Watershed Scale Response to Climate Change—East River Basin, Colorado

Introduction

General Circulation Model (GCM) simulations of future climate through 2099 project a wide range of possible scenarios (Intergovernmental Panel on Climate Change, 2007). To determine the sensitivity and potential effect of long-term climate change on the freshwater resources of the United States, the U.S. Geological Survey Global Change study, "An integrated watershed scale response to global change in selected basins across the United States" was started in 2008. The long-term goal of this national study is to provide the foundation for hydrologically based climate-change studies across the nation.

Fourteen basins for which the Precipitation Runoff Modeling System (PRMS) has been calibrated and evaluated were selected as study sites. PRMS is a deterministic, distributed-parameter watershed model developed to evaluate the effects of various combinations of precipitation, temperature, and land use on streamflow and general basin hydrology. Output from five GCMs and four emission scenarios were used to develop an ensemble of climate-change scenarios for each basin. These ensembles were simulated with the corresponding PRMS model. This fact sheet summarizes the hydrologic effect and sensitivity of the PRMS simulations to climate change for the East River Basin at Almont, in Colorado (U.S. Geological Survey streamflow-gaging station 09112500; fig. 1) presented in the project summary report (Markstrom and others, 2012) and two journal articles (Hay and others, 2001; Battaglin and others, 2011).

Study Area

The East River Basin above Almont, Colorado is part of the Gunnison River Basin, and is an important tributary of the Colorado River (fig. 1). The Gunnison River contributes approximately 40 percent of the streamflow of the Colorado River at the Utah/Colorado State line (Spahr and others, 1999), and the East River accounts for approximately 25 percent of the streamflow of the Gunnison River (Ugland and others, 1991). The 748-square kilometer (km^2) basin ranges in elevation from 2,440 to 4,350 meters and has a mean elevation of 3,100 meters. Current (2011) and projected water demand in the Gunnison River Basin is about equal to the native supply (Colorado Water Conservation Board, 2006). Because of the basin's importance as a source of water to the Colorado River, the U.S. Geological Survey studied the effects of potential climate change on the water resources of the East River Basin (McCabe and Hay, 1995). The East River Basin is representative of many snowmelt dominated, high-elevation basins in Colorado that supply much of the water to downstream users.

Tourism is the largest source of revenue in the region (Gunnison Country Chamber of Commerce, 2009). Many of the associated recreational activities such as fishing, whitewater boating, snowmobiling, and skiing, are dependent directly on the basin's water resources. The Crested Butte ski area is located within the East River Basin. The ski area has a base elevation of 2,856 meters and top elevation of 3,707 meters. The ski area typically receives more than 7 meters of snowfall annually, and operates from late November to early April.

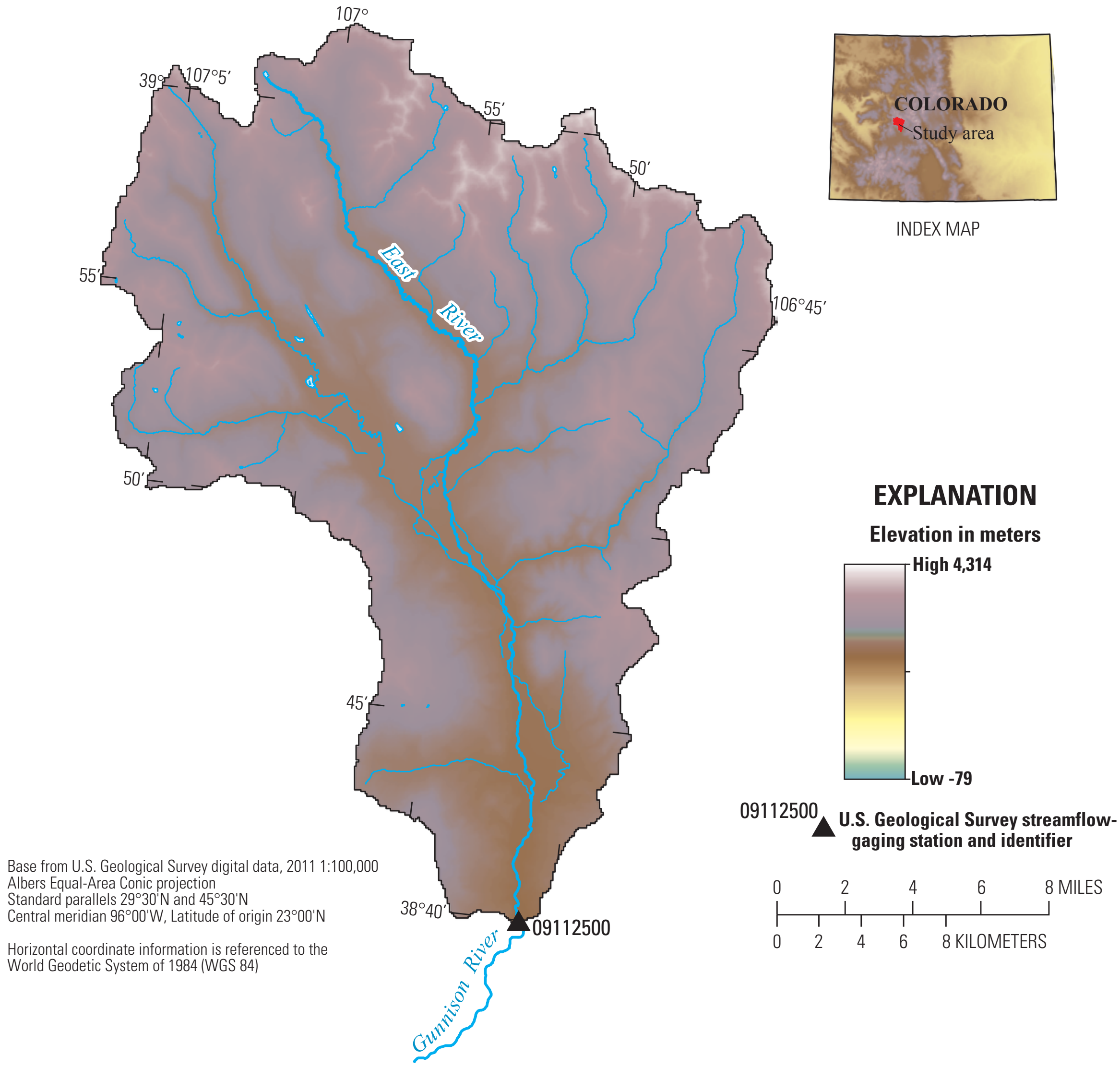


Figure 1. Precipitation Runoff Modeling System study locations, East River Basin, Colorado, and location of U.S. Geological Survey streamflow-gaging station 09112500 with a drainage area of 748 square kilometers and elevation range from 2,440 to 4,350 meters.

General Circulation Models

General Circulation Models

Given the uncertainty in climate modeling, it is desirable to use more than one GCM to obtain a range of potential future climatic conditions. Monthly precipitation and temperature output from five GCMs were processed (table 1).

Table 1. General Circulation Model (GCM) projections used in this study.

GCM	Center and country of origin
BCC–BCM2.0	Bjerknes Centre for Climate Research, Norway
CSIRO–Mk3.0	Australia's Commonwealth Scientific and Industrial Research Organization, Australia
CSIRO–Mk3.5	Australia's Commonwealth Scientific and Industrial Research Organization, Australia
INM–CM3.0	Institute for Numerical Mathematics, Russia
MIROC3.2	National Institute for Environmental Studies, Japan

The GCM outputs were obtained from the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 multi-model dataset archive, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Special Report on Emission scenarios (Intergovernmental Panel on Climate Change, 2007). For each GCM, one current (water years 1988–1999) and three future emission scenarios were used and are described in table 2.

Table 2. Climate-change emission scenarios simulated by the General Circulation Models in this study.

Emission scenario	Description/assumptions
20C3M	20th century climate used to determine baseline (1989–1999) conditions
A1B	Rapid economic growth, a global population that peaks in mid-21st century and rapid introduction of new and more efficient technologies with a balanced emphasis on all energy sources
B1	Convergent world, with the same global population as Emission scenario A1B, but with more rapid changes in economic structures toward a service and information economy that is more ecologically friendly
A2	Heterogeneous world with high population growth, slow economic development, and slow technological change

Climate-change fields were derived by calculating the change in climate from current (water years 1988–1999) to future conditions simulated by each GCM. The 20C3M simulation for water years 1988–1999 was used to represent current climatic conditions. This 12-year period of record was chosen based on the overlap of the available historical records from the 14 basins included in the national study. Climate change fields (percentage changes in precipitation and degree changes in temperature) were computed for 12-year moving window periods (from 2001–2099) using the 20C3M (1988–1999) and the A1B, B1, and A2 emission scenarios. A 12-year moving window, starting in 2001 and ending in 2099, results in 1,320 future scenarios [(88, 12-year climatologies, 1 per year starting with 2001–2012 and ending with 2088–2099) x (3 emission scenarios) x (5 GCMs)].

Climate-change scenarios were generated for PRMS by modifying PRMS precipitation and temperature inputs with the mean monthly climate change fields derived from the GCMs, resulting in 1,320 PRMS-input files. Table 3 shows the change (slope) and adjusted R^2 (adjR2) for the least squares fit to the trend line for selected output variables from the PRMS projections. The slope indicates the change in the selected variable by year. The adjusted R^2 value gives an indication of the variability in the central tendency of the trend line.

Figure 2 shows a summary of the projected range in 11-year moving mean daily values of maximum temperature (fig. 2*A*), minimum temperature (fig. 2*B*), and precipitation (fig. 2*C*) by emission scenario. The first year of each 12-year simulation was used as PRMS initialization and is not included in the results. The three solid-colored lines indicate the 11-year moving mean values (x-axis indicates center of 11-year window) for the three future emission scenarios (central tendency of the five GCMs for each emission scenario). The projected range shown for each emission scenario indicates the range of potential future climatic conditions simulated by the five GCMs. All GCM simulations project steady increases in maximum and minimum temperature (table 3), with uncertainties associated with these GCM projections increasing with time. Both maximum and minimum temperatures show the smallest projected changes for the B1 emission scenario. GCM projections of mean annual precipitation for the East River Basin are highly variable, with the A1B emission scenario showing a slight positive trend in the central tendency (table 3). The wide range in the precipitation projections indicates a large amount of uncertainty.

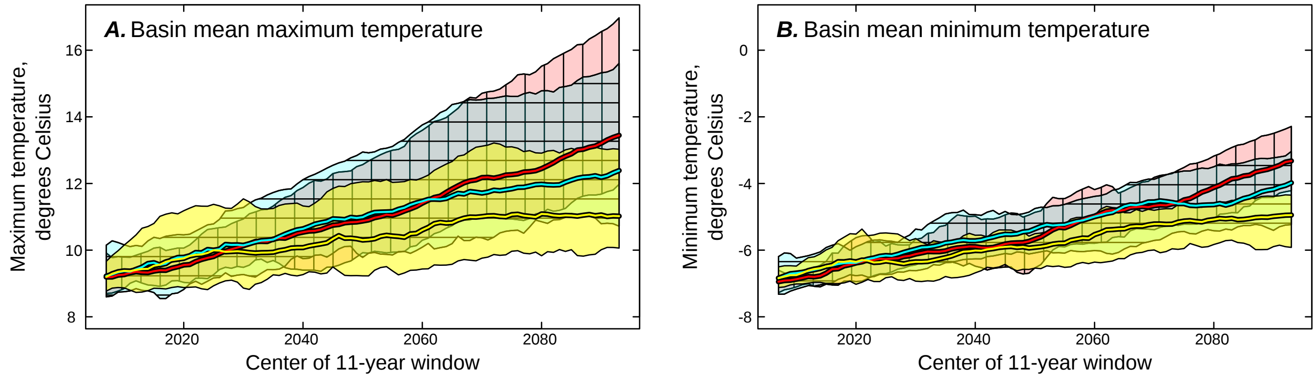
Results

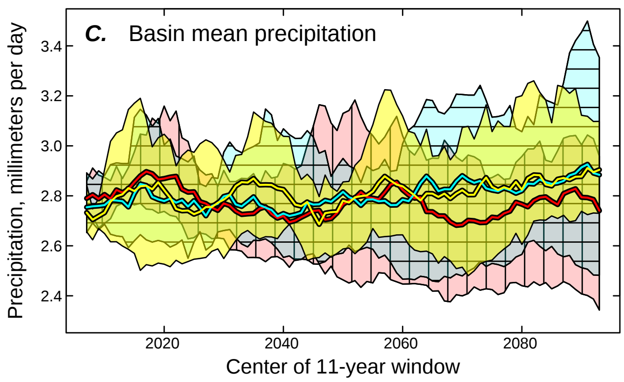
PRMS simulates spatially distributed streamflow, components of flow (surface, subsurface, and groundwater), snowpack conditions, and many other hydrologic components of interest. Figure 3 shows the projected range in 11-year moving mean daily values of streamflow by emission scenario. The simulations of annual mean streamflow vary by emission scenario, but the central tendency of the five GCMs for each of the three future emission scenarios (indicated by the solid colored lines) each projects a decrease in mean annual streamflow (table 3). However, the uncertainties associated with these streamflow projections are large, especially for the A1B and A2 emission scenarios.

Streamflow can be examined on a monthly basis to determine if the timing of peak runoff is expected to change (fig. 4). The solid red lines show PRMS-simulated mean monthly baseline conditions (1989–1999) for streamflow, and the boxplots represent the range in the projected mean monthly streamflow for the five GCMs and three emission scenarios for 2030 (green, 2025–2035), 2060 (tan, 2055–2065) and 2090 (green, 2085–2095). The figure indicates that minimal change is projected during the fall and winter months (September–February), however, streamflow is projected to increase slightly in March and more substantially in April and May. A large decrease in mean monthly streamflow is projected in June, followed by smaller decreases in July and August. The results suggest that timing of peak runoff may shift from June to May by 2060.

Analysis of other hydrologic components of interest produced by PRMS indicates areas of the water balance most susceptible to changes in climate. Changes in the accumulation of snowpack and the timing of snowmelt are important in the East River Basin from a water-supply standpoint, and also because of potential effects on recreational activities in the area. For example, figure 5 shows summaries of the basin mean annual snow-covered area. Because of the projected increase in temperatures (figs. 2*A* and 2*B*), a steady decrease in mean annual snow-covered area is projected in the basin (table 3), with uncertainty around the projected decreases increasing with time (fig. 5). The projected decreases in mean annual snow-covered area vary considerably for the three emission scenarios and the five GCMs.

Changes in snow-covered area on a mean monthly basis (fig. 6) project the most significant decreases in the fall (October and November) and spring (April through June). Minimal





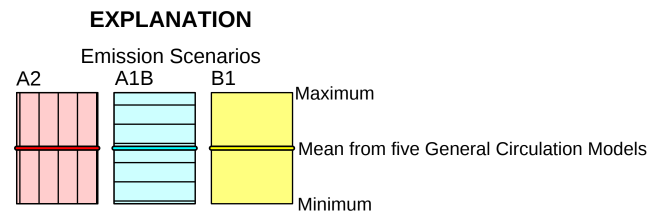


Figure 2. Projected range in 11-year moving mean daily values of (*A*) maximum temperature, (*B*) minimum temperature, and (*C*) precipitation by emission scenario.

Table 3. Projected change by year (slope) and adjusted R^2 (adjR2) based on the central tendencies of the five General Circulation Models for the three carbon emission scenarios for selected Precipitation Runoff Modeling System (PRMS) output variables.

[Blue indicates a significant negative trend and yellow indicates a significant positive trend ($p<0.05$) accounting for lag-1 autocorrelation]

PRMS output variable	Emission scenario A1B		Emission scenario A2		Emission scenario B1	
	slope	adjR2	slope	adjR2	slope	adjR2
Maximum temperature in degrees Celsius	0.037	0.99	0.049	0.99	0.022	0.95
Minimum temperature in degrees Celsius	0.031	0.98	0.040	0.98	0.022	0.98
Precipitation in millimeters per day	0.0013	0.50	-0.0007	0.11	0.0011	0.31
Streamflow in cubic meters per second	-0.0150	0.70	-0.0347	0.91	-0.0118	0.51
Snow-covered area in percent per day	-0.10	0.98	-0.15	0.98	-0.07	0.94

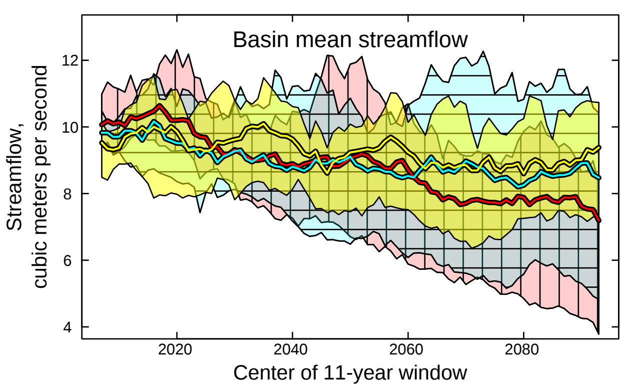


Figure 3. Projected range in 11-year moving mean daily values of streamflow by emission scenario.

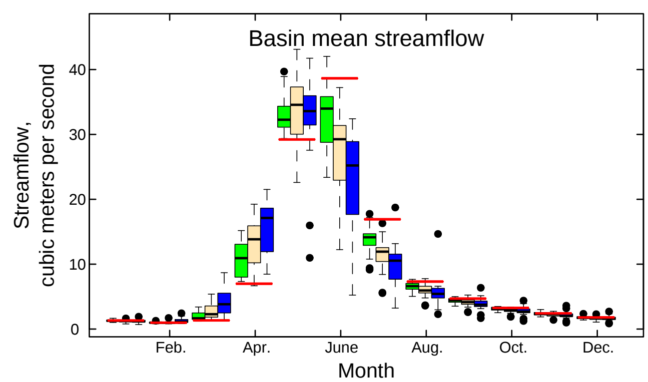


Figure 4. Mean daily streamflow values by month for baseline conditions and projected range (2030, 2060, and 2090) using the five General Circulation Models and three emission scenarios.

changes in mean monthly snow-covered area are projected from December through March. In Colorado, the month of March traditionally has the best ski conditions and often the most skier visits (Roark Kiklevich, oral commun., 2010). Therefore, basin mean annual changes in snow-covered area for the month of March only are shown in figure 7. Projected decreases for March only are not nearly as drastic as those shown for the entire year (fig. 5).

Presumably, ski area locations are picked at least in part because of a tendency to receive and/or keep snowpack. The effect of location within the basin can be examined by comparing basin mean simulations of snow-covered area with simulations from the individual hydrologic response unit (HRU) that represents the ski area in the model. Simulations of snow-covered area for March for an HRU that covers the base portion of Crested Butte ski area (and surrounding areas) show small projected changes for the B1 emission scenario (yellow) (fig. 8), but more substantial decreases for A1B emission scenario (blue) and A2 emission scenario (red), particularly after 2040.

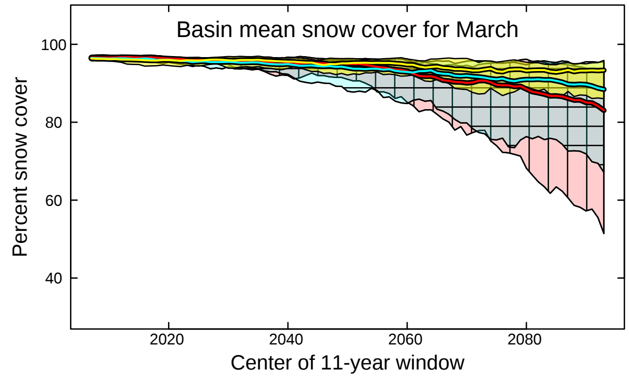


Figure 7. Basin mean annual changes in snow-covered area for the month of March.

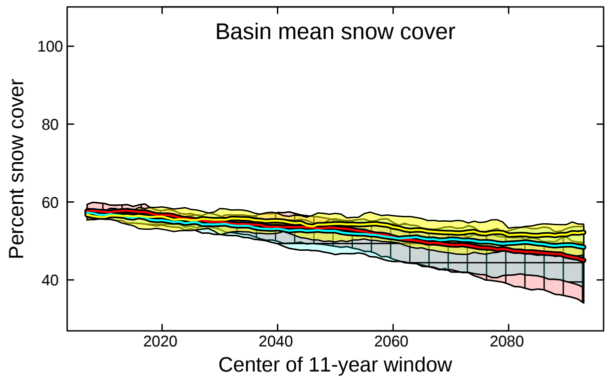


Figure 5. Projected range in 11-year moving mean daily values of snow-covered area by emission scenario.

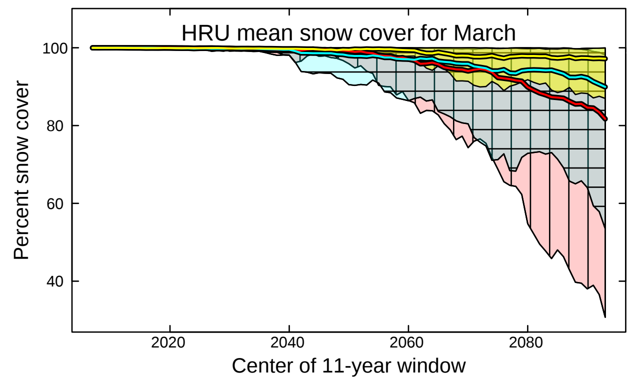


Figure 8. Hydrologic Response Unit (HRU) mean annual changes in snow-covered area for the month of March.

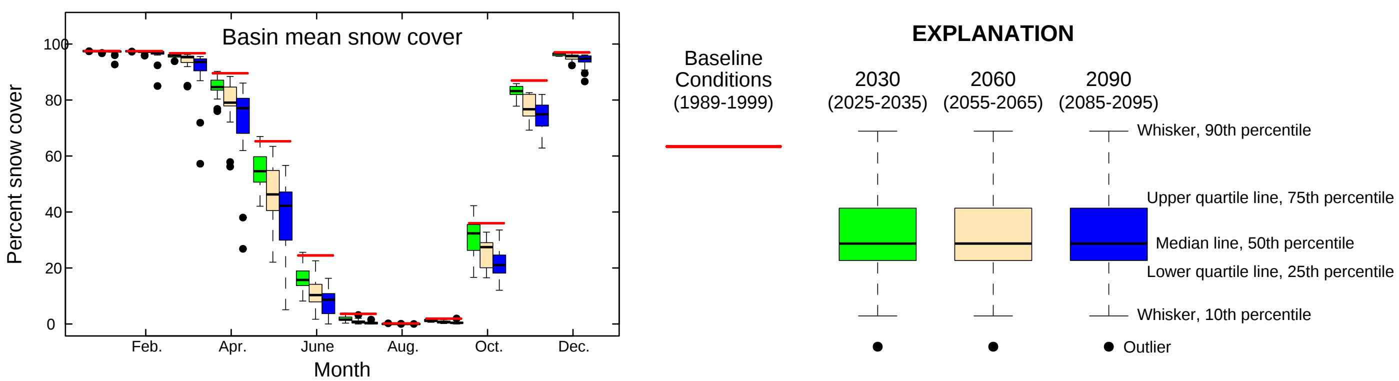


Figure 6. Mean daily snow-covered area values by month for baseline conditions and projected range (2030, 2060, and 2090) using the five General Circulation Models and three emission scenarios.

Conclusion and Discussion

Streamflow in the East River Basin is under increasing demand from water users in the southwestern United States and recreationalists within the basin. Potential changes in streamflow resulting from projected changes in climate may add to the stress that this basin could experience as a result of projected increases in domestic and industrial water use (Colorado Water Conservation Board, 2002). The effects of climate change in the East River Basin may alter both the quantity and timing of streamflow and have the potential to affect the conditions that support recreational activities, such as skiing. The scientific techniques described in the fact sheet can be augmented with other techniques in developing the science needed to address the effects of projected changes in climate on streamflow and snowpack dynamics in mountainous regions.

Selected References

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