in the 1980's through current day; additionally a growth model is being applied to these to simulate land use scenarios in the future. These landuse datasets will be retrofit into the calibrated model to get a more accurate representation of land use through time and ultimately be available thought the Santa Cruz Watershed Ecosystem Portfolio Model (SCWEPM; Norman et al. 2009).

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