Future water availability in Texas cities under urbanization and climate change: A case study in Dallas

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Reliability is a critical criteria for water supply, especially in the urban system. In most regions, supplied water are extracted from surface water and/or groundwater. However, because of the variability of natural climatology, there are large variations in the available amount for both surface water and groundwater. Specifically, surface water is more predominantly dependent on the local rainfall amount. For example, in the state of Texas, there is a significant precipitation shortage in the west regions, which results in higher drought risks than the east regions. In Texas history, droughts occurred periodically in the last hundred years. Specifically, there are three major devastating droughts that lead to dramatic ecological and economic losses including the Dust Bowl drought, 1950s drought, and 2011 drought. Meanwhile, demographic growth poses more pressure on the water stress, especially during drought periods. It is projected that Texas population is likely to be doubled in 2040 comparing with that in 2000 due to the fast migration rate. Therefore, how to reduce the uneven distribution of water resources and provide resilient water supply to the growing population is always a challenging issue facing with human communities.

Dallas City (Figure 1) was chosen as our pilot study area to evaluate how climate change and population growth will affect the water supply. In order to reduce the water stress more efficiently and assist the policy making process, we also tested several practical scenarios. In the past several decades, Dallas has witnessed a fast urbanization process. By 2010, water users in the city area is 2.4 million, which demands 430 million gallon of water every day. In the 1950s, Dallas experienced the worst drought in the city history. Dallas had to purchase low quality water from distant Red River during the drought. After this statewide drought, the Texas water related legislatures started to construct more water infrastructures to mitigate potential drought damages. Currently, Dallas has 7 reservoirs that can deliver supply water, which is sufficient for the current water users. However, how future potential droughts and demographic growth will affect the water supply system still needs detail assessment for making better water management plans.

To quantify the future potential droughts, we employed Palmer Drought Severity Index with Penman-Monteith Evapotranspiration (PDSI-PM) to select the worst potential drought from 7 General Circulation Models (GCMs), which belong to the Coupled Model Intercomparison Project Phase 5 (CMIP5). The future water demand (with uncertainties included) was projected using Monte Carlo simulation based on demographic growth projections. Subsequently, the future potential drought and future water demand were used to drive the hydrological model to simulate the reservoir storage and then to calculate the water supply surplus/deficit. The hydrological model that employed in this study is Distributed Hydrology Soil Vegetation Model with

Reservoirs (DHSVM-Res; Zhao et al., 2016), which has high spatiotemporal resolution and explicit physical basis.

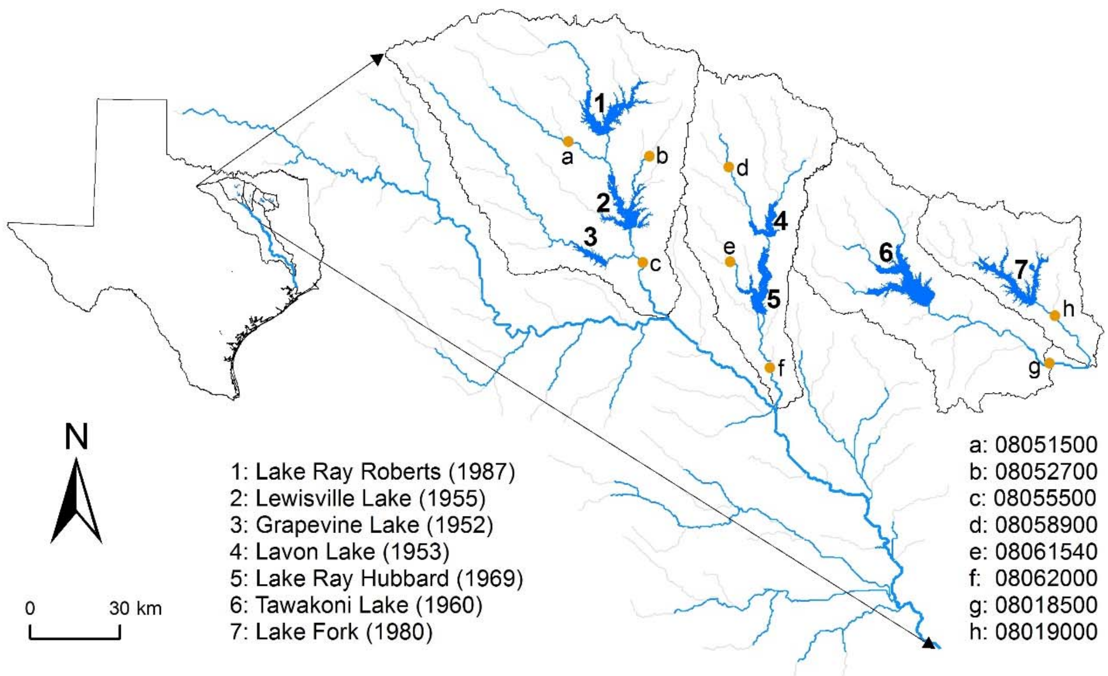

Figure 1. Dallas water source reservoirs and USGS streamflow gauges used for model calibration and validation.

Five year moving average of PDSI-PM values from ensemble CMIP5 suggests that there is significant decreases of PDSI-PM for both median and max/min after 2020. At the end of 21^{st} century, the median PDSI-PM decreases to -1.00, representing much drier condition than that at present. As a result, more effective mitigation strategies are necessary to reduce potential future severe drought damages.

Water demand projections show continuous increase of total water demand. The median water demand increases from 430 MGD in 2010 to 884 MGD in 2095. Along with the magnitude, the uncertainty is also increasing. In 2020, the uncertainty range (difference between 10% and 90%) is 35 MGD, which increases to 485 MGD in 2095. Even though Monte-Carlo simulation cannot perfectly represent the uncertainty in reality, it provides us more confidence when using the distribution rather than single value to assist the policy making process.

Before scenario simulations, DHSVM-Res was calibrated and validated. For streamflow simulations, coefficients of determination ranges from 0.70 to 0.85 and Nash-Sutcliff Efficiencies range from 0.43 to 0.84. For reservoir water elevation, coefficients of determination range from 0.60 to 0.95 and Nash-Sutcliff Efficiencies ranges from 0.46 to 0.95. Then impacts of drought on water availability was evaluated. Comparing with the 1950s drought, Period 1 (2020-2049) shows similar while Period 2 (2070-2099) shows faster reservoir storage depletion rate. For Period 1, the reservoirs can still provide sufficient amount of water to the city. Yet with respect to Period 2, water supply capability decreases dramatically due to the longer drought durations. Different water demand scenarios have significant impacts on the water supply reliability, especially in Period 2. Based on the DHSVM-Res simulations driven by CMIP5 ensemble, reservoir storage shows clear seasonality changes with October being the lowest. In addition, comparing with Period 1, Period 2 shows much larger uncertainty range for both reservoir storage and water supply/demand.

In order to improve the water supply reliability, Dallas city has proposed several adaptive strategies such as additional conservation, water reuse, new reservoir connections, and long distance water transfer. However, after these scenario simulations, we found that none of these individual scenarios can significantly reduce the water supply deficit. Yet if combined all these strategies together, significant increase of water availability can be reached. This indicates that comparing with individual strategies, combined strategy is more appropriate and efficient to increase water supply reliability.

References:

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