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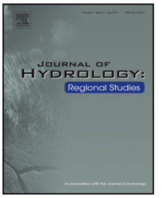

Assessing climate change impacts on water availability of snowmelt-dominated basins of the Upper Rio Grande basin

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ABSTRACT

Study region: Upper Rio Grande, Colorado and New Mexico, USA.
Study focus: Climate change is predicted to further limit the water availability of the arid southwestern U.S. We use the snowmelt runoff model to evaluate impacts of climate change on snow covered area (SCA), streamflow timing and runoff volume. Simulations investigate four future conditions using models downscaled to existing climate stations. Twenty-four subbasins of the Upper Rio Grande containing appreciable snowmelt and a long-term gauging station are simulated.
New hydrological insights for the region: Future annual volume is 193–204 million m^3 more to 448–476 million m^3 less than the pre-climate change value of 2688 million m^3. There is disparity between increased volume in wetter simulations (+7%) and decreased volume (−18%) in drier simulations. SCA on 1 April reduced by approximately 50% in all but the warmer/wetter climate. Peak flow is 14–24 days early in the future climates. Among the 24 subbasins there is considerable range in mean melt season SCA (−40% to −100%), total volume change (−30% to +57%) and runoff timing advancement indicating that climate change is best evaluated at the subbasin scale. Daily hydrographs show higher streamflow in March and April, but less from mid-May until the end of the water year. The large decrease in volume in May, June and July will compound water management challenges in the region.

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1. 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 United States, 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. From its headwaters in the San Juan and Sangre de Cristo Mountains of southern Colorado, the Rio Grande flows southward to eventually form the international boundary between Texas and Mexico. Here we focus on the mountainous headwaters of the Rio Grande and the river mainstem north of the city of Albuquerque, 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).

Rio Grande streamflow generally peaks in the late spring and early summer and diminishes rapidly by mid-summer. Local precipitation primarily occurs in the summertime and summer monsoons can provide additional peak flows in the river. Peak runoff is from April to June, but highest evapotranspiration and irrigation demands along the Rio Grande occur from June through mid-September (Llewellyn and Vaddey, 2013). Streamflow in the basin is historically highly variable as indicated by tree ring analysis and droughts, defined as a year or more with annual flows less than the long-term median, are common (Woodhouse et al., 2012). The URG basin is located on the boundary between the subtropical dry and temperate mid-latitude climate zones. This boundary is anticipated to shift northward and alter seasonal precipitation patterns in the region as a result of climate change (Llewellyn and Vaddey, 2013).

Temperature and precipitation vary by latitude and elevation in the URG (Kunkel et al., 2013). By the end of the century, temperatures in the URG are anticipated to increase by about 5 °C under high emissions global climate model scenarios (Cayan et al., 2013; NOAA, 2013). Temperature increases will be highest in summer and fall. While models are split between those showing declines in winter precipitation and those showing small increases, winter precipitation is expected to increasingly fall as rain rather than snow (Gutzler et al., 2006). Temperature driven increases in evaporation will change the components of the overall water budget, resulting in less available water even with potential small increases in precipitation (Nash and Gleick, 1993). Given the large percentage of Rio Grande streamflow derived from snowmelt, simulation of a snowmelt and streamflow response to anticipated increased temperatures of a changed climate is vital for developing adaptive management strategies. Water resources of this region are particularly vulnerable to the projected increased temperatures since supplies are presently limited. Increased temperatures and population growth in the Rio Grande basin will cause the gap between water supply and demand to continue to grow (Rango, 2006). The timing of water supply will shift to earlier in the year and water management flexibility for current water users may decrease because of the shift in runoff timing (Llewellyn and Vaddey, 2013). An analysis of Colorado River supplies under a changed climate suggests that water management flexibility will minimize climate change impacts (Rajagopalan et al., 2009). Additionally, the notion that groundwater supplies can be tapped to make up the deficit in future shortages ignores supply limitations as the groundwater reservoir is already heavily mined and depleted in the basin (Rango, 2006).

Previous URG modeling efforts have characterized streamflow response to a changed climate (Rango and Martinec, 1997, 2000). The Rio Grande near del Norte was simulated to represent an extremely wet year (1979), a dry year (1977) and a near average year (1976) with good results (Rango and Martinec, 1997). A projected climate change of +4 °C was simulated for this basin. In a dry year the proportion of total annual runoff occurring in the summer (76%) was less than a wet year (93%). Climate change increased winter runoff and decreased summer runoff in dry, moderate and wet simulations of the Rio Grande near del Norte. Rango and Martinec (2000) evaluate the impact of different climatic zones on climate change by simulating Illecillewaet (British Columbia, Canada, very humid), Kings River (California, USA, semi-humid) and Rio Grande at del Norte (Colorado, USA, semi arid). The smallest snowpack reduction occurred at Rio Grande near Del Norte and the decline in snow covered area was accelerated by about 1 month in all climates. Most of the Rio Grande runoff was shifted