IMPACT OF FUTURE CLIMATE ON WATER AVAILABILITY OF SNOWMELT DOMINATED WATERSHEDS OF THE UPPER RIO GRANDE BASIN

E. Elias [1] , A. Rango, [1], C. Steele, [2] and John F. Mejia [3]

ABSTRACT

Climate change is predicted to further limit the water availability of much of the arid southwestern U.S. In this study, the Snowmelt Runoff Model is used to evaluate the impacts of increased temperature and altered precipitation of a changed climate on snow covered area, streamflow timing and seasonal and total volume in the Upper Rio Grande. Simulations investigate a fairly hot and dry future condition at the end of the 21st century using a regionally recommended general circulation model downscaled to existing climate stations. Twenty-four subbasins of the Upper Rio Grande containing appreciable snowmelt and a long-term gauging station are simulated. Total basin snow covered area decreased by 55% due to future temperatures. SRM simulation shows that total annual 2099 volume for all basins was between 13% and 33% lower than 1999 total annual volume. Among the 24 basins there is considerable range in decrease in snow covered area (6-87%), total volume reduction (4-34%) and runoff timing shift (0-60 days early) indicating that climate change impacts are best evaluated at the subbasin scale in mountainous regions. Daily hydrographs for the snowmelt basins show higher streamflow in March and April, but less from mid-May until the end of the water year. SRM simulation provides a rapid and effective evaluation of the most resilient basins under a changed climate for planning and management purposes. (KEYWORDS: snowmelt runoff model, climate change, water resources, Rio Grande Basin)

INTRODUCTION

Water resources of the arid southwest are primarily a result of winter snowpack accumulation and spring snowmelt runoff. Climate change is predicted to decrease snowpack accumulation and cause earlier snowmelt runoff in the Upper Rio Grande (URG) basin (Llewellyn and Vaddey, 2013). Climate change could further limit water availability in much of the Southwestern US, including the URG (Garfin et al., 2013). The URG basin is located in the semi-arid southwestern United States and covers portions of southern Colorado and northern New Mexico. The most important source of water in the Rio Grande drainage results from snowmelt in the mountains of the upper basin as 50-75% of the flow in the Rio Grande is sustained by melting snow (Rango, 2006).

The Snowmelt Runoff Model (SRM) was designed to simulate daily streamflow in mountain basins where snowmelt is a major contribution to runoff. The model has been applied in over 100 basins in at least 29 different countries. The first evaluation of the effect of climate change using SRM dates back to 1980.

METHODS

SRM was used to simulate observed streamflow at the outlet of 24 subbasins tributary to the URG using observed precipitation and temperature data collected during an average runoff year (Oct 1, 1998 to Sept 30, 1999) at climate stations throughout the basin. SRM parameterization occurred in a basin-by-basin manner and adjustments to parameters were made until measured and simulated runoff reached an acceptable agreement. The 24 simulated subbasins range in size from 43 km^2 to 3,396 km^2 with measured annual runoff volume ranging from 6 million m^3 to 1,323 million m^3. The average difference in volume between measured and SRM computed runoff was 9.4% and average Nash-Sutcliffe coefficient was 0.82.

General circulation model (GCM) temperature and precipitation data were downscaled to 25 climate stations for use in SRM simulation of climate change using Bias-Correction Constructed Analogues (BCCA) (Maurer et al., 2010) along with station-based bias correction (Mejia et al., 2012). One climate model from the World Climate Research Program's Coupled Model Intercomparison Project (CMIP3) multi-model dataset was

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[1] Emile Elias,USDA-ARS Jornada Experimental Range, Las Cruces, NM, eliaseh@nmsu.edu
[1] Al Rango,USDA-ARS Jornada Experimental Range, Las Cruces, NM, alrango@nmsu.edu
[2] Caiti Steele, New Mexico State University, Las Cruces, NM, caiti@nmsu.edu
[3] John F. Mejia, Desert Research Institute, Reno, NV, john.mejia@dri.edu

selected for this work based upon performance compared with historical data (1950-2000) and simulation of the El Nino southern Oscillation (ENSO) (Dominguez at al., 2010). Max Planck Institute's ECHAM5 (MPI ECHAM5) A2 emissions scenario was used to simulate runoff with the predicted temperature of 2099.

SRM was used to evaluate the impact of future temperature on snow covered area by basin. SRM uses real snow cover in the present climate in order to produce a snow cover in a changed climate. The expected average two week change in temperature (°C) between 1999 and 2099 (24 values) was used in SRM to define a climate change scenario for each basin based upon the weather stations used during parameterization. The SRM climate change simulation was conducted to generate predicted 2099 snow covered area for each of the 24 URG basins for 2099.

To isolate the influence of changed temperature on runoff, only predicted future snow covered area and daily 2099 temperature data were used in the first climate change simulation (2099a). A second simulation using future snow covered area and both daily 2099 temperature and precipitation data (2099b) was conducted to predict 2099 runoff. Runoff results for 1999, 2099a (temperature only) and 2099b (temperature and precipitation) were analyzed for center of volume, 7-day peak flow and monthly and total volume for each basin.

RESULTS

Climate affected snow covered area was lower than 1999 snow covered area at the onset of snowmelt in all 24 basins due to the influence of increased 2099 temperatures (Figure 1). The total snow covered area in the simulated basins on April 1 decreased from 7,792 km^2 to 3,472 km^2 in the changed climate of 2099 (55% reduction). The reduced snow covered area was unique to each basin, ranging from a 6% reduction at the Trinchera Basin in the northern Sangre de Cristo Mountains to an 87% reduction at Rio Grande del Rancho in the southern Sangre de Cristo Mountains. Basins with the largest percent decrease in snow covered area are concentrated in the New Mexico Sangre de Cristo Mountains (76-87% decrease).

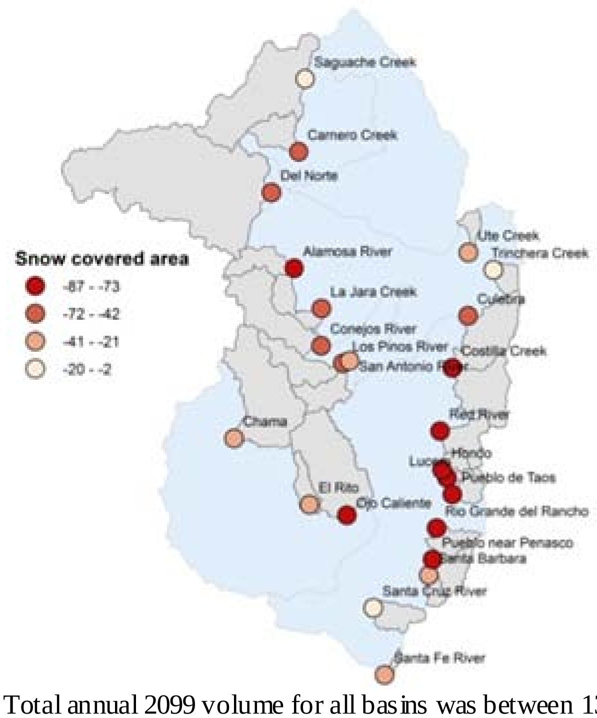
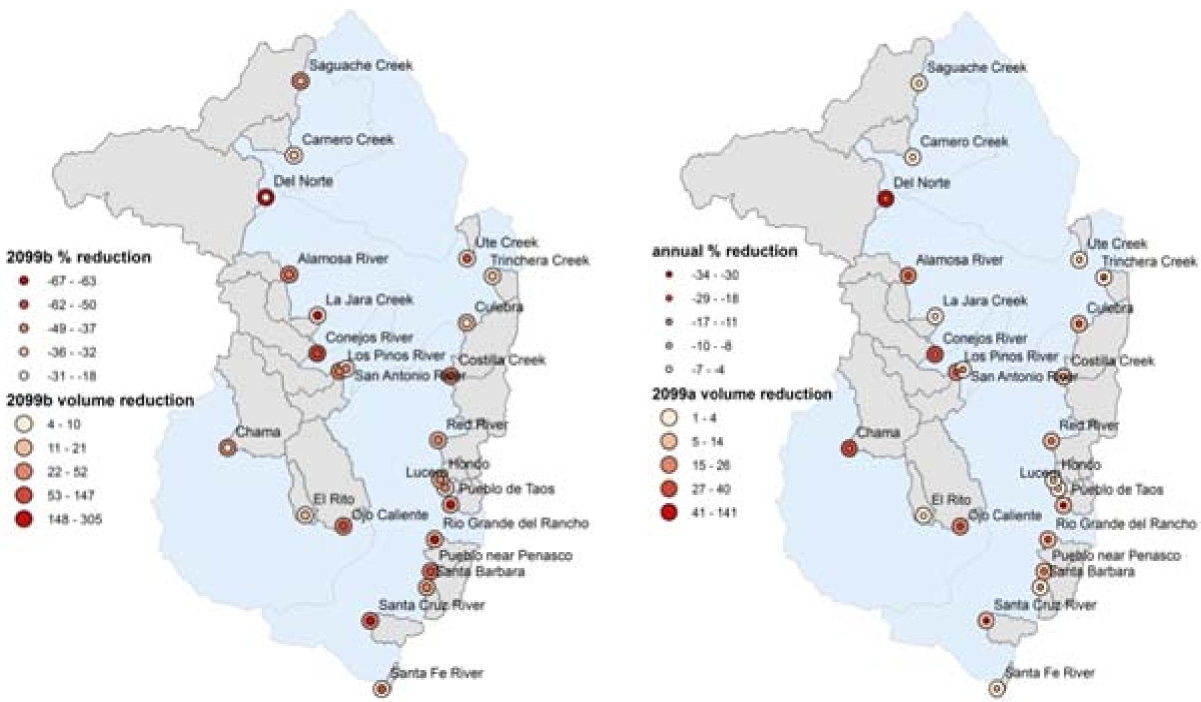


Figure 1. Percent decrease in snow covered area at the onset of snowmelt in basins of the Upper Rio Grande, 1999 - 2009

Total annual 2099 volume for all basins was between 13% (2099a) and 33% (2099b) lower than 1999 computed total annual volume. In 1999, the simulated total annual volume delivered by the snowmelt basins of the URG was 2,708 million m^3. In 2099, the total annual volume delivered is predicted to be 362 million m^3 (2099a) to 894 million m^3 (2099b) less than 1999 values. The percent decrease in total annual volume by basin ranges from 4% to 34% based upon changes in temperature alone. Incorporating the 2099 precipitation into simulations reduced the total annual volume for all basins, with the computed 2099b volume by basin ranging from 18% to 67% less than simulated 1999 volume. The six basins with the largest total volume reduction under future temperatures, ranging from 17 to 141 million m^3, are located in the San Juan Mountains (Figure 2).



2099a 2099b

Figure 2. Decrease in total and percent annual runoff volume (million m^3) in subbasins of the Upper Rio Grande using double downscaled future temperature (2099a) and temperature and precipitation (2099b).

Conducting simulations with 2099 precipitation instead of 1999 precipitation caused less total annual runoff volume for all basins, but the spatial distribution of volume reduction was similar using 1999 and 2099 precipitation, with highly productive San Juan basins losing the most total volume. Percent reduction shows a region in the southern New Mexico San Juan Mountains of basins losing a high percentage of their total runoff (Rio Pueblo de Taos, Rio Pueblo near Penasco, Rio Grande del Rancho, Santa Cruz). The northern-most Colorado basins (Saguache Creek, Carnero Creek and Rio Grande at Del Norte) have a small percent reduction in total annual volume.

Peak runoff and center of annual volume are predicted to be earlier in 2099 than 1999 (See Rango et al., Figures 2 and 3). Some of the largest and most productive basins of the San Juan Mountains (Rio Grande at Del Norte, Conejos River and Alamosa River) had the earliest center of volume and 7-day maximum flow, predicted to be a month to two months early. Since these basins collectively supplied 60% of the total URG volume in 1999, the shift to earlier runoff in 2099 may pose management challenges for URG water managers. There has also been a documented advance in the timing of peak spring season flows over the past 50 years (Regonda et al., 2005).

CONCLUSIONS

This research evaluates the impact of a relatively hot and dry climate at the end of the 21st century on water resources of the water-limited URG basin. SRM simulation shows that total annual 2099 volume for all basins was between 13% (2099a) and 33% (2099b) lower than 1999 computed total annual volume. The total snow covered area in the simulated basins decreased by 55%. Basins with the largest percent decrease in snow covered area are concentrated in the New Mexico Sangre de Cristo Mountains (76-87% decrease).

Annual peak runoff occurs earlier due to the increased temperatures of a changed climate. Some of the largest and most productive basins of the San Juan Mountains produce the earliest center of volume and 7-day maximum flow, predicted to be a month to two months early in 2099. Models also predict decreased streamflow in May, June and July, months with high water demand. The 2002 hydrologic drought caused measured streamflow conditions more severe than those reported in this climate change simulation indicating that the SRM predicted changes are within previously observed values.

Although the basins are situated within a relatively small area of the mountainous western U.S., there is a wide range in snow covered area and annual volume reduction, as well as earlier peak flow and center of volume. This indicates the importance of planning for a changed climate at a subbasin scale, especially in mountainous regions where large elevation gradients have an influence on temperature and precipitation. Climate change analysis at the subbasin scale also affords a more informed planning of regional water management.

SRM proved to be a fairly rapid and effective model to simulate the impacts for changed temperature and precipitation on 24 subwatersheds of the URG. Several recommendations evolved from this effort. First, because of the differences in measured and computed volume of the initial basin simulations, evaluating the impacts of climate change should be conducted by comparing results with initial SRM simulations rather than measured values. Second, we recommend criteria for initial SRM measured vs. computed volume of <10% prior to conducting climate change simulations.

This study confirms the work of others on the impacts of climate change on snowmelt basins. Results show that snow covered area and total volume will decrease and streamflow will be earlier. The study adds to previous work by showing the wide range of climate change impacts on snowpack, streamflow and runoff timing even on adjacent basins within a relatively small region. It also provides an assessment of the impacts of future temperature alone, to allow for evaluation of results without the uncertainty associated with future precipitation projections. Finally, it provides an evaluation of the least affected basins under a changed climate for planning and management purposes and a methodology to perform similar assessments elsewhere.

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