Impact of future climate on water availability of snowmelt-dominated watersheds of the Upper Rio Grande Basin

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Abstract

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 and peak runoff in the Upper Rio Grande (URG) basin. The Snowmelt Runoff Model was used to evaluate the impacts of increased temperature and altered precipitation on snow covered area, streamflow timing and seasonal and total volume. Simulations investigate a fairly hot and dry future condition at the end of the century using a regionally recommended global climate model downscaled to existing climate stations. Subbasins of the URG containing appreciable snowmelt and a long-term gauging station were simulated (n=24). Total basin snow covered area on April 1 decreased by 54%. There was considerable range in decrease in snow covered area (6-94%), total volume (1-30%) and runoff timing (0-60) days earlier by basin. Total runoff volume decreased by 7% based upon temperature changes alone and 26% using future temperature and precipitation. The simulated results of reduced snow cover, increased March flow and earlier runoff have been observed in recent measured data. The large predicted decrease in May, June and July volume will likely exacerbate water management challenges in the URG. Shallow groundwater return flows from irrigation in the basin may help provide delayed flow to the river in the driest months most affected by warming temperatures of a changing climate.

Methods

- Snowmelt runoff model (SRM) was parameterized for each basin (n=24)
- Global climate model (GCM) temperature and precipitation data were downscaled to the climate station using BCCA and station-based bias correction (double statistical downscaling; Mejia et al. 2012).
- Expected change in temperature for each two week period was used to define each climate change scenario and generate predicted 2099 snow covered area (figure 1 and 2) for each basin.
- Future snow covered area and daily 2099 temperature data from Max Planck Institute's ECHAM5 (MPI ECHAM5) A2 scenario were used to simulate runoff under the predicted temperature of 2099 (2099a simulation). This GCM was reported to best capture seasonal temperature and precipitation over the Southwestern U.S. (Dominguez et al., 2010).
- A second simulation using future snow covered area and both daily 2099 temperature and precipitation data was conducted to predict 2099 runoff (2099b).
- Runoff results for 1999, 2002, 2099a (temperature only) and 2099b (temperature and precipitation) were analyzed for center of volume, 7-day peak flow, spring streamflow (fraction of annual flow occurring between April and July) and monthly and total volume for each basin.

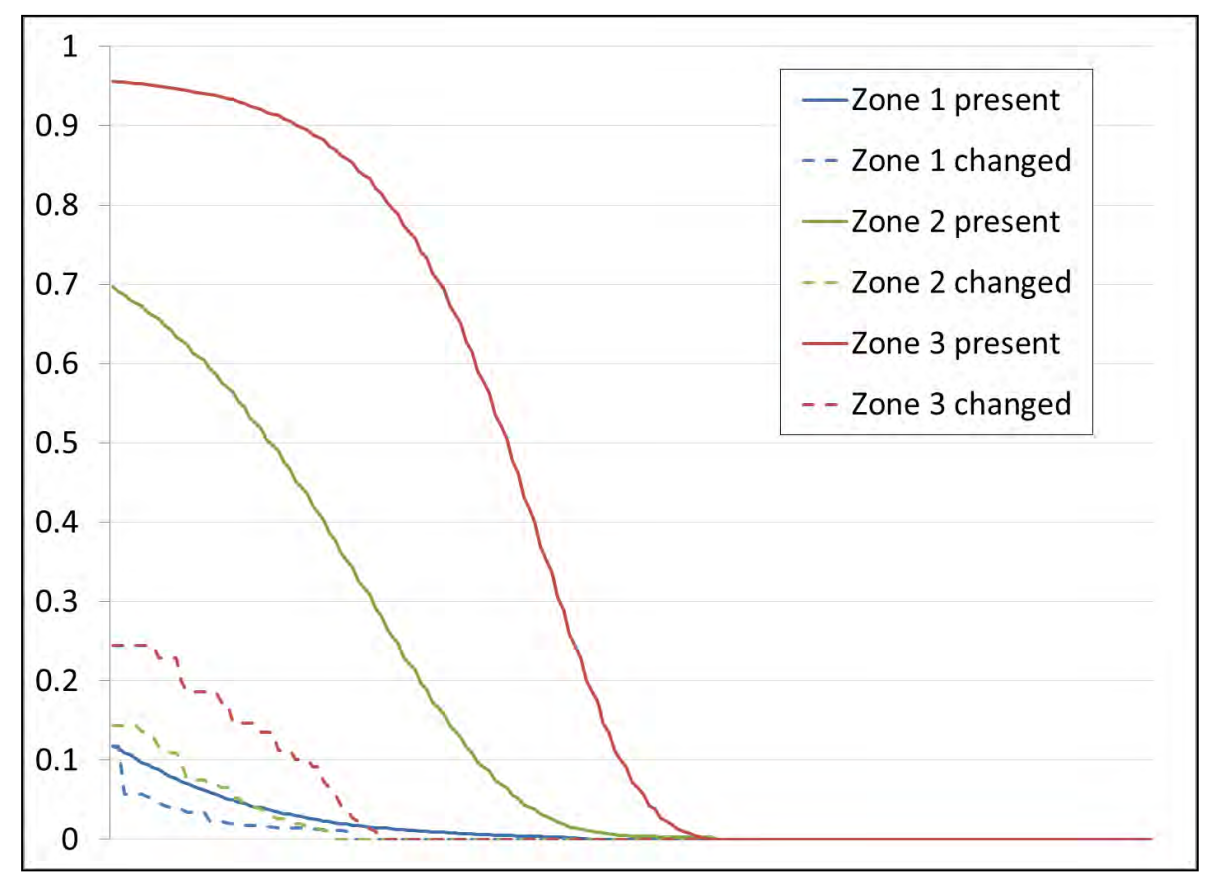


Figure 1. Snow covered area from SRM climate change simulation.

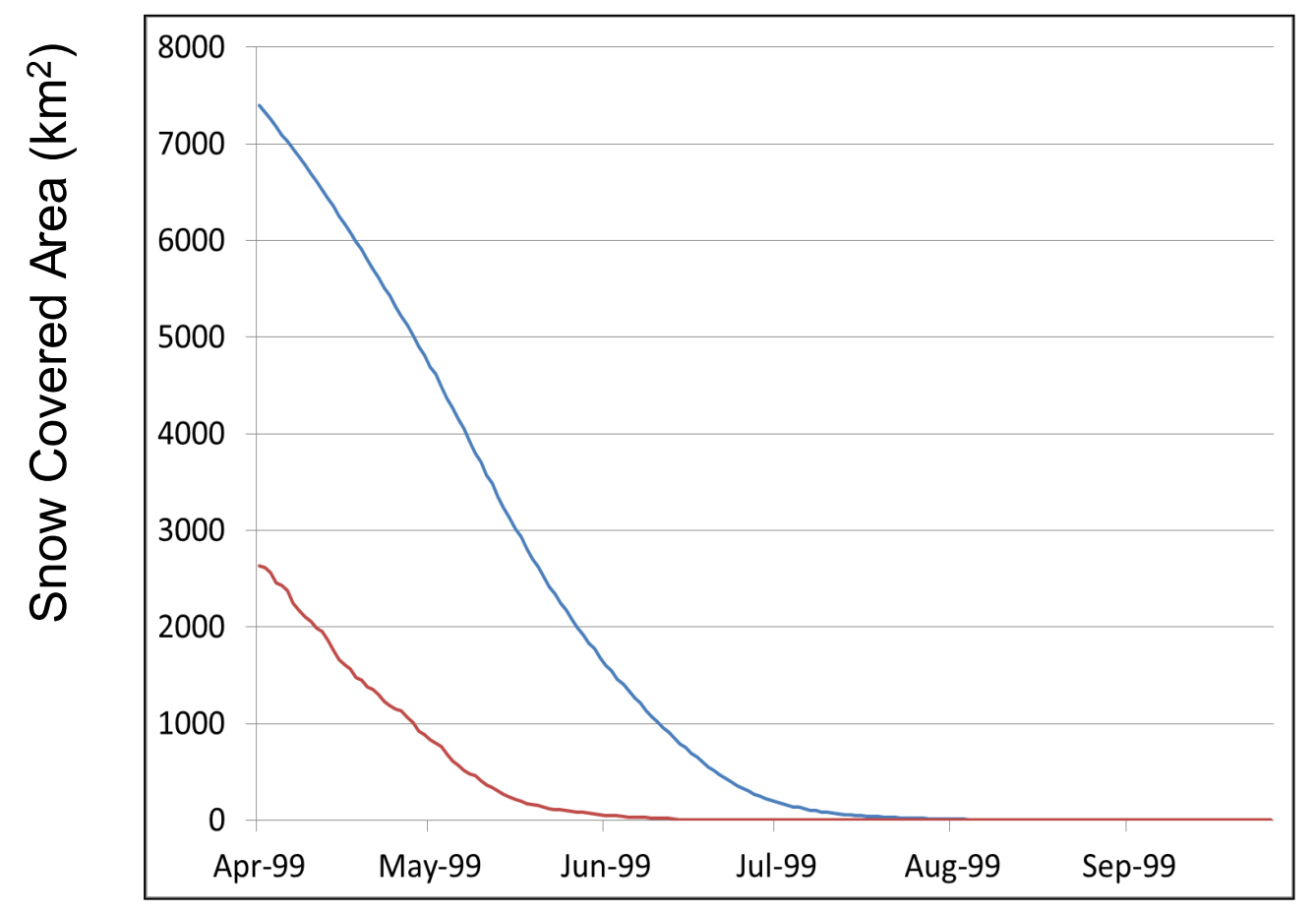


Figure 2. Snow covered area before (1999; blue) and after (2099; red) simulated climate change for basins of the Upper Rio Grande.

Results

Parameterization

SRM parameters were generated for 24 basins. The average difference in volume between measured and SRM computed runoff was 9.8%. Average Nash-Sutcliffe coefficient (E) was 0.82.

Downscaled GCM future temperature and precipitation

MPI ECHAM5 temperature and precipitation (2046-2065; 2081-2100) were compared with 2099 water year temperature and precipitation. Future precipitation is highly variable from year to year with a minimum average of 38 cm and a maximum average of 82 cm. The simulated year is dry, but 10 of the 40 future simulated years are drier than 2099. Compared with the future simulated years, 2099 has some of the highest average maximum and minimum temperatures (18.5 and 3.0 ˚C, respectively), thus the results presented here represent a fairly hot and dry future condition.

Figure 3. Percent change in precipitation 1999 to 2099.

Figure 4. Percent decrease in snow covered area 1999 to 2099.

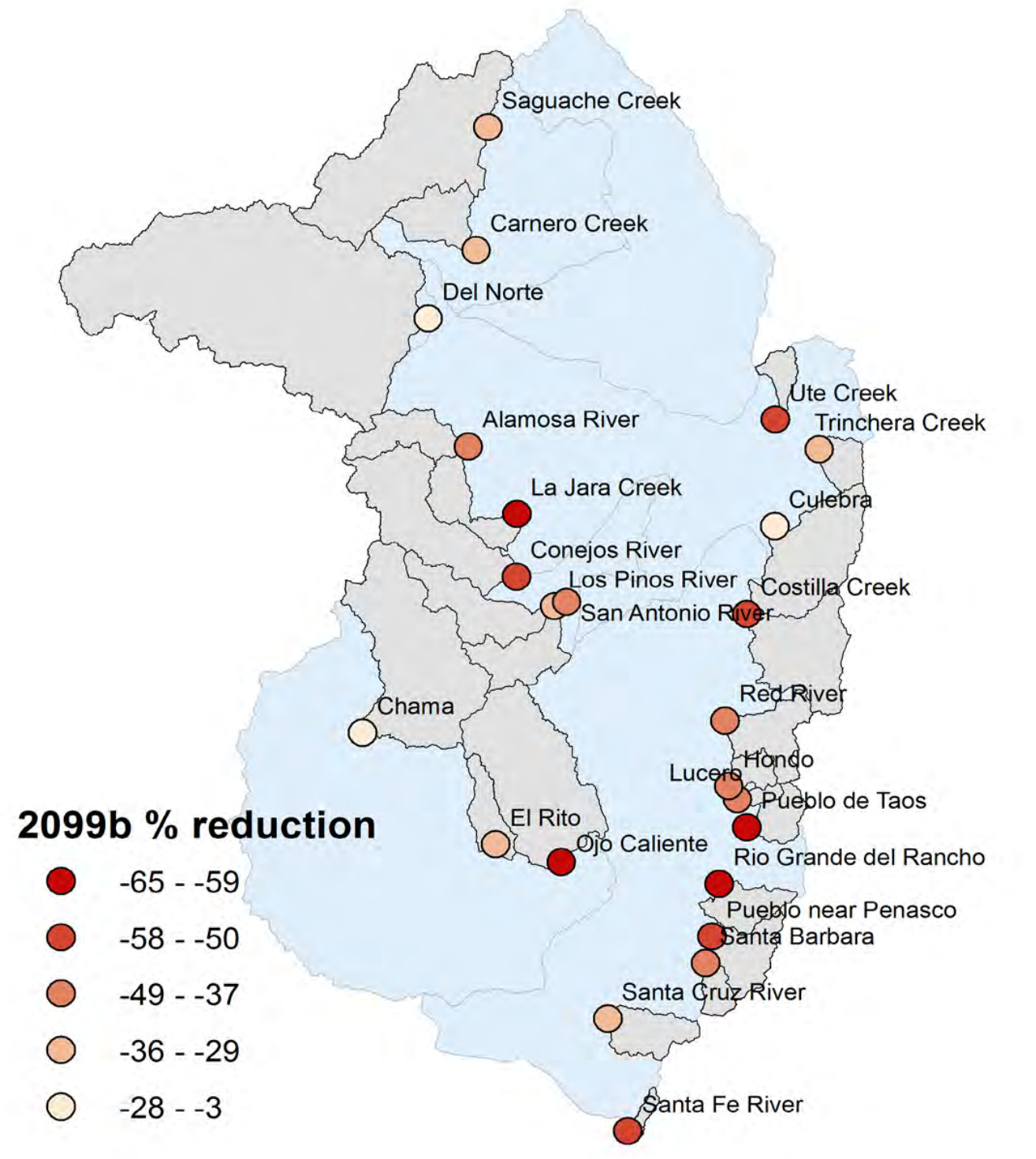


Figure 5. Percent change in streamflow (2099b)

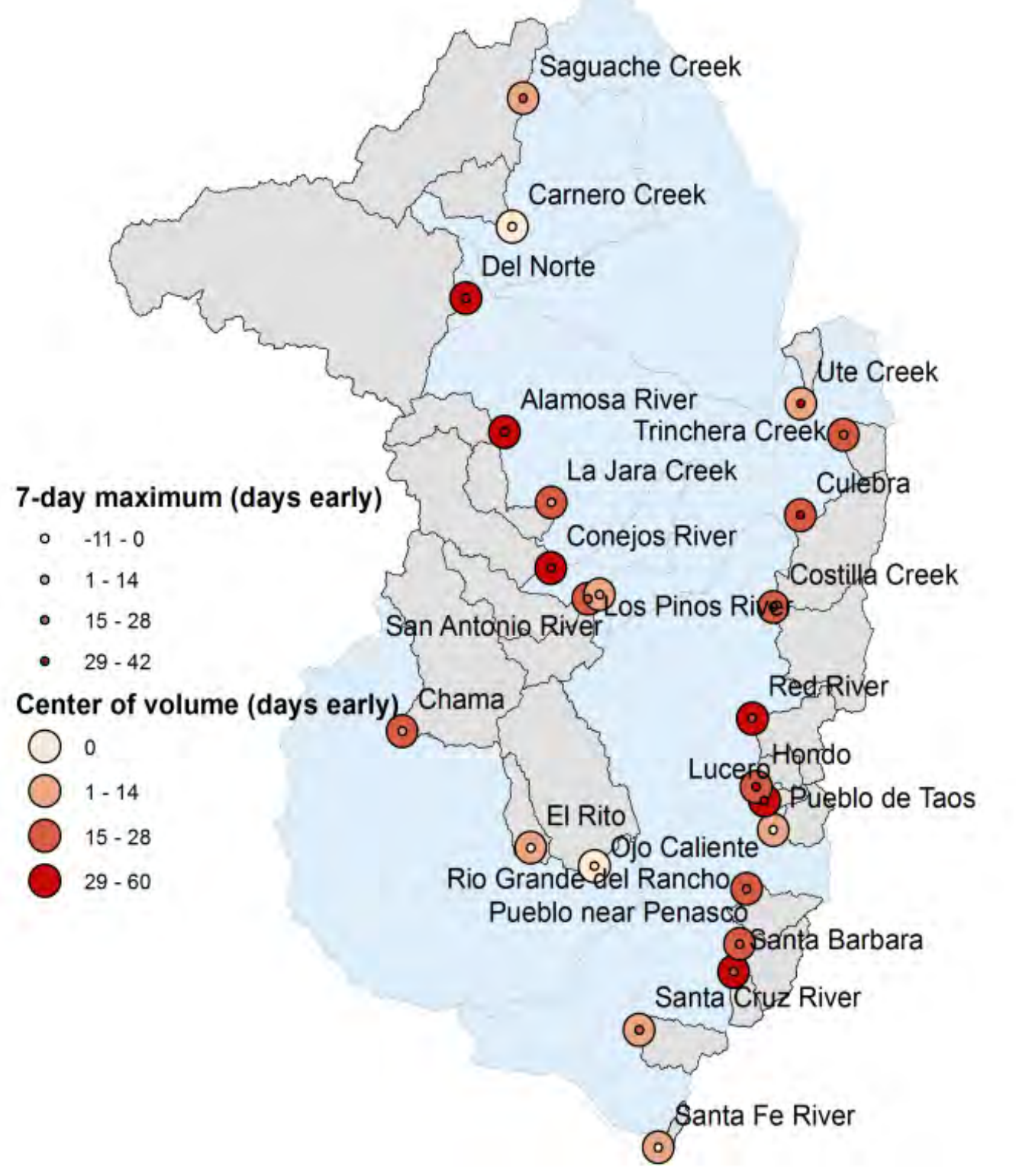


Figure 6. Changes in center of volume and 7-day peak flow (2099a)

Snow Covered Area

Snow covered area was lower at the onset of snowmelt in all 24 basins due to the influence of increased 2099 temperatures. The total snow covered area on April 1 decreased from 7,623 km² to 3,502 km² in the changed climate of 2099 (54% reduction; figure 2). The reduced snow covered area was unique to each basin, ranging from 6% to 94% (Table 1; figure 4). Basins with the largest percent decrease in snow covered area are concentrated in the New Mexico Sangre de Cristo Mountains (76-94% decrease). Our results are consistent with recent observed trends of lower spring snowpack across much of the western United States.

Changes in streamflow and runoff volume

Based on monthly streamflow volume analysis, climate affected streamflow is often lower in May, June and July (figure 7). This result was evident in simulations using 2099 temperature alone as well as 2099 temperature and precipitation. Total 2099 annual volume for all basins was between 7% (2099a) and 26% (2099b) lower than measured 1999 volume. Percent change in total annual volume by basin ranged from +3% to -30% (2099a) (figure 5). After inclusion of 2099 precipitation, the percent change in total annual volume by basin ranged from 3% to 65% decrease.

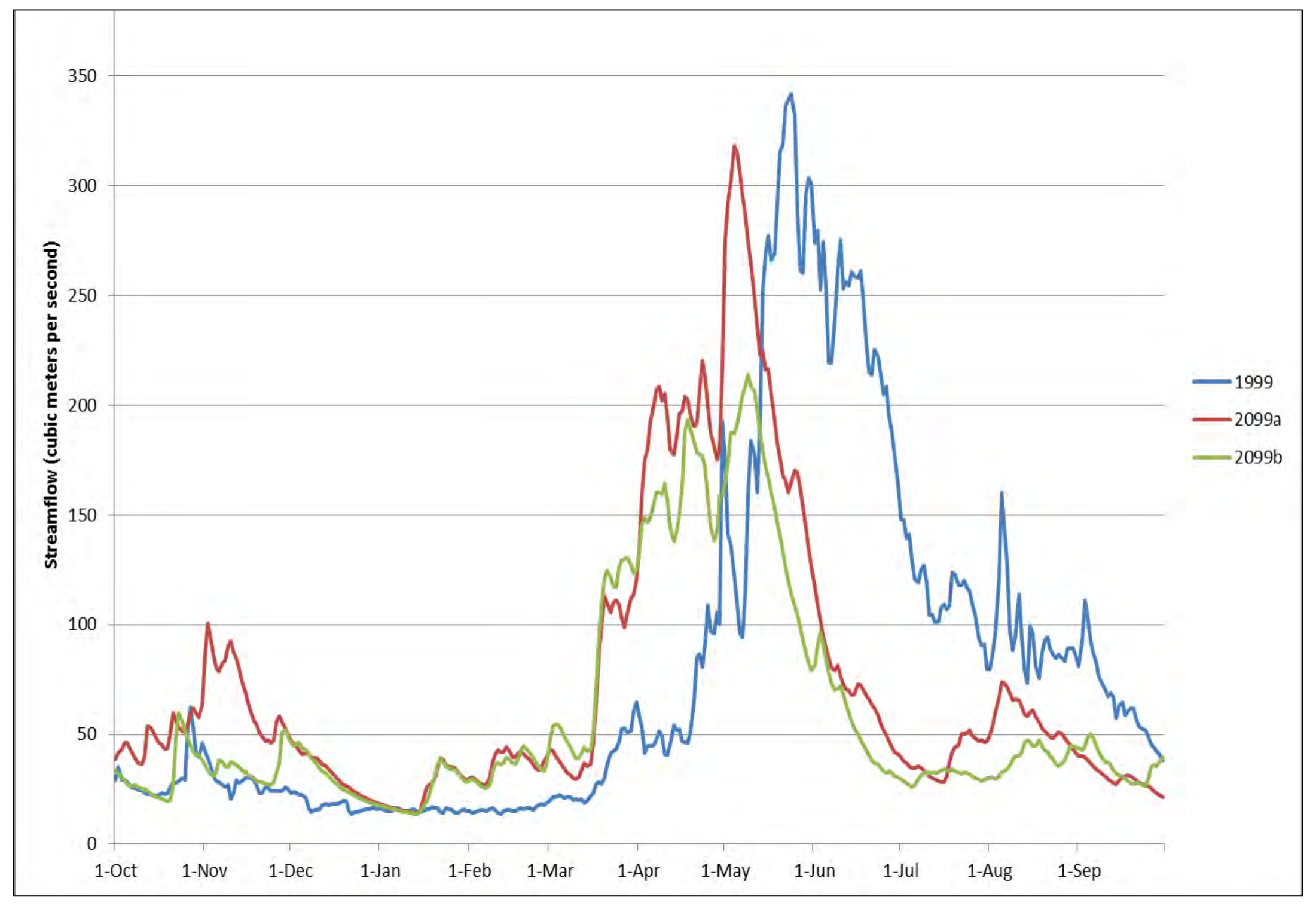


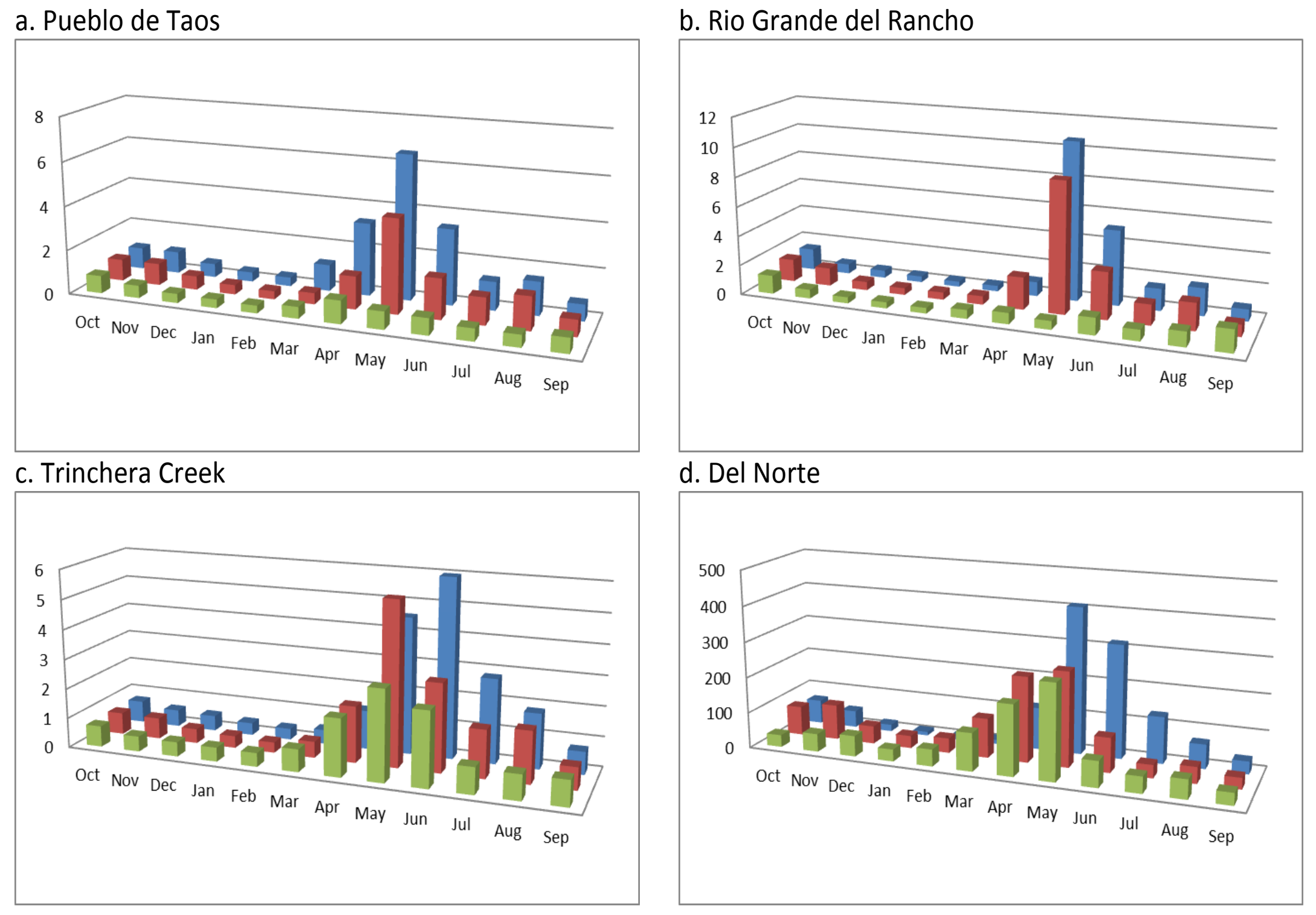
Figure 7. Total streamflow from simulated URG basins in 1999, with the changed climate of 2099a (temperature) and 2099b (temperature and precipitation.

Shifts in runoff timing

Total April to July volume was 21% (365 million m³) lower than measured volume using 1999 precipitation (2099a) and 39% (681 million m³) lower than measured volume using 2099 precipitation (2099b). This is partially attributable to a shift towards earlier springtime runoff. Runoff volume in March 1999 was 2% of total annual volume whereas runoff volume in March 2099 was 8% (2099a) to 12% (2099b) of total annual volume. A similar shift in volume occurred in April, which represented 11% of the total volume in 1999 and 22% in 2099. The shift in 2099 streamflow timing is unique to each basin, ranging from no change to 60 days earlier than 1999 (figure 6). Some of the largest and most productive basins of the San Juan Mountains (Del Norte, Conejos and Alamosa River) had the earliest center of volume and 7-day maximum flow, predicted to be 1-2 months early based upon temperature change alone.

Monthly volume by subbasin

In comparing 1999 and 2099a volume by month, four basins exhibited consistently lower flow for each month (figure 8, a). Four other basins had similar April volumes for 1999 and 2099a and lower monthly volumes during other months. The remaining basins (n=16) exhibited earlier runoff, increased April volume and diminished June volume based only upon changed temperature (figures 8 b, c and d), though magnitude varied by basin.


a. Pueblo de Taos

b. Rio Grande del Rancho

c. Trinchera Creek

d. Del Norte

Figure 8. Monthly volume of selected basins in 1999 (blue), 2099a (red) and 2099b (green).

Results in the context of a recent drought

The 2002 drought hydrograph was often lower than hydrographs generated using climate change data. The average center of volume was 66 days earlier in 2002, 20 days earlier in 2099a and 37 days earlier in 2099b than 1999 center of volume. The total measured volume for 2002 was 510 million m³, as compared with total annual future volume 2,332 million m³ (2099a) and 1,852 million m³ (2099b). Management lessons from the recent past, such as the severe 2002 drought, may help build future resilience in terms of climate impacts.

Table 1. 1999 and 2099 snow covered area and percent difference in 1999 to 2099 precipitation and snow covered area

Subbasin	% change in ppt	1999 SCA km²	2099 SCA km²	% change in SCA
Alamosa River	-20%	214	53	-75%
Carnero Creek	-25%	125	52	-59%
Conejos	-68%	543	315	-42%
Costilla	-42%	278	40	-86%
Culebra (1994)	-11%	357	285	-20%
Del Norte (1987)	-8%	3234	1260	-61%
El Rito	-34%	78	56	-28%
La Jara	-68%	149	78	-48%
Los Pinos	-22%	250	128	-49%
Lucero	-34%	35	14	-59%
Ojo Caliente	-34%	244	66	-73%
Red River	-35%	169	24	-86%
Rio Chama (2001)	2%	1028	780	-24%
Rio Grande del Rancho	-43%	124	7	-94%
Rio Hondo	-20%	70	9	-87%
Rio Pueblo de Penasco	-33%	149	34	-77%
Rio Pueblo de Taos	-45%	98	24	-75%
Saguache Creek	-42%	765	647	-15%
San Antonio	-27%	124	97	-21%
Santa Barbara	-34%	75	27	-64%
Santa Cruz	-22%	116	106	-8%
Santa Fe	-22%	11	8	-25%
Trinchera	-26%	78	73	-6%
Ute Creek	-63%	21	16	-25%

Conclusions

Future center of volume and 7-day peak flow based upon temperature change alone was up to two months earlier in 2099 than 1999. Total annual runoff volume was 7% to 26% less in 2099 than 1999.

The large range in decrease in snow covered area (6-94%), total volume (1-30%) and runoff timing (0-60 days early) suggests some basins are fairly resilient in terms of changed temperature and others are highly vulnerable.

The shift to earlier streamflow is more evident in the San Juan Mountains. Streams draining the Sangre de Cristo Mountains have shifted from snowmelt dominated to increasingly rain dominated from 1948 to 2008, but this trend was not observed in the San Juan Mountains (Fritze et al. 2011).

The predicted decrease in volume in May, June and July will exacerbate water management challenges in the URG. Shallow groundwater return flows from irrigation in the basin may help provide delayed flow to the river.

Management information from recent severe droughts, such as the 2002 drought, should be considered in terms of climate change adaptation plans.

Future research

1. Incorporate other downscaled GCM data to generate ensemble predictions of streamflow
2. Simulate multiple sequential years to evaluate cumulative effects of prior hydrologic response
3. Conduct a vulnerability assessment using a range of temperature and precipitation values
4. Evaluate the impacts of acequia irrigation return flow on the river mainstem north of Albuquerque.

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