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

Project Type: Research

Focus Categories: WATER SUPPLY, FLOODS, DROUGHT

Research Category: Climate and Hydrological Processes

Keywords: Climate Variability, Water Supply, Trinity River Basin

Start Date: March 1, 2016

End Date: February 28, 2017

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Congressional District: Texas's 17th congressional district

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). Therefore, the objective of this study is to evaluate how climate variability and population growth will impact 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 will be used to drive a fully distributed hydrologic model, which has a multi-purpose reservoir module. The Quantile Mapping Downscaling method will be adopted to represent the climatic heterogeneity at a fine scale. Results for future time periods will be analyzed and compared with the historical baseline to exploit the long-term trend. Accordingly, optimal plans to improve the adaptive capacity of the water supply—while mitigating the losses due to disasters in the TRB—will be recommended.

Budget Breakdown

Cost Category	Federal	Non-Federal	Total
1. Salaries and Wages - Principal Investigator(s) - Graduate Student(s) - Undergraduate Student(s) - Others Total Salaries and Wages		$10000.00	$10000.00
2. Fringe Benefits - Principal Investigator(s) - Graduate Student(s) - Undergraduate Student(s) - Others Total Salaries and Wages			
3. Tuition - Graduate Student(s) - Undergraduate Student(s) Total Tuition	$ 5000.00		$ 5000.00
4. Supplies			
5. Equipment			
6. Services or Consultants			
7. Travel			
8. Other direct costs			
9. Total direct costs			
10a. Indirect costs on federal share			
10b. Indirect costs on non-federal share			
11. Total estimated costs	$ 5000.00	$10000.00	$15000.00
Total Costs at Campus of the University on which the Institute or Center is located.	$	$	$
Total Costs at other University Campus Name of University:	$	$	$

Budget Justification

Salaries and Wages for PIs. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.
N/A.
Salaries and Wages for Graduate Students. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)

$10000. Gang Zhao, Research assistant, $1650/mo.
Salaries and Wages for Undergraduate Students. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)
N/A.
Salaries and Wages for Others. Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.
N/A.
Fringe Benefits for PIs. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.
N/A.
Fringe Benefits for Graduate Students. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable.
2.7%
Fringe Benefits for Undergraduate Students. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable
N/A.
Fringe Benefits for Others. Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.
N/A.
Tuition for Graduate Students.
$5000
Tuition for Undergraduate Students
N/A.
Supplies. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies. Provide a breakdown of the supplies in each category.
N/A.
Services or Consultants. Identify the specific tasks for which these services, consultants, or subcontracts would be used. Provide a detailed breakdown of the services or consultants to include personnel, time, salary, supplies, travel, etc.
N/A.
Travel. Provide purpose and estimated costs for all travel. A breakdown should be provided to include location, number of personnel, number of days, per diem rate, lodging rate, mileage and mileage rate, airfare (whatever is applicable).
N/A.
Other Direct Costs. Itemize costs not included elsewhere, including publication costs. Costs for services and consultants should be included and justified under “Services or Consultants (above). Please provide a breakdown for costs listed under this category.
N/A.
Indirect Costs. Provide negotiated indirect (“Facilities and Administration”) cost rate.
N/A.

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

Statement of regional or State water problem

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., 2008). 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., 2015). 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.

References

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer, 2008: Stationarity Is Dead: Whither Water Management? Science, 319, 573-574.

Zhao, Gang, Huilin Gao, and Lan Cuo, 2015. Effects of Urbanization and Climate Change on Peak Flows over the San Antonio River Basin, Texas. Journal of Hydrometeorology. (in review).

Statement of results or benefits

Results of this study mainly consist of three parts: trends of climate variability from the past into the future, the effects of these trends on the hydrological cycle, and the subsequent impacts on the water supply system in the TRB.

First, the trend analysis of climate variability will be able to demonstrate whether climate change will induce more variability. Texas is located in the climate transition zone (from the humid zone to the arid/semi-arid zone), which makes it vulnerable to changes in climate variability. Several studies show that global climate variability will increase dramatically with the growing GHG concentration in the atmosphere. However, for specific regions, this statement is still uncertain. Thus, the initial results of this study intend to find the answer by quantitatively revealing the changes of climate within the TRB.

Second, using a modeling approach, the response of the hydrological cycle to this change of climate variability will be evaluated. Hydrological variables to be investigated include soil moisture, evapotranspiration, streamflow, and reservoir water level.

Third, due to the inclusion of a reservoir module in our modeling method, water supply reliability will be quantified for the entire basin (which bears water supply responsibility for two megacities—Dallas and Houston). Using the results obtained, some practical strategies will be proposed in this study.

It is expected that this study will be beneficial for improving the adaptive capacity—and the overall sustainability—of Texas water resources management practices, under the substantial impacts of a more variable climate.

Nature, scope, and objectives of the project, including a timeline of activities

Nature

This project is a systematic analysis of basin scale water supply reliability under the impacts of climate variability. Some basic features of this project are as follows:

1. It focuses on one Texas river basin (i.e., TRB), which is of the highest importance for Texas urban water supply.
2. It will evaluate the effects of large climate variability on the water supply system at the basin scale.
3. It will take into account climate uncertainties, such as the GCM uncertainty and the GHG emission uncertainty.
4. Results from this project will be used to assist decision making related to future water resources management practices.
5. The methodology of this study is applicable to most of the managed watersheds throughout the world.

Scope

The scope of this project focuses on the TRB. Because it is a basin scale study, the potential beneficial groups include: policy makers for the basin, current and potential water users in the area, and two megacities (i.e. Dallas and Houston).

Objective

The objective of this study is to evaluate future water supply reliability in the TRB through simulating reservoir storage in this basin under various scenarios.

Timeline of activities

1. March 2016 – March 2016: Literature review
2. April 2016 – June 2016: Model input data preparation
3. July 2016 – October 2016: Model calibration, validation, and scenario based simulations
4. November 2016 – December 2016: Results analysis
5. January 2017 – February 2017: Project finalization and report writing

Methods, procedures, and facilities

Climate variability includes natural long-term variability and short-term GHG induced variability. Basically, the natural long-term variability range is bounded by a specific envelope, while the near-term variability increases with the rising GHG concentration (resulting in overall increases of climate variability). In this study, to assess the trend of climate variability, three time periods (i.e. 1970-1999, 2020-2049, and 2070-2099) will be compared. A physically-based and fully-distributed hydrologic model (i.e. the Distributed Hydrology Soil Vegetation Model, DHSVM) will be used to conduct the study. Due to its high spatial/temporal resolution and its accurate representation of most of the hydrological processes, DHSVM is highly appropriate for regional water resources management. However, the current public version of DHSVM lacks the capability for reservoir simulation. Thus, the applicant developed a new multi-purpose reservoir module and tested it over Lake Whitney (Zhao et al., 2016). This newly integrated model will be employed in this study.

First of all, to guarantee the applicability of the model, calibration and validation will be implemented. Then simulation will be made during the three study periods. During the historical period, observed climatology from Livneh et al. (2013) will be used to drive the model. For the two future periods, forcings from the Coupled Model Intercomparison Project Phase 5 (CMIP5) will be employed. Trend analysis will be implemented based on the results comparison between these three periods. In order to take the GHG emission uncertainty into account, all four Representative Concentration Pathways (RCPs) will be incorporated into the simulations. Detailed modeling steps are proposed as follows:

1. Bias-corrected projected forcing data will be downloaded and then spatially and temporally downscaled using the quantile mapping method. The quantile mapping method is selected because it can successfully capture the distribution of future climate (in terms of both mean and variance). Accordingly, the future climate variability can be incorporated into the downscaled forcing data.
2. Driven by the downscaled forcing data under different RCPs, DHSVM will be employed to investigate the climate change effects on streamflow and reservoir systems.
3. Future water supply reliability (with population growth and its uncertainty incorporated) will be calculated and compared with the baseline run (i.e. 1970-1999).

4. Based on the results of the analyses, feasible adaptive strategies for reservoir management in the TRB will be proposed.

References

Livneh, Ben, Eric A. Rosenberg, Chiyu Lin, Bart Nijssen, Vimal Mishra, Kostas M. Andreadis, Edwin P. Maurer, and Dennis P. Lettenmaier, 2013. A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States: Update and extensions. Journal of Climate 26, no. 23: 9384-9392.

Zhao, Gang, Huilin Gao, Bibi S. Naz, and Shih-Chieh Kao, 2016, Integrating reservoir regulation scheme into a spatially distributed hydrological model. Advances in Water Resources. (to be submitted).

Related research

This USGS Graduate Research Program is related to the other program the applicant is working on – the Mills Scholars Program for 2015-2016, entitled “Future water availability in Texas cities under urbanization and climate change: A case study in Dallas”. However, the scope for the Mills program is focused on the city of Dallas and the combined effects of urbanization and climate change. Climate change effects will be evaluated based on magnitude changes (e.g. the observed and predicted amount of precipitation change from 1970-1999 to 2020-2049). This USGS program will be focused on the basin scale (i.e. TRB) and on connecting climate variability with water supply reliability. Climate variability will be the major concern because it has a tighter connection with extreme events such as flood and drought, which are more critical issues in water resources management. The matching fund to this project is from Dr. Huilin Gao.

Training potential

This proposed study will mainly be carried out by the applicant, who is currently a Ph.D student.

Investigator's qualifications

Gang Zhao

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Phone: (979)587-4367

Education

Jan.2015 – Present	Ph.D. candidate; Water Resources Engineering Zachry Department of Civil Engineering, Texas A&M University Advisor: Dr. Huilin Gao
Sep.2013 – Dec.2014	Master of Science; Water Resources Engineering Zachry Department of Civil Engineering, Texas A&M University GPA: 4.0/4.0
Sep.2012 – Jun.2013	Master Candidate; Environmental Science College of Environmental Science and Engineering, Nankai University, China GPA: 89.21/100
Sep.2008 - Jun.2012	Bachelor of Science; Environmental Science College of Environmental Science and Engineering, Nankai University, China Major GPA: 90.57/100; Overall GPA: 88.15/100

Research Experience

Jun.2014 – Present	Hydrologic simulations of reservoir systems using the Distributed Hydrology Soil Vegetation Model (DHSVM)
Sep.2013 – Jun.2014	Effects of urbanization and climate change on hydrological processes over the San Antonio River Basin, Texas
Oct.2011 – Dec.2012	Surface water quality modeling with a case study from Xin'An River Basin, China
Nov.2011 – Jun.2012	Uncertainty analysis based on Bayesian statistics for nutrient reduction in Yuqiao Reservoir, Tianjin
May.2010 – May.2011	Watershed management by using combined water quality models

Papers & Presentations

Zhao, Gang, Huilin Gao, and Lan Cuo, Effects of urbanization and climate change on hydrological processes over the San Antonio River Basin, Texas. Journal of Hydrometeorology. (in review)

Zhao, Gang, Huilin Gao, Bibi S. Naz, and Shih-Chieh Kao, 2016, Integrating reservoir regulation scheme into a spatially distributed hydrological model. Advances in Water Resources. (to be submitted).

Zhao, Gang, Huilin Gao, Bibi S. Naz, Shih-Chieh Kao, and Nathalie Voisin, Sensitivity of Reservoir Storage and Outflow to Climate Change in a Water-limited River Basin. American Geophysical Union, Fall Meeting 2015, abstract #H33D-1644

Zhao, Gang, Huilin Gao, and Lan Cuo, (2014) Effects of urbanization and climate change on streamflows over the San Antonio River Basin, Texas. Abstract 34.3, UCOWR/NIWR/CUAHSI Conference.

Zhao, Gang, Chuan Li, Yuchao Lu, and Yuqiu Wang, (2013) Application of QUAL2Kw model to simulation of water quality in Huangshan section of Xin'an River, Journal of Water Resources and Water Engineering, 24(5): 1-5 (in Chinese).

Awards & Honors

Jun.2015 Mills Scholarship from Texas Water Resources Institute

May.2012 Merit Student Scholarship, Nankai University

Oct.2011 First Prize of Excellent Undergraduate Scholarship in Nankai University

Jun.2009 Second Prize in University Mathematics Competition of Tianjin City

Nov.2007 First Prize in National High School Mathematics Competition

HUILIN GAO

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EDUCATION

Ph.D. 2005, Civil and Environmental Engineering, Princeton University
M.A. 2002, Civil and Environmental Engineering, Princeton University
M.S. 2000, Atmospheric Sciences, Peking University
B.S. 1997, Atmospheric Sciences, Peking University

PROFESSIONAL POSITIONS

2012~present: *Assistant Professor*
Zachry Dept. of Civil Engineering, Texas A&M University
2008~2012: *Research Associate*
Dept. of Civil and Environmental Engineering, University of Washington
2005~2007: *Research Scientist II/Research Faculty*
School of Earth and Atmospheric Sciences, Georgia Institute of Technology

RESEARCH INTERESTS

Hydroclimatology, hydrometeorology, remote sensing, and water resources management

HONORS AND AWARDS

2015: National Science Foundation (NSF) CAREER Award

MEMBERSHIP

- Member of American Geophysical Union (AGU)
- Member of the Institute of Electrical and Electronics Engineers (IEEE)
- Member of American Meteorology Society (AMS)
- Member of Sigma Xi Scientific Research Society
- Member of American Society of Civil Engineers

REVIEWER for

A. Journals

Advances in Space Research, Journal of Hydrometeorology, Journal of Hydrology: Regional Studies, Water Resource Research, Hydrological Processes, Journal of Atmospheric and Oceanic Technology, Remote Sensing of Environment, IEEE Transactions on Geosciences and Remote Sensing, Journal of Geophysical Research – Atmosphere, Journal of Natural Resources Policy Research, Journal of the Meteorological Society of Japan, Journal of Plant Ecology (UK), Atmosphere-Ocean, Vadose Zone Journal, Marine Geodesy, Water, Climatic Change, Journal of the American Water Resources Association.

B. Funding agencies

National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Netherlands Organization for Scientific Research (NOSR)

SERVICES

- Judge for the Summer Undergraduate Research Symposium at Texas A&M University, 2014.
- Committee member of ‘Water initiative committee working group 3 (integrated water funding)’ at Texas A&M University
- Co-convener of AGU 2014 fall meeting, session GC11G: From Glacierized Watersheds to Global River Basins: Advances in water resources management modeling and monitoring
- Chair convener of AGU 2013 fall meeting, session GC012: Advances in Reservoir Modeling and Monitoring from Regional to Global Scales
- Associate Editor of Journal of Plant Ecology (UK) (2010-2012)
- Invited Editor for the special issue on “Plant and Water” (Journal of Plant Ecology, 2011)
- Co-convener of AGU 2010 fall meeting, session H52A: Detecting and Predicting Change in Coupled Human-Water Systems
- Judge for the Outstanding Student Paper Awards of AGU fall meetings (2010, 2011,2012, 2014)

Selected Peer Reviewed Journal Papers (* represent student; # represent corresponding author)

1. Kang, D., **H. Gao**, X. Shi, and S. J. Dery, 2016: Impacts of a rapidly declining mountain snowpack on streamflow timing in Canada’s Fraser River Basin, *Scientific Reports*, 5:19299.
2. Zhou, T., B. Nijssen, **H. Gao**, and D.P. Lettenmaier, 2016: The contribution of reservoirs to global land surface water storage variations, *J. Hydrometeorology*, 17, 309–325.
3. **Gao, H#**., S. Zhang*, R. Fu, W. Li, and R. E. Dickinson, Inter-annual Variation of the Surface Temperature of Tropical Forests from SSM/I Observations, Advances in Meteorology, Article ID 564126, 2015. (Invited)
4. Qiao, X., J. Hu, S. Zhang*, S. H. Kota, J. Li, L. Wu, **H. Gao,** H. Zhang, Y. Tang and Q. Ying, Modeling Dry and Wet Deposition of Sulfate, Nitrate, and Ammonium Ion in Jiuzhaigou National Nature Reserve, China using a Source-Oriented CMAQ Model: Part I. Base Case Model Results, Atmospheric Environment, doi:10.1016/j.scitotenv.2015.05.108, 2015.
5. **Gao, H.#**, Satellite remote sensing of large lakes and reservoirs: from elevation and area to storage, *WIREs Water*, doi:10.1002/wat2.1065, 2015.
6. Zhang, S.***, H. Gao#**, and B. Naz, Monitoring Reservoir Storage in South Asia from Satellite Remote Sensing, *Water Resource Research*, *Water Resource Research*, 50, doi:10.1002/2014WR015829, 2014.
7. Nijssen, B., S. Shukla, C. Lin, **H. Gao**, T. Zhou, J. Sheffield, E. F. Wood, D. P. Lettenmaier, 2013: A prototype Global Drought Information System based on multiple land surface models, *J. Hydrometeorology*, 15, 1661-1676, 2014.
8. Kang, D., X. Shi, **H. Gao**, and S. Dery, A modeling study of the changing contribution of snow to the hydrology of the Fraser River Basin, *J. Hydrometeorology*, 15, 1344-1365, 2014.
9. Leng, G., M. Huang, Q. Tang, **H. Gao**, L. Leung, Impacts of irrigated agriculture on surface and groundwater resources simulated by the Community Land Model, *J. Hydrometeorology*, 15, 957-972, 2014.
10. **Gao, H.**, C. Birkett, and D. P. Lettenmaier, Global monitoring of large reservoir storage from satellite remote sensing. *Water Resources Research*, 48, doi:10.1029/2012WR012063. ***(Selected as Eos Transactions American Geophysical Union research spotlight)*.**
11. **Gao, H.,** T.J. Bohn, E. Podest, K.C. McDonald, and D.P. Lettenmaier, On the causes of the shrinking of Lake Chad. *Environ. Res. Lett.* 6, doi:10.1088/1748-9326/6/3/034021, 2011.
12. Su, F., **H. Gao**, G. J. Huffman, and D. P. Lettenmaier, Potential utility of the real-time TMPA-RT precipitation estimates in streamflow prediction, *J. Hydromet.*, 12, 444-455, 2011.
13. Waring, R. H., J. Chen, and **H. Gao,** Plant-water relations at multiple scales: integration from observations, modeling and remote sensing, *J. Plant Ecology*, 4(1-2), 1-2, 2011.