Watershed Scale Response to Climate Change—Starkweather Coulee Basin, North Dakota

Introduction

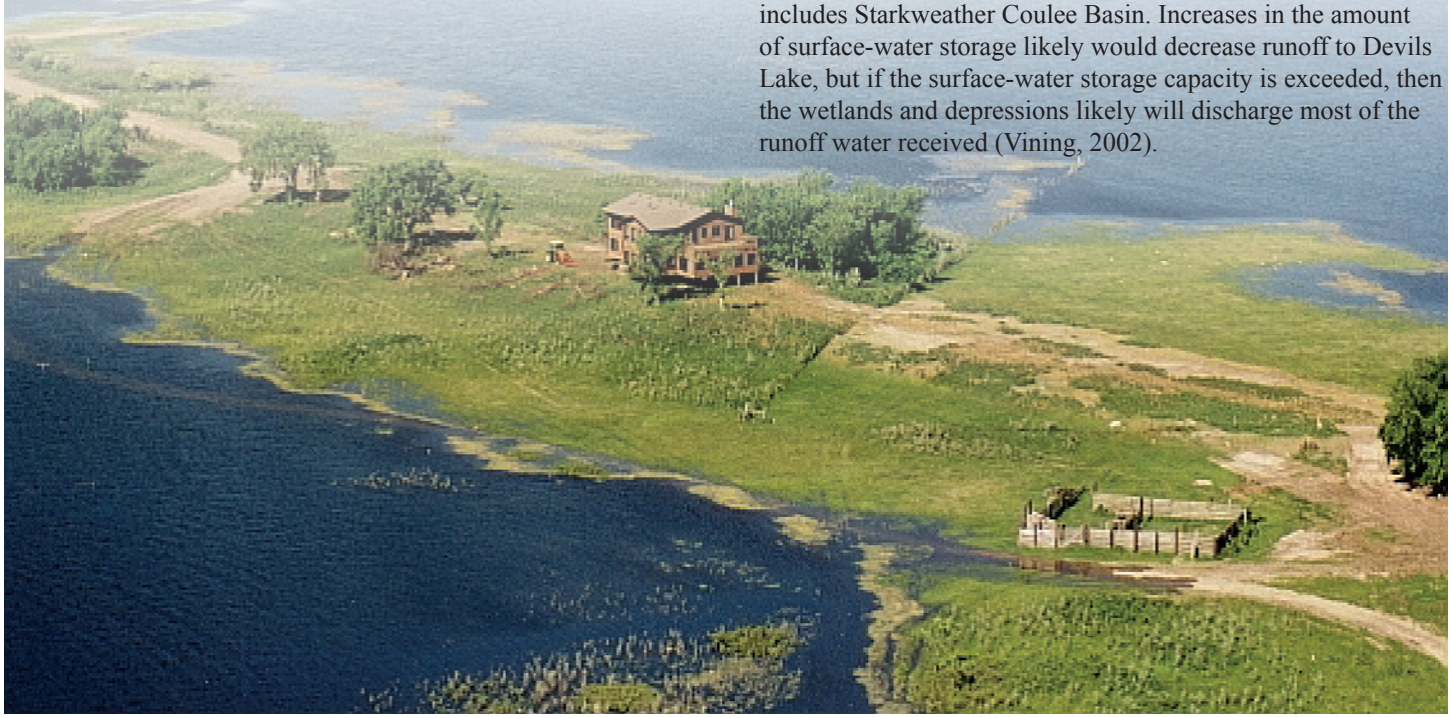
General Circulation Model (GCM) simulations of future climate through 2099 project a wide range of possible scenarios (Intergovernmental Panel on Climate Change, 2007). To determine the sensitivity and potential effect of long-term climate change on the freshwater resources of the United States, the 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 Starkweather Coulee Basin near Webster, North Dakota (U.S. Geological Survey streamflow-gaging station 05056239; fig. 1) presented in the project summary report (Markstrom and others, 2012) and a journal article (Hay and others, 2011).

Study Area

The Starkweather Coulee Basin is a major subbasin within the Devils Lake Basin in northeastern North Dakota. Starkweather Coulee Basin covers an area of about 543 square kilometers (km^2) of which about 259 km^2 probably do not contribute to streamflow (Vining, 2002). The topography of the basin mostly is level to slightly rolling in the south, somewhat more rolling in the central, and mostly level in the north. The soil predominately is loam to silty clay throughout the basin. Thousands of small depressions and wetlands exist on the surface. Many of the original depressions and wetlands were drained years ago and currently (2011) are being farmed. The majority of the land in the basin is used for agricultural production, although some areas are used as pasture or are enrolled in conservation programs.

The region around the Devils Lake Basin has experienced intermittent flooding conditions since the summer of 1993 during which copious amounts of precipitation filled many lakes, wetlands, and depressions. The low-relief topography of the region and the lack of a prominent outlet from Devils Lake means that precipitation and runoff water remains within the basin. Millions of dollars have been spent protecting infrastructure around Devils Lake from rising waters. Alternatives have been proposed for stabilizing basin water levels. One of these alternatives is storing water by re-establishing and expanding wetlands and depressions in the upper Devils Lake Basin which includes Starkweather Coulee Basin. Increases in the amount of surface-water storage likely would decrease runoff to Devils Lake, but if the surface-water storage capacity is exceeded, then the wetlands and depressions likely will discharge most of the runoff water received (Vining, 2002).



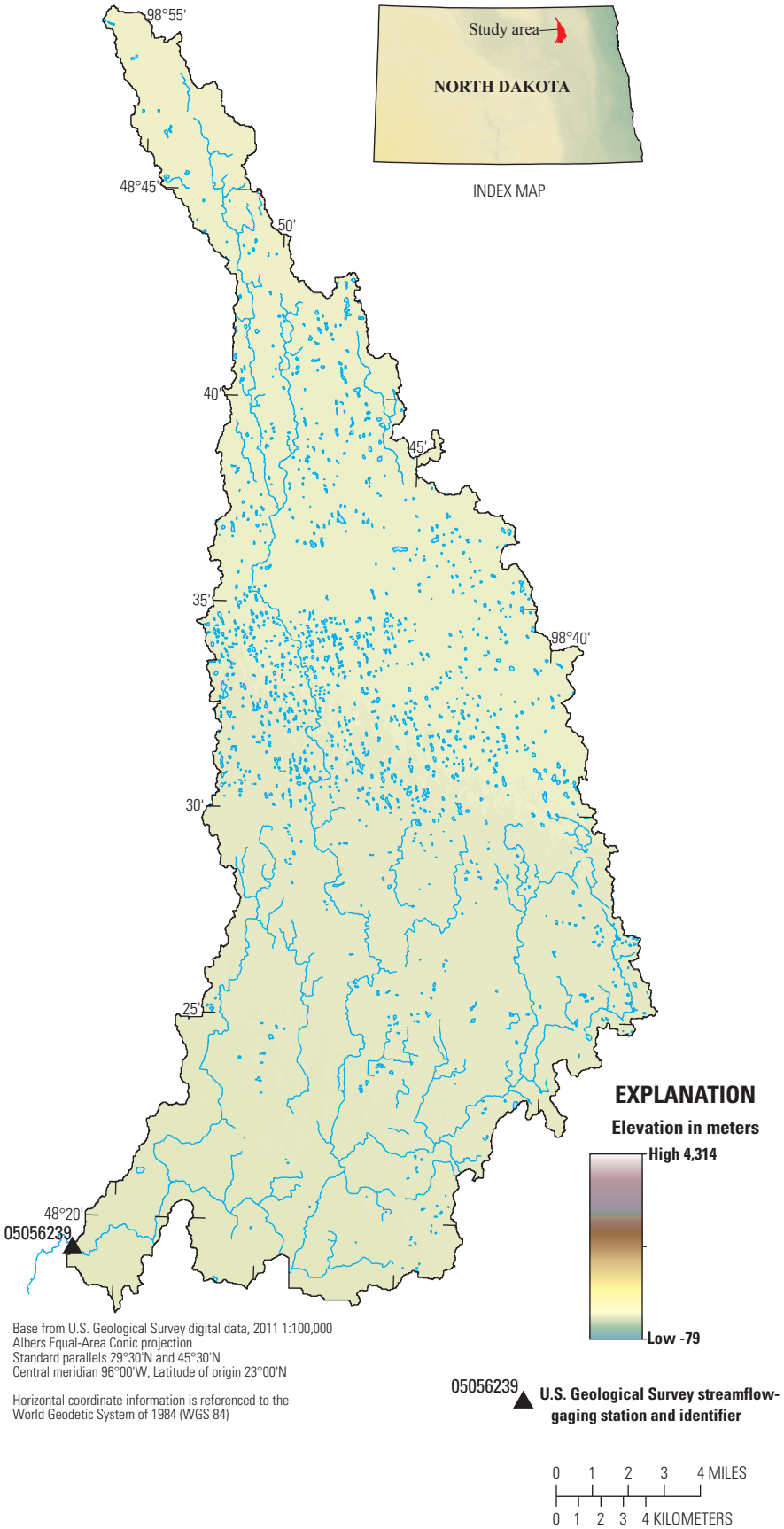


Figure 1. Precipitation Runoff Modeling System study locations, Starkweather Coulee Basin, North Dakota, and location of U.S. Geological Survey streamflow-gaging station 05056239 with a drainage area of 543 square kilometers and elevation range from 446 to 491 meters.

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 was 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. Projections of mean annual precipitation for the Starkweather Coulee Basin are highly variable, showing both increases and decreases in future precipitation estimates both between GCM simulations, and within the projected emission scenario ranges. The wide range and lack of significant trend in the precipitation projections indicate a large amount of uncertainty in the GCM scenarios used in this study (table 3).

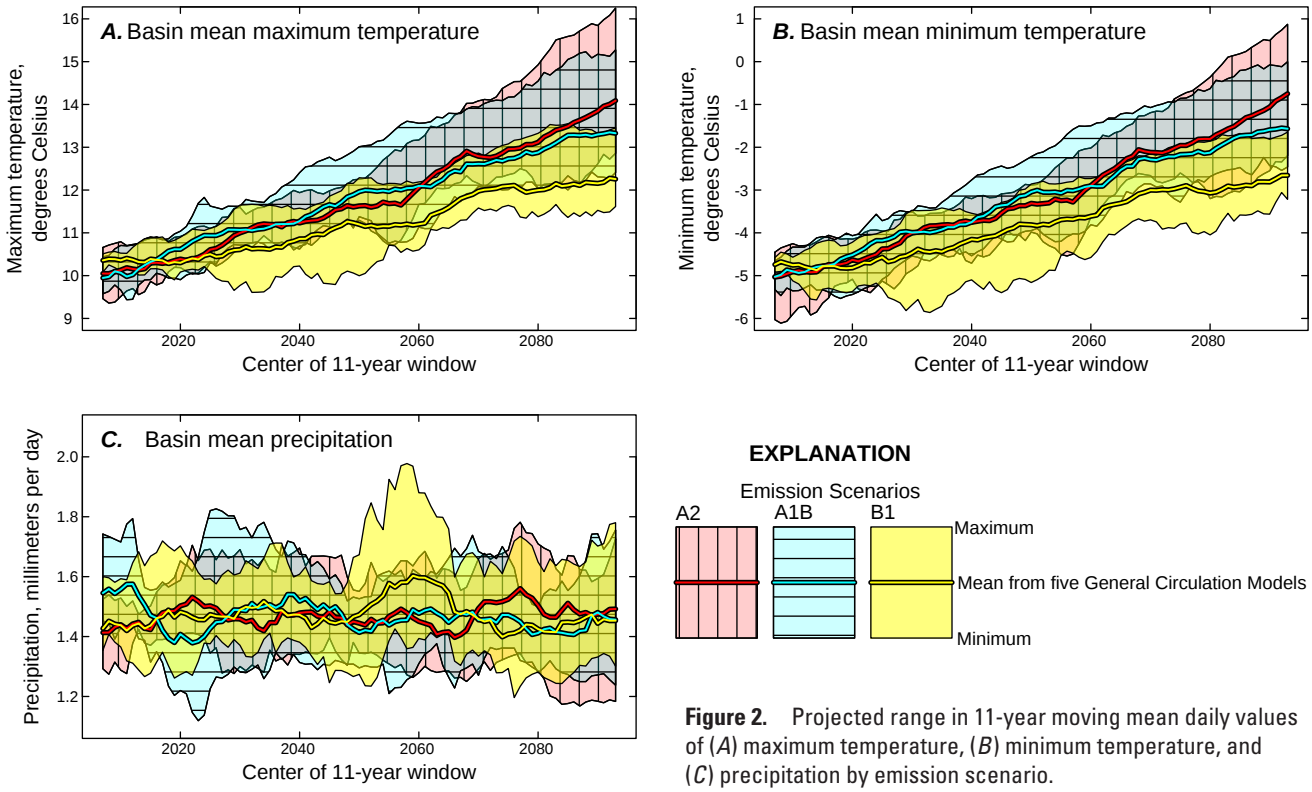


Figure 2. Projected range in 11-year moving mean daily values of (*A*) maximum temperature, (*B*) minimum temperature, and (*C*) precipitation by emission scenario.

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	0.040	0.99	0.046	0.98	0.026	0.96
Minimum temperature in degrees Celsius	0.042	0.99	0.049	0.98	0.028	0.97
Precipitation in millimeters per day	-0.0006	0.11	0.0004	0.08	0.0000	-0.01
Evapotranspiration in millimeters per day	0.0012	0.75	0.0018	0.88	0.0010	0.66
Streamflow in cubic meters per second	-0.0056	0.66	-0.0047	0.75	-0.0031	0.37
Surface runoff in cubic meters per second	-0.00141	0.73	-0.00112	0.85	-0.00084	0.47
Infiltration in millimeters per day	0.0006	0.30	0.0014	0.73	0.0007	0.31

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 (fig. 3*A*), evapotranspiration (fig. 3*B*), infiltration (fig. 3*C*), and surface runoff (fig. 3*D*) by emission scenario. The lines of central tendency of the five GCMs for the three emission scenarios show a significant negative trend in mean annual streamflow and surface runoff for the A1B and A2 emission scenarios (table 3). These decreases in streamflow and surface runoff may be related to corresponding projected increases in infiltration and evapotranspiration over time.

Projected changes in PRMS simulated variables can be examined on a monthly basis. The red lines in figure 4 show PRMS-simulated mean monthly streamflow and evapotranspiration for baseline conditions (1989–1999). The boxplots represent the range in the mean monthly projections for the five GCMs and three scenarios for 2030 (green, 2025–2035), 2060 (tan, 2055–2065) and 2090 (magenta, 2085–2095). The range of values indicated by the boxplots in figure 4 illustrates the high degree of uncertainty associated with the magnitude of projected changes. The basin exhibits little to no streamflow from September through February, mainly because of the sub-freezing temperatures in the basin. This is not projected to

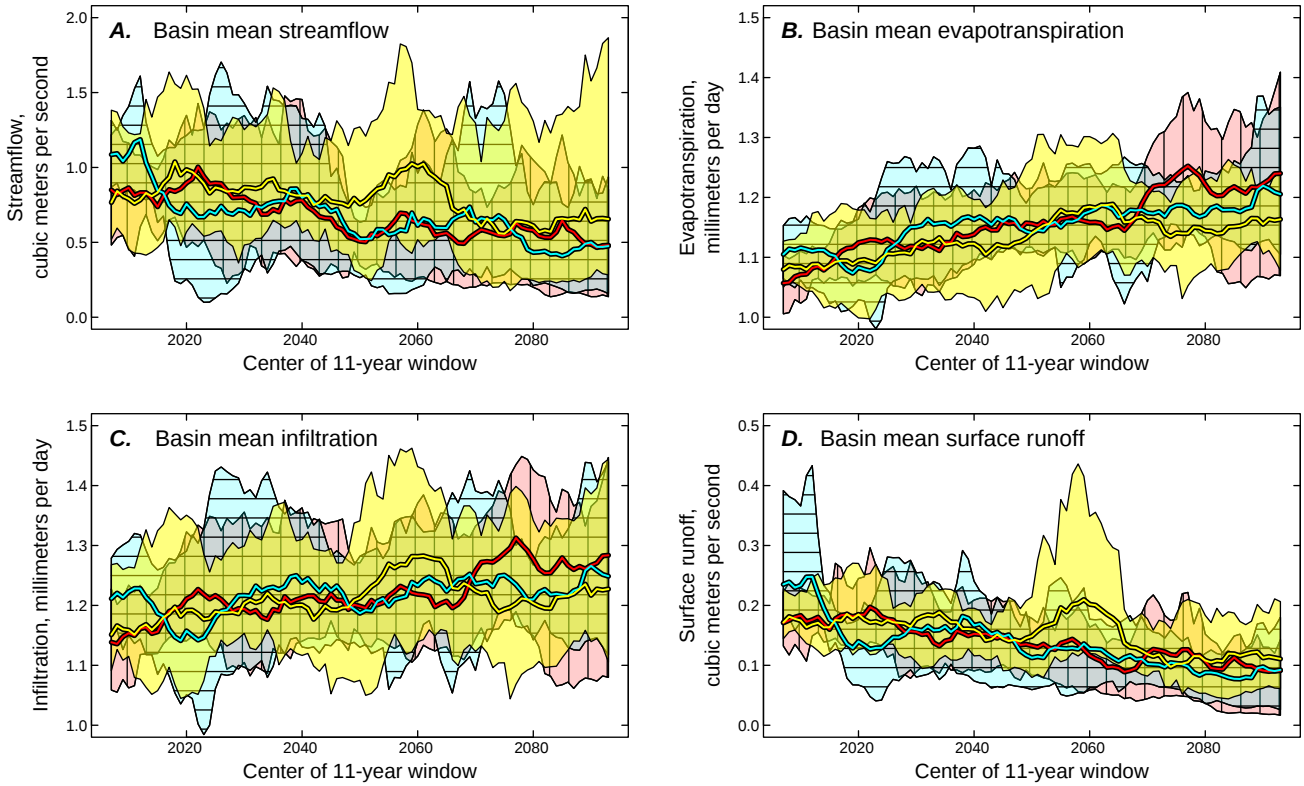


Figure 3. Projected range in 11-year moving mean daily values of (*A*) streamflow, (*B*) evapotranspiration, (*C*) infiltration, and (*D*) surface runoff by emission scenario.

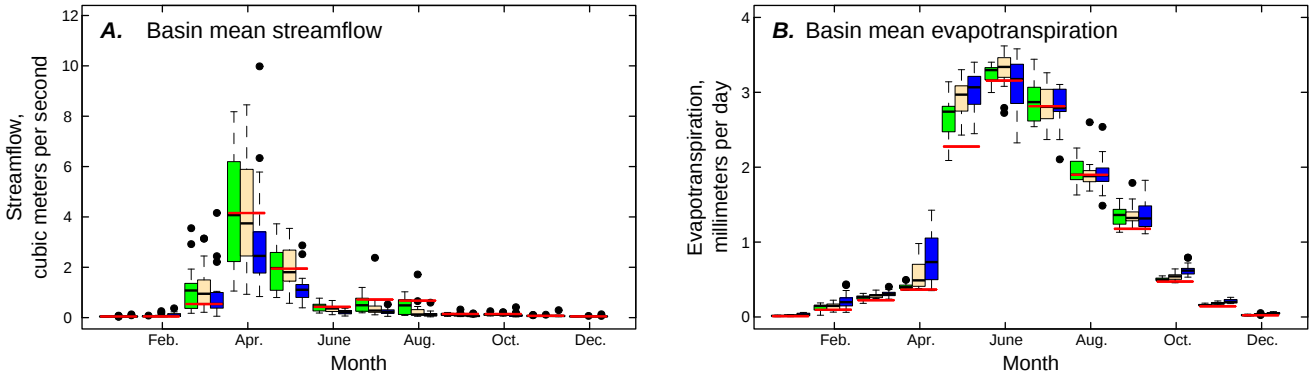
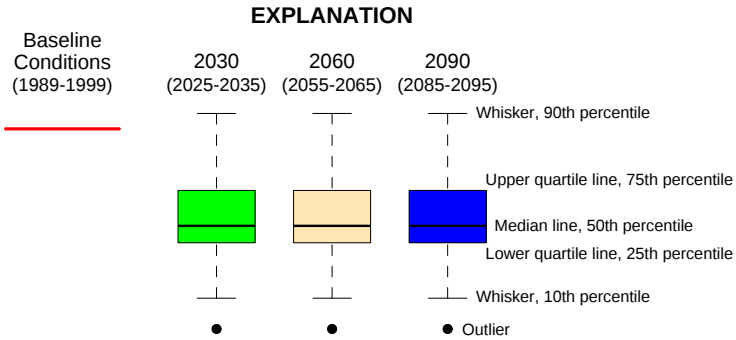


Figure 4. Mean daily (*A*) streamflow and (*B*) evapotranspiration values by month for baseline conditions and projected range (2030, 2060, and 2090) using the five General Circulation Models and three emission scenarios.



change substantially. As projected temperatures increase, evapotranspiration increases, resulting in less streamflow available for runoff and storage. The projected increases in mean monthly evapotranspiration in April and May by the end of the 21st century directly result in the projected decrease in mean monthly streamflow during those months.

Conclusion and Discussion

In the Starkweather Coulee Basin, continued above-normal precipitation along with drainage of wetlands and depressions could allow intermittent flooding conditions to occur. Additional flows downstream could increase Devils Lake water levels which potentially may cause additional damage to regional infrastructure, requiring additional spending on protective measures.

The broader-scale effects of climate change on streamflow and water storage in the Starkweather Coulee Basin indicates the possibility of an overall slight drying of the basin, but the uncertainty associated with this drying is large. Alternating flood and drought conditions, which occurred in the past, also are possible. The results did not consider potential future land-cover dynamics which likely would be limited to the type of agriculture and drainage practiced on the landscape. The scientific techniques described in the fact sheet can be augmented with other techniques in developing the science needed to address the combined effects of climate and land-cover dynamics on streamflow regimes.

Selected References

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