REPORT

Title: Connecting Climate Variability with Water Supply Reliability: A Case Study in the Trinity River Basin, Texas

Project Number: 2016TX501B

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Abstract

Supplying water to two of the top ten largest cities in the U.S. (i.e. Dallas and Houston), the Trinity River Basin (TRB) plays an important role in the Texas' growth. To meet the needs from the increasing water demand, and to mitigate flood risks, a number of reservoirs have been constructed during the past 60 years. Due to global warming, the climate has become extremely variable, which has exacerbated the frequency and magnitude of extreme events (e.g., flood and drought). The objective of this study was to evaluate how climate variability impacts water supply reliability in the TRB. To this end, future forcings generated from an ensemble of General Circulation Models (GCMs) under different Representative Concentration Pathways (RCP) scenarios was used to drive a fully distributed hydrologic model, which has a multi-purpose reservoir module. The Quantile Mapping Downscaling method was adopted to represent the climatic heterogeneity at a fine scale. Results show that flood risks in TRB will increase first and then decrease while the drought risks keep increasing. Consequently, water availability issues will be enlarged. It is possible that available water can reduce 18% around the end of this century. Therefore, more drought mitigation strategies are necessary for TRB.

Problem and Research Objectives

A reliable water supply system is crucial for sustaining socio-economic development in the fast growing State of Texas. The reliability of the water supply affects the availability of municipal, industrial, agricultural, and environmental water use. To enhance the reliability level of local water supplies, many efforts have been proposed and implemented around the world—including reservoir construction, water conservation, and salt/brackish water desalination. In the past, most water infrastructure projects and policies were designed and operated based on the assumption of stationarity—that the local climate is fixed and, on average, the weather moving forward will be the same as it has been in the past (Milly et al., 2007). However, with the increasing amount of greenhouse gases (GHG) accumulating in the atmosphere, both energy and water budget terms have been altered considerably across multiple scales. Consequently, natural variability can no longer explain the increased frequency of extreme events (e.g. floods and droughts; Zhao et al., 2016a). Thus, understanding the extent to which the water supply reliability level will be affected by the joint pressures of climate change and population growth is of great importance to better support the decision making process in Texas.

In this study, we focus on the Trinity River Basin (TRB) to evaluate the effect of climate change induced variability on water supply reliability. As the longest river (1142 km) flowing entirely in Texas, the Trinity River adds an average of 5.7 billion cubic meters of freshwater to the Gulf of Mexico per year. However, its streamflow is highly variable due to the large precipitation anomalies in the region. Meanwhile, the TRB bears the water supply responsibility for Dallas (entirely) and Houston (partially), two of the top ten cities (in terms of population) in the US. During the past 60 years, a number of reservoirs have been constructed to mitigate losses due to extreme events (e.g., floods and drought) and to increase water resilience. Specifically, Lake Livingston, which provides water for the City of Houston, is the second largest reservoir in Texas. Even though these reservoirs can meet current water demand, there is a growing concern about whether they will be sustainable under the combined pressures from population growth and more variable climate conditions.

Materials/Methodology

The hydrological model employed in this study is distributed hydrology soil and vegetation model (DHSVM), which is a physically based fully distributed model. Because of the fully distributed property, it can better simulate the spatial heterogeneity of different land cover types, especially urban impervious coverage. For impervious surface, DHSVM uses simple drainage system to route the water to the nearest stream channel directly. In addition, Zhao et al. (2016b) incorporated water management module into DHSVM, making it suitable to simulate the regulated water resources.

Before scenario simulation, DHSVM was calibrated and validated in TRB using data from multiple stream gauges and reservoirs (Figure 1). By using multiple sites, overfitting problems can be mitigated. In addition, it can better show the performance of the model over different locations inside of the river basin. The calibration period was chosen from 2005 to 2011 while validation period was chosen from 1980 to 2004. The coefficient of determination (R^2) for streamflow ranges from 0.65 to 0.90 and Nash-Sutcliffe Efficiency (NSE) ranges from 0.62 to 0.88 (values were calculated from 1980 to 2011). With respect to reservoir storage, the R^2 for the total storage of the 16 reservoirs is 0.97 and NSE is 0.96. Both R^2 and NSE show the good agreement between model simulation and observation, indicating robust performance of DHSVM.

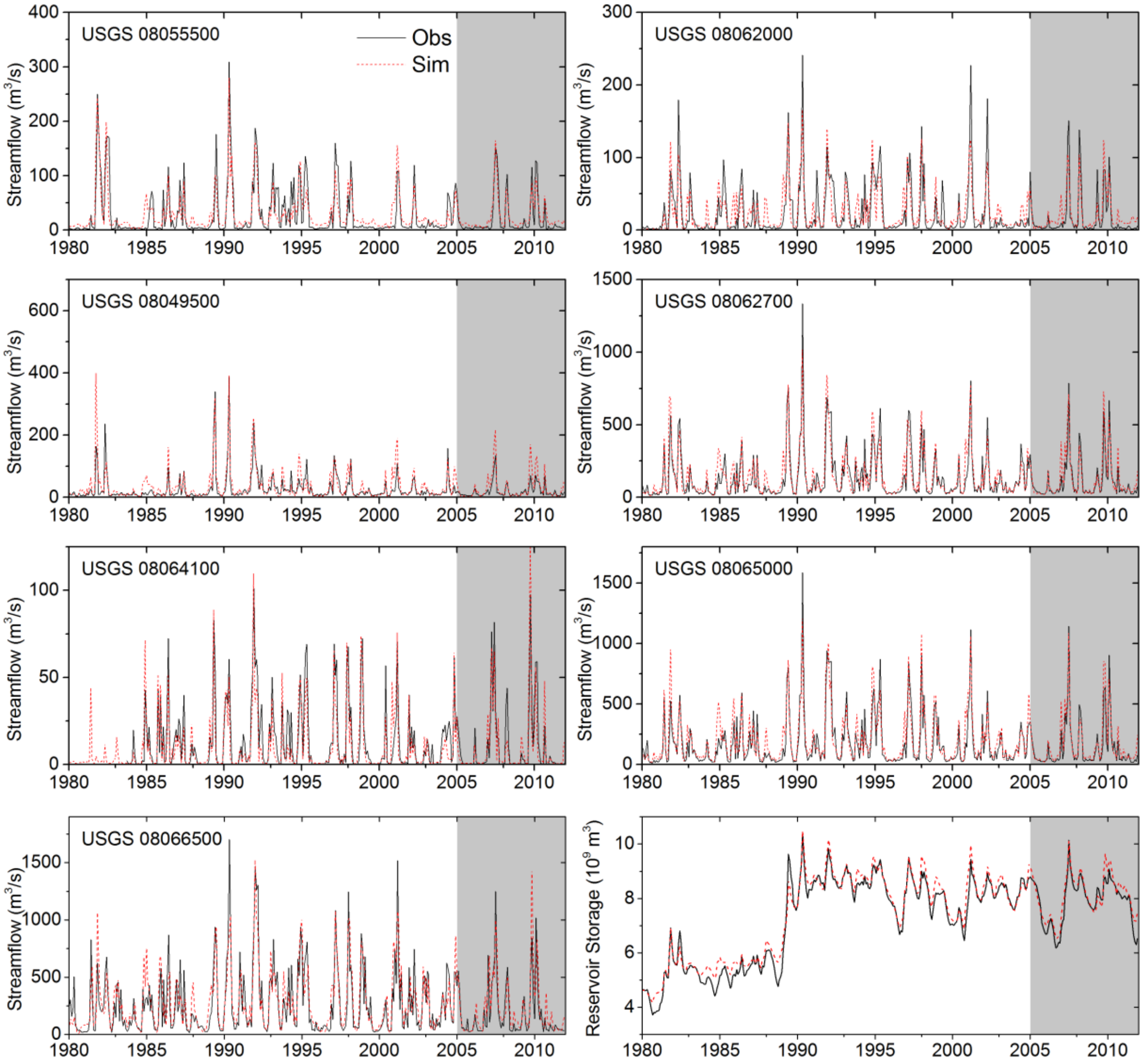

Figure 1. DHSVM calibration and validation results for 7 streamflow gauges and total reservoir storage for 16 reservoirs in TRB.

To evaluate climate change impacts, multiple general circulation models (GCMs) from international research groups were developed. Currently, Coupled Model Intercomparison Project Phase 5 (CMIP5) is the newest and most comprehensive projection. In this study, we chose 10 GCMs from CMIP5 to conduct the climate change impacts assessment (Table 1). By using multiple GCMs, uncertainty originated from climate model structure, which is proven to be the largest, can be represented. Because the spatial resolution of current GCMs is relatively coarse (~1 degree), which is not appropriate for basin scale hydrological studies. Thus, the common practice is to downscale the original GCM outputs using local climate observations. There are two major downscaling categories including statistical downscaling and dynamical downscaling. The former one is to use statistical method such as quantile mapping to adjust the GCM to match with the observation. The latter one is to use regional climate model (RCM) to re-simulate the regional climate using GCM outputs as forcing data. Comparing with dynamical downscaling, statistical downscaling has the advantages of less computation. Therefore, most climate assessment studies used statistical downscaling regardless of its limitations such as mass balance problems.

In this study, we used quantile mapping downscaling technique to downscale the original GCM outputs (Figure 2). Comparing with other downscaling techniques such as delta change and variance matching, quantile mapping takes the full distribution of both simulated and observed time series into consideration, resulting in better translation of climate signals.

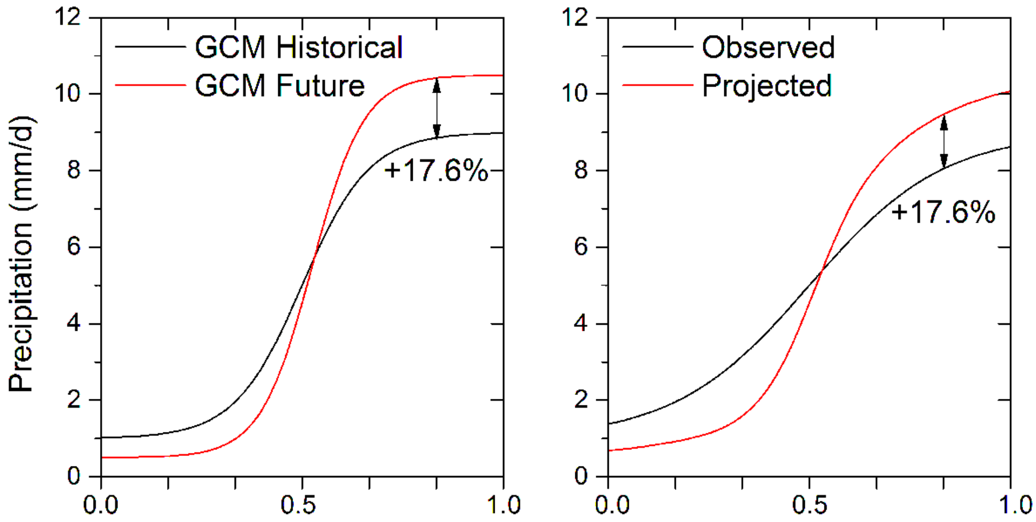

Figure 2. Quantile mapping technique to match the accumulative distributions of original GCM outputs to observation.

Table 1. 10 GCMs from CMIP5 that used in this study.

BCC-CSM1-1	MIROC-ESM
CCSM4	MIROC-ESM-CHEM
GFDL-ESM2G	MIROC5
GFDL-ESM2M	MRI-CGCM3
IPSL-CM5A-LR	NORESM1-M

Downscaled GCM outputs were used as the meteorological forcing data to drive the DHSVM. Three periods were chosen to evaluate the long term trends. The baseline period is from 1970 to 1999. Period 1 is from 2020 to 2049 while Period 2 is from 2070 to 2099. To evaluate the reservoir effects, we employed two different version of DHSVM. The one with no reservoir module was used to simulate naturalized flow and the one with reservoir module was used to simulate the regulated flow. The results of these two were compared subsequently. The metrics we used here is weekly maximum and weekly minimum, which can represent the extreme conditions with reasonable accuracy.

Principal Findings

There is clear pattern for the maximum precipitation for all four seasons (Figure 3). It is projected to increase first from baseline to Period 1, and then decrease to Period 2. On average, the maximum weekly precipitation is 8.53 mm/day for baseline run. It will increase to 9.37 mm/day for Period 1 and then decrease to 8.28 mm/day. With respect to minimum precipitation, it will decrease from 0.035 mm/day to 0.034 mm/day and then to 0.029 mm/day. Specifically, winter and summer values keep decreasing while spring increase first and then decrease. There is little change in terms of autumn minimum precipitation. Simulation from DHSVM shows the same pattern between naturalized flow and precipitation. Maximum weekly streamflow also increase first and then decrease and minimum weekly streamflow keep decreasing for the most seasons.

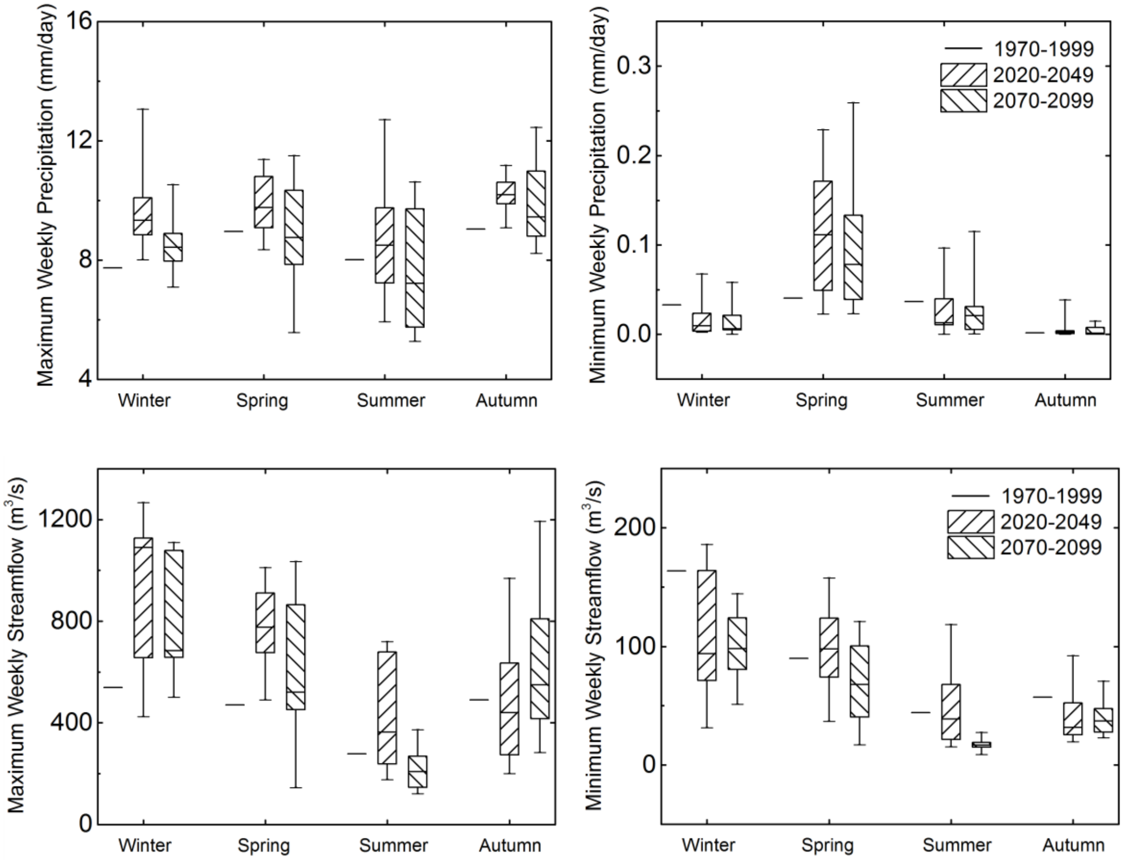

Figure 3. Seasonal precipitation and naturalized flow extremes at the outlet of Trinity River Basin

On the other hand, after reservoir regulation, different pattern was shown for maximum weekly streamflow (Figure 4). Generally, maximum weekly streamflow keep decreasing from baseline to Period 1 and then to Period 2. This pattern can be attributed to the flood control practices from the reservoirs. For minimum weekly streamflow, it follows the same pattern with the naturalized flow. Reservoir storage is a good indicator for flood risks and water supply reliability. In this study, we also calculated the maximum weekly storage and minimum weekly storage. They generally have the same trends with the regulated flow. Specifically, minimum weekly storage shows significant decrease in Period 2. It indicates that the water supply reliability might be at risk around the end of this century for TRB. The median value to reservoir storage will drop to 6.22×10^6 m^3 and the minimum possible total storage is 5.35×10^6 m^3, which is about 18% percent less than the baseline run. Considering TRB is already a water limited river basin, drought can be problematic in the future.

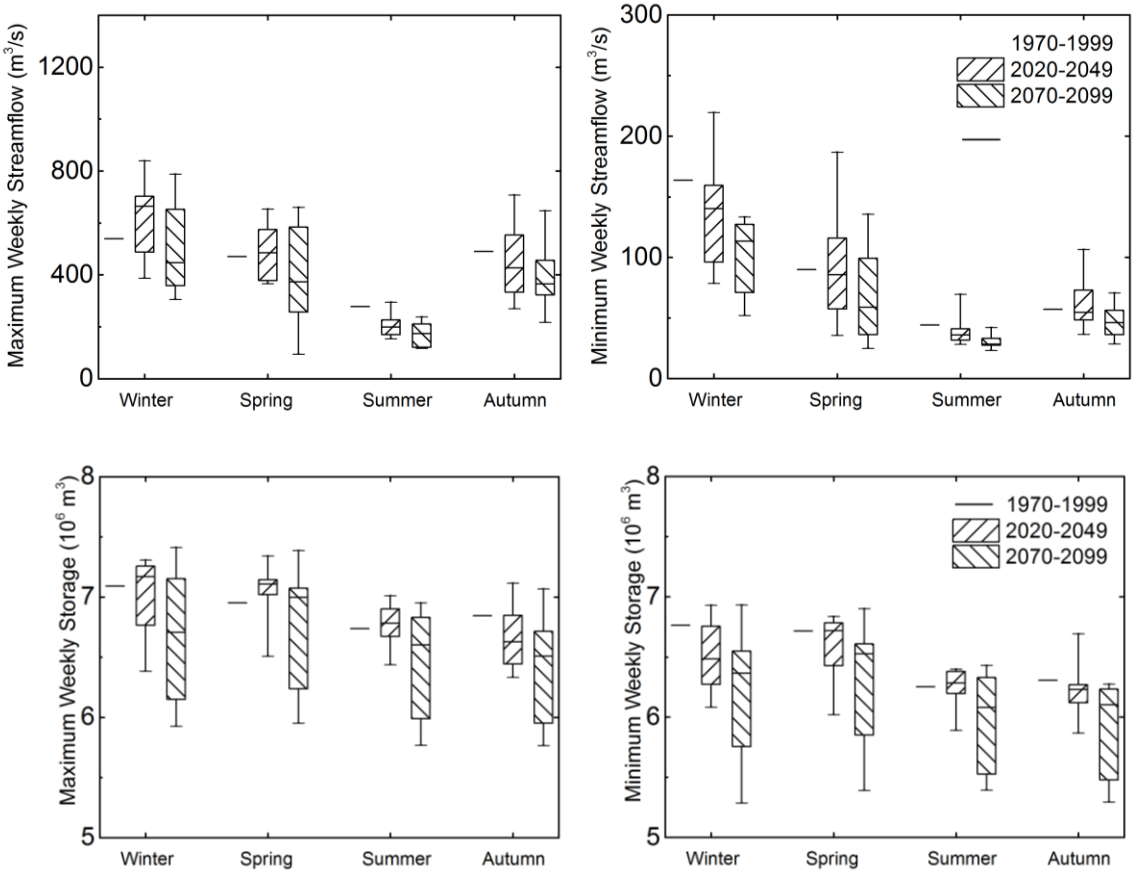

Figure 4. Seasonal regulated flow extremes at the outlet of Trinity River Basin and reservoir storage extremes for the entire basin.

Significance

Extreme events are always big concern for water managers. By using multiple GCM outputs, downscaling technique, and hydrological modeling, we assessed the impacts of climate change on the extreme events in Trinity River Basin. Results show that from baseline to Period 1 (2020-2049) and then to Period 2 (2070-2099), flood risks from naturalized flow will increase first and then decrease while drought risks are always increasing. With the help of reservoir operations, actual flood risks can be controlled. However, drought risks stays the same. For example, the water availability (average reservoir storage) might decrease 18% in 2070-2099. To this end, drought risks need to be better prepared for water managers in TRB. The quantification of the precipitation, streamflow, and reservoir storage extremes can help making more precise decisions to mitigate the corresponding risks.

References

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