SIMULATING STREAMFLOW UNDER A WARMING CLIMATE: IMPLICATIONS FOR ACEQUIA COMMUNITIES IN THE UPPER RIO GRANDE

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ABSTRACT

Over the next century, it is predicted that warmer temperatures and altered precipitation patterns in the Upper Rio Grande (URG) basin will have a deleterious effect on the seasonal accumulation of snowpack and the timing and duration of snowmelt. In Northern New Mexico, acequia communities situated at the outlet of snowmelt basins are particularly exposed to climate-induced changes in snowmelt runoff. In this paper, we assess the variability in climate-affected streamflow of four tributaries of the Rio Grande. Each tributary is an important source of surface water for acequia communities. We used the Snowmelt Runoff Model (SRM) to simulate runoff from 4 sub-basins for years when the annual volume of water produced was above the median annual value (1984-2013). This exercise yielded basin-specific model parameters that could be then applied in SRM simulations of snowmelt runoff under altered climate conditions. For 60 CMIP-3 and CMIP-5 general circulation models we determined central tendency and spread of projected changes in precipitation and temperature at two locations, comparing the period 1980-1999 with 2040-2069 and 2080-2099. For simulations of streamflow under a changed climate, we used data from those models which best represented hotter-dryer (HD), warmer-dryer (WD), hotter-wetter (HW) and warmer-wetter (WW) conditions. Our results suggest that in agreement with other studies, annual volume of runoff is closely tied to changes in precipitation amount, while peak flow timing is affected by warming temperatures. If there is sufficient snow accumulation, increasing temperatures result in earlier occurrence of peak springtime flows. With insufficient snow accumulation, the characteristic snowmelt hydrograph is lost entirely. In a warmer climate with wetter conditions, springtime peak flows occur earlier in the year, are of shorter duration and are of greater volume than historic flows. (KEYWORDS**:** Streamflow simulation, climate change, New Mexico, irrigation)

INTRODUCTION

Acequia is a term used primarily in Spain and former Spanish colonies to describe community-owned irrigation canals. Acequia communities are amongst some of the oldest communities in the United States that still practice traditional flood irrigation and low-intensity agriculture and as such there is strong historical justification for their preservation. However, acequias are much more than just a means of water delivery. Acequias have hydrological and ecological importance as well as social and political roles. For example, during irrigation season, water seepage from the earthen ditches recharges local groundwater and supplies moisture to the riparian ecosystem of the irrigated valleys (Fernald et al., 2008).

Acequia communities in the URG are often located in narrow valleys situated just below high-elevation, snowmelt runoff-dominated sub-basins. The seasonal snowpack that accumulates in these high-elevation sub-basins provides a natural reservoir for water storage, one whose release of water coincides with the growing season in the valley below. Climate change projections suggest that temperatures will increase over the 21st century and there will be more frequent and longer periods of drought, especially in the second half of the 21st century (Cayan et al., 2010). Warmer temperatures will lead to earlier snowmelt and drought will reduce snowpack. Changes in the timing of peak streamflow and reductions in the quantity of water available for irrigation are likely to have unfavorable consequences for acequia communities. It is our objective in this paper to explore for four sub-basins that supply water to acequia communities, (i) if SRM can satisfactorily model runoff from snowmelt for a moderately productive historical year and (ii) based on this historical year, how water supplies might change as a result of warming temperatures and changed precipitation.

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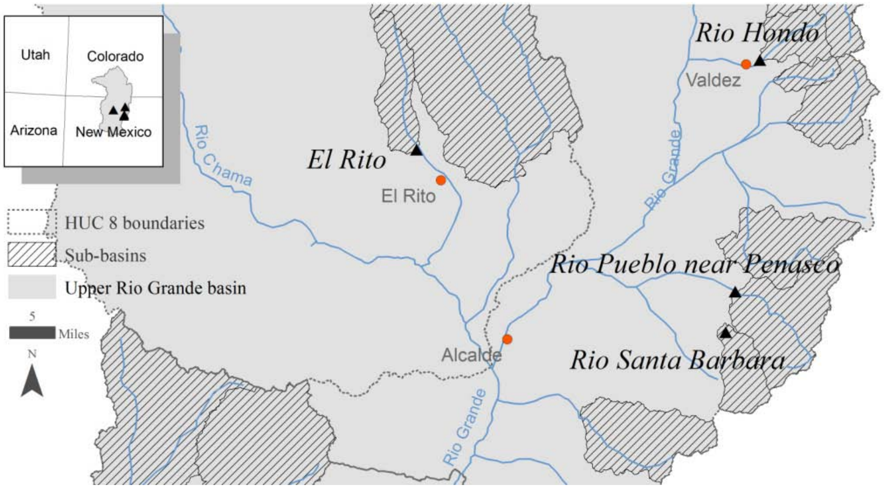
METHODS

Our study basins are located in the southern San Juan Mountains and Sangre de Cristo mountains in northern New Mexico (Figure 1). Elevations of these basins range from 2200 m to 4000 m. The basins are some of the smallest in the URG, but are vital sources of water for the communities of El Rito, Alcalde (Santa Barbara and Rio Pueblo) and Valdez (Rio Hondo) as well as other small farming communities in the vicinity.



Rio Hondo
Area: 96.12 km^2
Elevation: 2349-3992 m

Rio Pueblo near Peñasco
Area: 257.9 km^2
Elevation: 2384-3908 m

Rio Santa Barbara,
Area: 101.6 km^2
Elevation: 2956-3593 m

El Rito
Area: 129.2 km^2
Elevation: 2264-3246 m

Figure 1. Study basin location

There are two main stages to our methodology. First, we used the Snowmelt Runoff Model (SRM; Martinec et al., 2008) to simulate runoff under historical conditions; second, we used the SRM climate change module to simulate runoff under changed climate conditions. SRM (1) is a conceptual, degree-day model which computes average daily stream discharge (Q) from snowmelt and precipitation inputs from the preceding day (n).

$$Q_{n+1} = [c_{Sn} \cdot \alpha_n (T_n + \Delta T_n) S_n + c_{Rn} P_n] \cdot (A \cdot 10{,}000)/86{,}400 \cdot (1 - k_{n+1}) + Q_n k_{n+1} \quad (1)$$

Snowmelt is calculated from the product of fractional snow-covered area (S), the degree-day factor (α: cm °$C^{-1}d^{-1}$), zonal degree days (T+ΔT: °C d) and snowmelt losses defined by the snowmelt runoff coefficient (C_S). Precipitation is calculated from precipitation (P: cm) and precipitation losses defined by the rainfall runoff coefficient (C_R). The decline in Q during snowmelt- or precipitation-free periods is specified by the recession coefficient (k). The factor [(A·10,000)/86,400] converts Q from cm km^{-2} d^{-1} to m^3 s^{-1}. A full description of the input dataset is beyond the scope of this proceedings paper, therefore we have summarized the input data in Table 1.

Table 1. Input data

Variable	Source	Reference
Temperature, precipitation	National Cooperative Observer Network: COOP stations	NOAA, 2014
	National Water & Climate Center: SNOTEL stations	NRCS, 2014
Streamflow	USGS stream gauges	USGS, 2014a
Snow cover fraction	Landsat Thematic Mapper	USGS, 2014b
	In-house classification product	Steele et al., 2014

For the second stage of analysis, we used the basin-specific model parameters generated from historical SRM simulations and then applied mean annual temperature and precipitation changes in the WinSRM climate change module. Change values were derived from analysis of data from 60 CMIP-3 and CMIP-5 general circulation models that have been statistically downscaled using Bias-Correction Constructed Analogue datasets (Hidalgo et al., 2008; Reclamation, 2013). Data were further downscaled to Hopewell SNOTEL and Red River SNOTEL using double-statistical downscaling method (Mejia et al., 2012). Period change analysis was used to determine an envelope of variability for increases in mean annual temperature and increases or decreases in precipitation. We identified the climate projections that represented hotter-dryer, warmer-dryer, hotter-wetter, warmer-wetter and central tendency (ensemble mean) conditions between 1981-2000 and two future periods: 2046-2065 and 2081-2100 (Brekke, 2011).

RESULTS

Historical Simulations

To evaluate historical simulations, we compare (i) percent difference between measured and simulated annual runoff volume (D_v), measured and the Nash-Sutcliffe coefficient (E_f) and (ii) differences between simulated and measured hydrographs (Figure 2). D_v ranges between -6.05% (simulation overestimates) and 13.45% (simulation underestimates). According to the E_f values, the Rio Hondo (0.92) and El Rito (0.90) simulations were the most successful. For the most part, rising and falling limbs of the simulated hydrographs line up with those of the measured hydrographs. The El Rito simulation overestimates a dip in streamflow in early May and then underestimates a peak in streamflow in late May as well as missing a large runoff event in late August. (However, El Rito results must be viewed with some caution because "measured" flow was reconstructed through analogy with a neighboring basin.) There is some deviation from the winter baseflow in the Rio Hondo simulation and July-August streamflow is underestimated. The Rio Pueblo simulation misses a very large runoff event at the end of April, which coincided with a large rain-on-snow-event. Despite yielding relatively unimpressive D_v and E_f statistics, the Santa Barbara hydrograph shows that the simulation performed moderately well. The two most obvious discrepancies between the simulated hydrograph and the measured hydrograph are underestimates in late June and July through August.

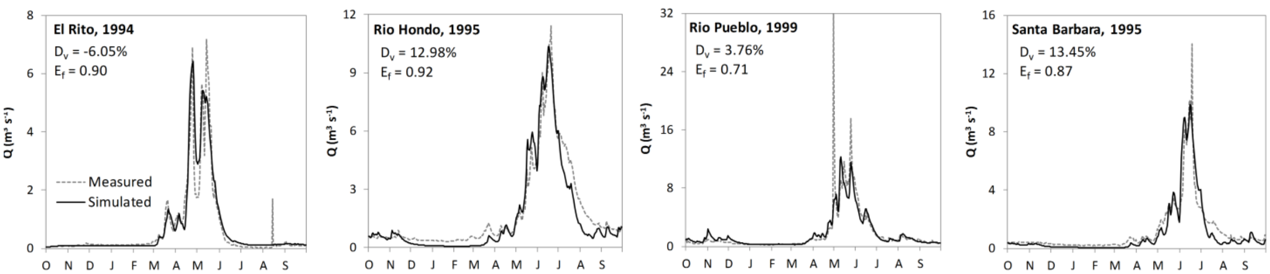


Figure 2. Results of the historical simulations. Solid lines indicate the simulated hydrographs; dashed lines are the measured hydrographs. Note that the "measured" hydrograph for El Rito was reconstructed through analogy with its neighboring basin, Ojo Caliente.

Climate Change Simulations

Table 2 summarizes period change analysis results. For all models, precipitation and temperature changes were analyzed with reference to modeled historical conditions. Listed in the table are the models that were identified for Hopewell and Red River SNOTEL stations as predicting ensemble mean (CT), hotter-dryer (HD), warmer-dryer (WD), hotter-wetter (HW) and warmer-wetter (WW) conditions. Hopewell values were used to drive climate change simulations for El Rito; Red River values were used for Rio Hondo, Rio Pueblo and Santa Barbara.

Table 2. Results from period change analysis.

	Hopewell			**Red River**		
2046 - 2065	Model	T°C	Precip (%)	Model	T°C	Precip (%)
CT	MIROC5 (2)	2.93	100	IPSL CM5A LR (1)	2.95	103
HD	IPSL CM5A LR (2)	3.35	91	CSIRO Mk 360 (10)	3.18	91
WD	ECHAM5	2.04	92	CCCma CGCM3 (1)	2.13	91
WW	MRI-CGCM3	1.74	115	CGCM232 (1)	1.55	113
HW	CanESM (1)	3.64	115	CanESM (1)	3.50	113
2081 - 2100	Model	T°C	Precip (%)	Model	T°C	Precip (%)
CT	MPI-ESM LR (3)	5.09	100	MPI-ESM MR	4.57	105
HD	IPSL CM5A LR (1)	5.98	88	IPSL CM5A LR (1)	5.94	86
WD	INM-CM4	3.47	91	INM-CM4	3.41	90
WW	MRI-CGCM3	3.22	120	CGCM232 (5)	3.04	119
HW	CanESM (1)	5.80	126	CanESM (1)	5.76	121

The preliminary results in Figure 3 represent the possible changes in runoff for 4 sub-basins in the Upper Rio Grande. In each case, the new hydrographs are based on historical water years and as such, they show what would happen to runoff in that year with increasing temperature or changing precipitation. Applying temperature and precipitation changes to historical climate data in SRM leads to earlier peak runoff in all basins. The Hondo and Santa Barbara hydrographs lose the characteristic sharp "snowmelt" peak in the hydrograph. Although runoff starts earlier, the duration of runoff from snowmelt from Hondo, Santa Barbara and Rio Pueblo is unchanged, meaning that the spring snowmelt also finishes earlier. Three streams see reduced streamflow volume: Hondo (14-38%), Santa Barbara (22-52%), Rio Pueblo (10-36%). There is slightly reduced volume at El Rito (by up to 2.6% below 1994 values) or slightly increased streamflow volume under wetter scenarios (by up to 5.21% over 1994 values).

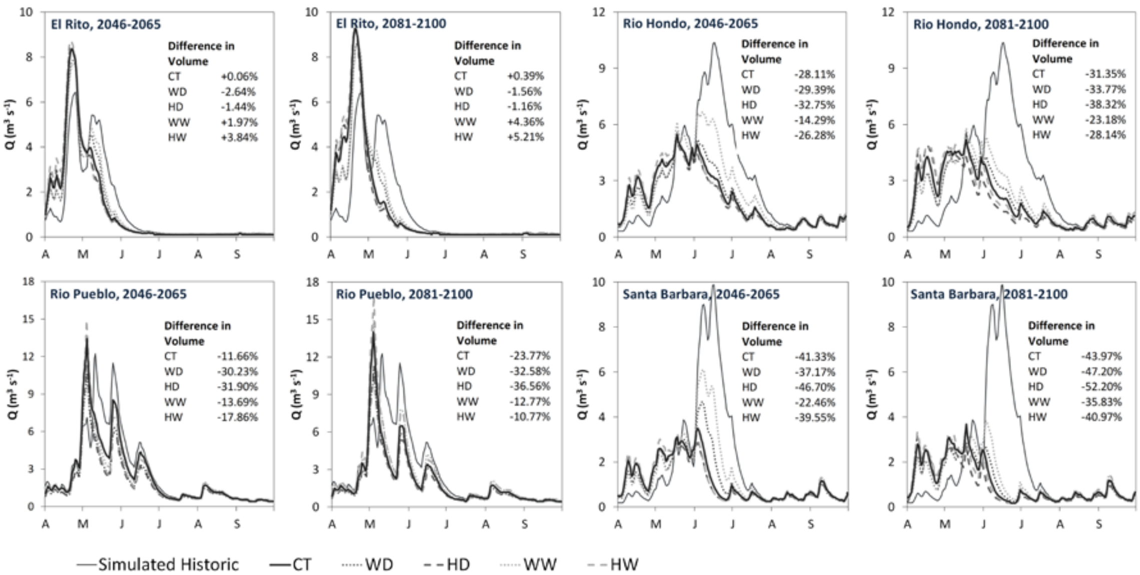


Figure 3. Results of model runs for central tendency, HD, WD, WW and HW projected conditions for future periods 2046-2065 and 2081-2100

Runoff volume is a critical variable at risk with respect to irrigation practices. Runoff volumes calculated in this case study generally fall within the range of historical low years and are significantly higher than runoff during drought years. Although water is still available in scenarios explored here, the timing of delivery may be problematic. Further, equitable distribution of water to all acequia parciantes will be challenging; especially where water scarcity is coupled with reduced pressure head.

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