Texas Water Resources Institute
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Introduction

The Texas Water Resources Institute (TWRI), a unit of Texas A&M AgriLife Research, Texas A&M AgriLife Extension Service and the College of Agriculture and Life Sciences at Texas A&M University, and a member of the National Institutes for Water Resources, provides leadership in working to stimulate priority research and extension educational programs in water resources. AgriLife Research and AgriLife Extension provide administrative support for TWRI, and the Institute is housed on the campus of Texas A&M University.

TWRI thrives on collaborations and partnerships and in fiscal year 2016 managed 32 active projects with more than $8,000,000 in funds. Those projects involved more than 100 Texas A&M University System faculty members and graduate students as well as faculty from other universities across the state. The Institute maintained joint projects with both Texas universities and out-of-state universities; federal, state and local governmental organizations; consulting engineering firms, commodity groups and environmental organizations; and numerous others. In 2016, the Institute was awarded 17 new TWRI-lead projects with direct funding of $3,300,622.

TWRI works closely with agencies and stakeholders to provide research-derived, science-based information to help answer diverse water questions and also to produce communications to convey critical information and to gain visibility for its cooperative programs. Looking to the future, TWRI awards water scholarships to graduate students at Texas A&M through funding provided by the W.G. Mills Endowment and at Texas A&M and other universities in Texas by the U.S. Geological Survey.

Research Program Introduction

Through the funds provided by the U.S. Geological Survey in combination with funding from the W.G. Mills Endowment, TWRI funded two graduate student research projects in 2016-2017 conducted by one graduate student at Texas A&M University and one at the University of Texas.

Ricardo Lugo, Department of Civil, Architectural and Environmental Engineering at the University of Texas at Austin. Advisor: Dr. Mary Jo Kirisits. Research: Impact of coagulation on biofiltration: removal of trace organic contaminants to mitigate the effects of wastewater reuse on drinking water treatment.

Gang Zhao, Zachry Department of Civil Engineering at Texas A&M University. Advisor: Dr. Huilin Gao. Research: Connecting climate variability with water supply reliability: A case study in the Trinity River Basin, Texas.

Impact of coagulation on biofiltration: removal of trace organic contaminants to mitigate the effects of wastewater reuse on drinking water treatment

Basic Information

Title:	Impact of coagulation on biofiltration: removal of trace organic contaminants to mitigate the effects of wastewater reuse on drinking water treatment
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Principal Investigators:	Ricardo Lugo, Mary Jo Kirisits

Publications

There are no publications.

Title Impact of coagulation on biofiltration: removal of trace organic contaminants to mitigate the effects of wastewater reuse on drinking water treatment

Project Number 2016TX500B

Primary PI Ricardo Lugo, M.S. Student, Fall 2015-2017. Department of Civil, Architectural, and Environmental Engineering, The University of Texas at Austin, 301 E Dean Keeton St, Stop C1786, Austin, TX 78712. E-mail: lugo689@gmail.com. Phone: 512.965.9695

Other PIs Mary Jo Kirisits, Associate Professor, Department of Civil, Architectural, and Environmental Engineering, The University of Texas at Austin, 301 E Dean Keeton St, Stop C1786, Austin, TX 78712. E-mail: kirisits@utexas.edu. Phone: 512.232.7120

Abstract Biofiltration has been assessed for the removal of several types of trace organic contaminants (TrOCs), including endocrine-disrupting compounds, pharmaceuticals and personal care products, and taste and odor compounds. Biofiltration is often preceded by the unit processes of coagulation, flocculation, and sedimentation. Maximizing the simultaneous removal of multiple TrOCs via independent optimization of each such unit process in a treatment train ignores synergism and antagonism among the processes. Thus, a holistic consideration of contaminant removal by biofiltration must include examination of common upstream processes, such as coagulation. Overall, coagulation will impact the amount and composition of natural organic matter in the biofilter influent; this could influence microbial community structure and biodegradation capability, with implications for the removal of TrOCs, total organic carbon, biodegradable dissolved organic carbon, and assimilable organic carbon. In this study, we examine the impact of coagulant type, coagulant dose, and coagulation pH on the simultaneous removal of multiple TrOCs in downstream biofiltration. Synthetic water was prepared for these experiments using natural organic matter concentrated from Lake Austin in Austin, Texas. Four parallel bench-scale biofilter trains were operated. One granular activated carbon (GAC) biofilter train and one sand biofilter train were operated as controls, using non-coagulated synthetic water. One GAC biofilter train is being operated with alum-coagulated synthetic water, and one GAC biofilter train is being operated with ferric-coagulated synthetic water. A suite of nine common TrOCs was selected to cover a range of chemical classes, product applications, and relative biodegradabilities. The TrOCs are added to the synthetic water after coagulation, each at a concentration of 0.5 μg/L. Coagulation doses and optimum coagulation pH were determined via jar-testing to be 50 mg/L at

pH 6.5 for alum and 60 mg/L at pH 5.5 for ferric chloride. As expected, iron coagulation removed more dissolved organic carbon than did alum coagulation. Atenolol, caffeine, DEET, naproxen, diclofenac, and gemfibrozil all showed the highest removal in the biofilter train receiving ferric-coagulated water, which had the highest removal of dissolved organic carbon as compared to the other biofilter trains. For 2-MIB and geosmin, the highest removal was observed in the GAC biofilter receiving non-coagulated water as compared to the other biofilter trains. The sand biofilter only removed atenolol, but at a low percent removal (10%). Thus far ferric chloride may be more beneficial to use during treatment since it appears to have better removal of a greater variety of TrOCs in treatment train 4 and removes a greater amount of DOC during coagulation, which can be beneficial to the operational parameters of biofilters at a water treatment plant.

Problem and Research Objectives

A key problem in the drinking-water industry is to find effective treatment processes to remove an increasing variety and concentration of trace organic compounds (TrOCs), such as endocrine-disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs), and taste and odor compounds, many of which occur due to increased wastewater influence. As water scarcity continues, the number of wastewater-impacted drinking water treatment plants likewise will increase. Thus, indirect and direct potable reuse will become more commonplace. The 2012 Texas State Water Plan predicts that water reuse will provide approximately 1.53 million acre-feet per year of water supply statewide by 2060 and will meet 18% of the projected water needs. During low-flow conditions in the summer, the influent to drinking water treatment plants in many Texas cities consists mainly, if not 100 percent, of wastewater from upstream cities (Rice et al., 2015). The increase in reuse, application of more conservation measures, and longer drought periods means that drinking water treatment plants will see both a greater variety and increasing concentration of TrOCs. Therefore, the drinking-water industry needs to find effective treatment processes to remove this increasing variety and concentration of TrOCs. The multi-barrier benefits of biofiltration, including particle removal, biodegradation, and adsorption, make this an attractive process for addressing the TrOC problem.

Biofiltration has been assessed for the removal of several types of TrOCs, including EDCs (Zearley & Summers, 2012); PPCPs (Zearley & Summers, 2012); and taste and odor compounds (Nerenberg et al., 2000). Biofiltration is often preceded by coagulation, flocculation, and sedimentation. Maximizing the simultaneous removal of multiple TrOCs via independent optimization of each unit process in a treatment train ignores synergism and antagonism among the processes. Thus, a holistic consideration of contaminant removal by biofiltration must include examination of common upstream processes, such as coagulation.

Coagulation, flocculation, and sedimentation reduce particle loading to the biofilter and can remove a portion of natural organic matter (NOM) from the water (reviewed by Matilainen et al., 2010). To help minimize disinfectant byproduct (DBP) concentrations in finished drinking water, U.S. Environmental Protection Agency regulations specify the removal of total organic carbon (TOC) by enhanced coagulation, where the required TOC removal depends on the TOC and alkalinity of the source water. Coagulation and biofiltration should be used in concert with one another to minimize effluent organic carbon and DBP formation potential. Lauderdale and Brown (2013) demonstrated that purposefully decreasing TOC removal via coagulation (by halving the coagulant dose) could be offset by increased TOC removal via biofiltration, resulting in similar overall TOC removals by coagulation/biofiltration under both coagulant conditions. These results suggest that shifting greater burden for TOC removal to the biofilters, which are operationally less expensive than is coagulation, could provide cost-savings to a utility.

Some studies have noted greater NOM removal with ferric- as compared to aluminum-based coagulants (e.g., Bell-Ajy et al., 2000). The hydrophilic neutral fraction of NOM, which strongly contributes to biodegradable dissolved organic carbon (BDOC), tends to remain at a higher concentration in the water after alum coagulation (Soh et al., 2008) as compared to ferric coagulants, which generally removed up to 20% more BDOC(Volk et al. 2000). ; however, removal within these processes is highly dependent on pH (Matilainen et al., 2010). Hence, when coagulation occurs upstream of biofiltration, the coagulant choice and pH selection must be made in light of how those choices will impact overall NOM and TrOC removal. In particular, the influent BDOC concentration to the biofilter must be sufficient to sustain the biomass needed for TrOC removal because TrOCs are likely to be secondary microbial substrates due to their low concentrations.

Several studies have suggested that the amount of biomass in a biofilter, as long as it is above some critical minimum amount, does not impact the overall removal of biodegradable organic matter in a biofilter (e.g., Urfer et al., 1997). However, Urfer et al. (1997) also suggest that the critical minimum amount of biomass might be higher for more slowly biodegradable components as compared to the amount of biomass necessary for more easily biodegradable components. Thus, the biodegradation of some TrOCs (e.g., sulfamethoxazole) could be improved by increased biomass concentrations in the biofilter. Overall, coagulation will impact the amount and composition of NOM in the biofilter influent; this could influence microbial community structure and biodegradation capability, with implications for the removal of TrOCs, TOC, BDOC, assimilable organic carbon, and DBP formation potential.

The goal of this project was to develop a holistic understanding of coagulation-biofiltration, such that the removal of TrOCs can be maximized. Specific objectives are as follows:

1. Examine the impact of coagulant type, coagulant dose, and coagulation pH on the simultaneous removal of multiple TrOCs in downstream biofiltration;
2. Examine the impact of coagulant type, coagulant dose, and coagulation pH on the microbial community in downstream biofiltration.

Materials/Methodology

Synthetic water

The first task was to design the synthetic water, concentrate NOM from Lake Austin, and choose a diverse set of TrOCs. The final synthetic water parameters are as follows: alkalinity=100 mg/L as $CaCO_3$, pH=8.2, TOC=5 mg/L, and hardness=20 mg/L as $CaCO_3$. The synthetic water is supplemented with nitrogen (NH_4Cl) and phosphorus (KH_2PO_4) prior to biofiltration to prevent nutrient limitation, and the pH of the biofilter influent is adjusted to 8.2, for both non-coagulated and coagulated waters, to prevent phosphate adsorption in case of floc carryover to the biofilters. NOM has been extracted and concentrated from 9000 L of Lake Austin water (Austin, TX) to 90 L. The NOM concentration process includes filtration through two progressively smaller filters, the first 5 micron Pentek PD-5-934 filter to remove all suspended particles greater than 5 microns and finally a 0.5 μm Pentek 155403-75 filter, followed by cation exchange with the Ambersorb 200H resin (a strong-acid cation-exchange resin) and reverse osmosis with a Dow Filmtec spiral-wound TW30 membrane (Pressman et al., 2010, Barrett et al., 2014). The water was run repeatedly through a reverse osmosis membrane, rejecting the "clean" water, and retaining the concentrated organic-rich water until the desired volume was reached. A suite of nine common TrOCs was selected to cover a range of chemical classes, product applications and relative biodegradabilities (Table 1). The nine chosen TrOC are added to the synthetic water after coagulation (just before entering the biofilter), each at a concentration of 0.5 μg/L.

Table 1. Suite of diverse TrOC and their associated analytical methods

Compound	*TrOC category*	*Chemical class*	*Method*
2-MIB	microbial derived odor	borneo	Gas chromatograph/mass spectrometer (GC-MS)Martínez (2013)
Geosmin	microbial derived odor	bicyclic alcohol	
Diclofenac	pharmaceutical/ nonsteroidal anti-inflammatory drugs (NSAID)	phenylacetic acid	Liquid chromatograph/mass spectrometer (LC-MS) Vanderford et al. (2012)
Naproxen	pharmaceutical/NSAID	propionic acid	
Gemfibrozil	pharmaceutical/ anti-convulsant	fibric acid derivative	
Atenolol	pharmaceutical/ cardiovascular	isopropylamino-propanol derivative	
Caffeine	food product	xanthines	
Thiabendazole	pesticide/fungicide	benzimidazole	
N,N-Diethyl-meta-toluamide (DEET)	pesticide	aromatic amide	

Biofilters

Assembly: Eight glass columns with 1.5-cm diameters were used for the biofilters. The columns were set up in 4 parallel treatment trains (with 2 biofilters in series) and filled with media to a height of 5 cm. Two different types of media were studied, exhausted granular activated carbon (GAC) taken from a water treatment plant in Arlington, TX, and silica sand (Sigma Aldrich, St. Louis, MO). Many conventional plants are now using GAC as the media of choice because it provides excellent mechanical filtration of particulate matter, in addition to providing a large amount of surface area for bacterial growth and removing organic compounds. Exhausted GAC was chosen to reduce the amount of TrOCs and dissolved organic carbon (DOC) lost to adsorption on the media and focus on removal by biodegradation (Volk 2009). Sand was chosen to be a nonadsorptive control. Each filter will have an empty bed contact time (EBCT) of 3 minutes, for a total contact time of 6 minutes for the 2 columns in series.

The columns were sized by using a scaling model (Manem and Rittmann 1990) to simulate a full scale biofilter. A summary of the full-scale and bench-scale biofiltration parameters is provided in Table 2.

Table 2 - Biofilter Parameters

	Full Scale	**Bench Scale**
Diameter (cm)	34.4	1.5
Height (cm)	260	5
EBCT (min)	10 (X2 columns)	3 (X2 columns)
Flowrate (L/min)	253	0.003

Operation: After designing and constructing the biofilters (Figure 1), each train was run for one week with raw Lake Austin water to seed the filters with local microorganisms. Trains 1 and 2 are operated as controls with uncoagulated synthetic water. Additionally, Train 1 is operated with silica sand as the non-adsorptive control. Train 3 was run sequentially using synthetic water coagulated under the optimized conditions for alum. Train 4 will be run sequentially using synthetic water coagulated under the optimized conditions for ferric chloride.

The suite of TrOCs is spiked to the synthetic water after the coagulated synthetic water wastransfer to the glass carboy to prevent loss of TrOCs thorugh coagulation and through sorption in case of floc carryover into the final storage containers. The biofilter influent for each train is housed in an individual 20-L glass carboy that is covered with aluminum foil to minimize loss of volatile components. The influent, columns, and tubing were kept in darkened room to prevent photodegradation of contaminants and algal growth. The columns are run upflow via peristaltic pumps, and the total EBCT of each train is 6 min to simulate a 20-min full-scale EBCT (Manem and Rittmann 1990). The flow rate, pH and dissolved oxygen concentration were measured in the influent and effluent.

Samples were analyzed for pH, heterotrophic plate counts, DO, and DOC(Table 3). The suite of TrOCs was measured monthly.

Table 3. Water quality analyses

Parameter	Method No.	Method Title	Source
pH	4500-H+	pH Value	Standard Methods (2005)
TOC/DOC	5310 B	Total Organic Carbon: High T Combustion	Standard Methods (2005)
DO	4500-O G	Membrane Electrode Method	Standard Methods (2005)
HPC	9215	Heterotrophic Plate Count	Standard Methods (2005)

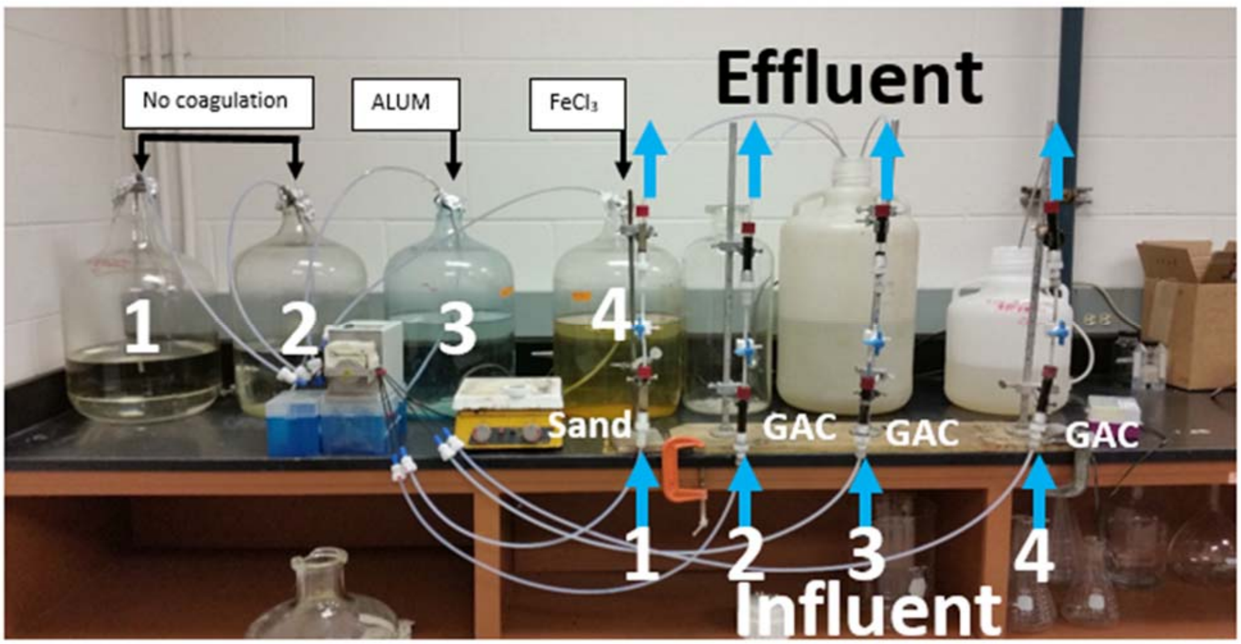

Figure 1. Bench-scale biofilter setup.

Coagulation

Optimization: Coagulation dosage and optimum pH were determined by performing jar tests on a range of concentrations for both coagulants following the jar-test procedure in Bell-Ajy et al. (2000). Briefly, 200 mL of raw (non-coagulated) water were added to a jar and dosed with the same concentration of appropriate coagulant. The pH was adjusted in each jar using 1 N HNO_3 or 1 N NaOH. The water was then rapidly stirred (250 rpm) for 2 minutes, stirred slowly (20 rpm) for 30 minutes, and then flocs were allowed to settle for 40 minutes. Each sample was filtered through a 0.45-µm Gelman Supro filter, and DOC was analyzed using a Shimadzu TOC analyzer in non-purgeable organic carbon mode. At the optimum pH, the same coagulation procedure was repeated except that the coagulant dose was varied such that the optimum dose for each coagulant was determined.

Bench scale: For the control columns 20 L of Millipore water are used to prepare the synthetic water. After mixing the salts and trace metals to the appropriate concentrations (Table 4), the solution is transferred to a glass carboy (carboys 1 and 2 in Figure 1), and the final pH is brought to 8.2. For the other biofilter trains, 20 L of synthetic water are prepared prior to starting the coagulation process. For train 3, 50 mg/L of alum is added to the synthetic water, and, for Train 4, 60 mg/L of ferric chloride is added to the synthetic water. The water is rapidly stirred using a paddle impeller (250 rpm) for 2 minutes, stirred slowly (20 rpm) for 30 minutes, and then flocs are allowed to settle for 40 minutes. The supernatant is then transferred to a glass carboy (carboys 3 and 4 in Figure 1), and the final pH is brought to 8.2.

Table 4. Synthetic water salts and trace metal final concentrations

CO3 & Salts	mg/L
NaHCO3	168.01
Na2SO4	17.75
NaCl	13.68
CaCl2*2H20	2.81
MgCl2*6H20	3.88
NH4Cl	0.45
KH2PO4	0.11
CH3COONa	10

Trace Metals	mg/L
AlCl3*6H2O	0.2
CoCl2*6H2O	0.0382
CuSO4*5H2O	0.0574
FeSO4*7H2O	0.7016
H3BO3	0.0303
MnCl2*4H2O	0.2807
Na2MoO4*2H2O	0.0254
Na2SO4	0.142
NiCl2*6H2O	0.0216
ZnSO4*7H2O	0.288

TrOC Analyses

LC-MS: TrOCs are concentrated using solid phase extraction (Waters Oasis® HLB™, 200 mg resin/6cc cartridge) and then analyzed with a TS Ultimate 3000 liquid chromatograph connected to a TSQ Quantiva tandem mass spectrometer (Thermo Fisher LC-MS/MS). The SPE cartridge is first conditioned with 3.0 mL of LCMS grade dichloromethane (DCM), 5.0 mL of LCMS grade methanol, and then 7.0 mL of LCMS grade water. Using a vacuum flask, 200 mL of sample is loaded through the cartridge at approximately 10 mL/min. When the loading is complete, the columns are rinsed with 3.0 mL of deionized (DI) water and then rinsed with 4.0 mL of a methanol/water solution (95/5 v/v). The columns are then dried under vacuum using a vacuum manifold for 40 minutes, after which they are sequentially eluted with 6.0 mL of methanol followed by 4.0 mL of methanol/DCM (70/30 v/v). The eluted samples are then concentrated via evaporation using a 35ºC water bath, under an ultra-pure nitrogen stream, down to approximately 0.5 mL. The samples are then brought to a final volume of 1 mL using LC/MS grade methanol (Honeywell).

Two separate analyses are conducted on the same extract: one in positive electrospray ionization mode [(+) ESI] and the other in negative electrospray ionization mode [(-) ESI]. For the (+) ESI, 2.0 µL of the sample extract is separated on a high pressure liquid chromatography (HPLC) system incorporating a reversed phase C18 column, using formic acid 99.5+% and ammonium formate ≥99.0% as solvent A, and methanol/acetonitrile with 0.1% formic acid as solvent B. For the (–) ESI: 3.0 µL of the extract is separated on an HPLC system incorporating a reversed phase C18 column, 40 mg/L ammonium acetate as solvent A, and LCMS grade methanol as solvent B.

GC-MS: 2-MIB and geosmin are concentrated using solid phase microextraction fibers (SPME) from 10 mL of sample and then analyzed with an Agilent 5977A gas chromatograph/mass spectrometer (GC-MS).

Principal Findings

Coagulation Optimization: Based on the jar-test results (Figure 2), a dosage of 50 mg/L at pH 6.5 was chosen for alum and 60 mg/L at pH 5.5 was chosen for ferric chloride.

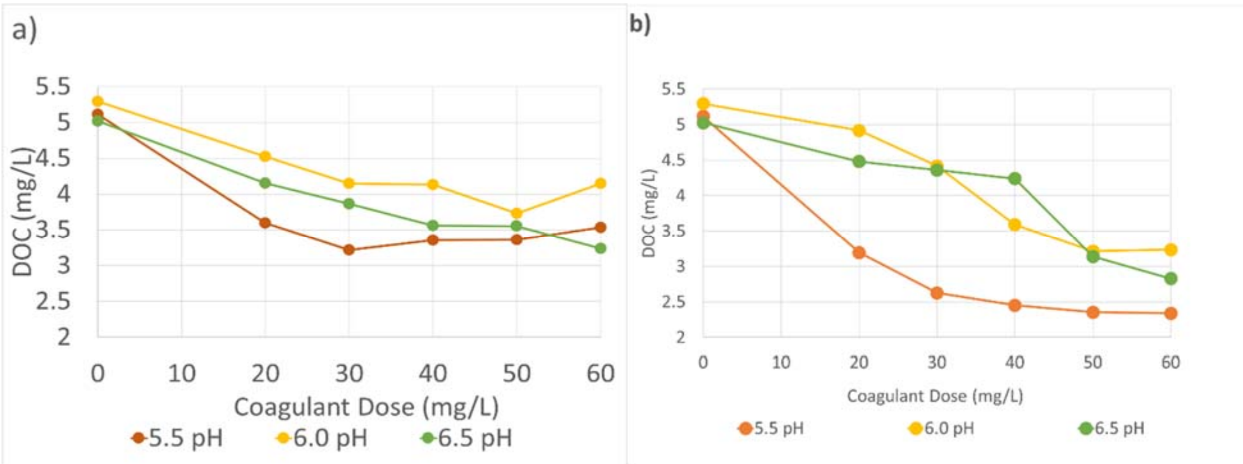

Figure 2. Jar test results for (a) alum and (b) ferric chloride coagulation.

Initial results for TrOC removal in the biofilter trains are shown in Figure 3. Atenolol, caffeine, DEET, naproxen, diclofenac, and gemfibrozil all showed higher removal in the biofilter train receiving ferric-coagulated water (Train 4). For both 2-MIB and geosmin, higher removal was observed in the GAC biofilter receiving non-coagulated water (Train 2). The sand biofilter (Train 1)only showed removal of atenolol, at less than 10% removal.

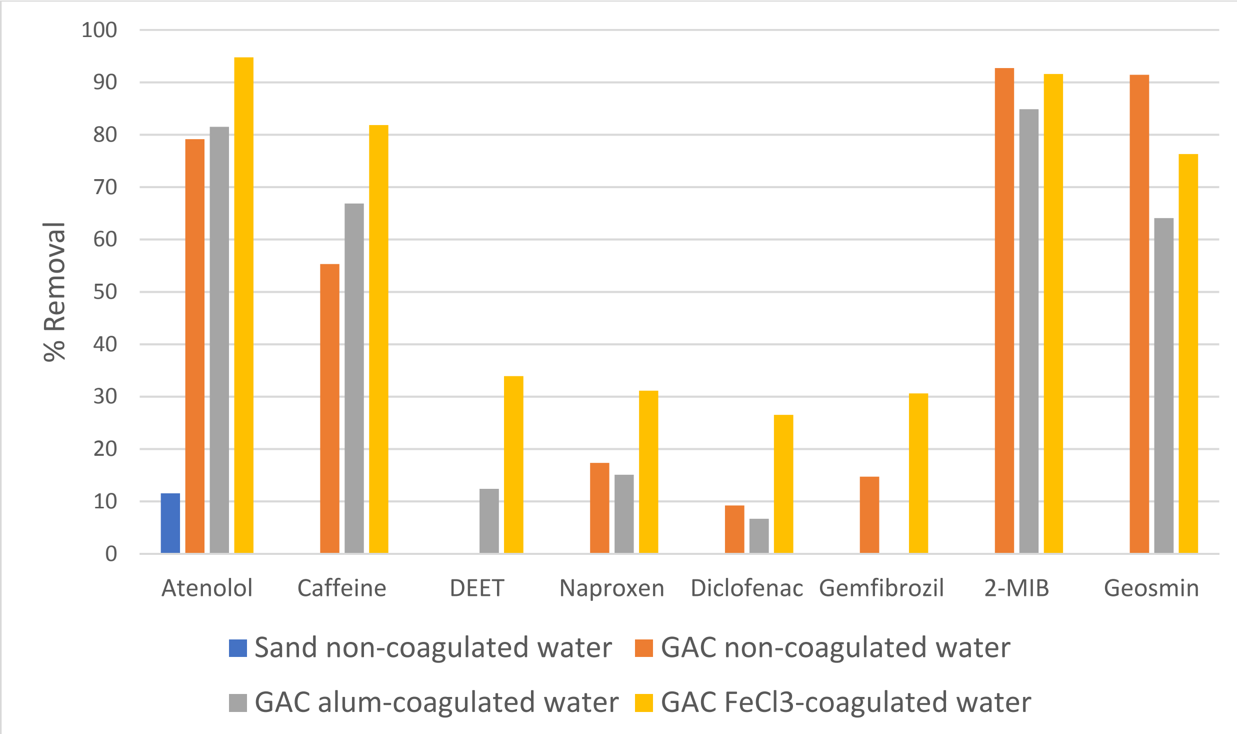

Figure 3. GC-MS and LC-MS/MS data for TrOC removal in the biofilter trains (6 months after start up). Each train was fed synthetic water with 0.5 µg/L of each TrOC.

Significance

In coagulation, ferric chloride removed more DOC than did alum. Atenolol, caffeine, DEET, naproxen, diclofenac, and gemfibrozil all showed the highest removal in the biofilter train receiving ferric-coagulated water as compared to the other biofilter trains. For both 2-MIB and geosmin, the highest removal was observed in the GAC biofilter receiving non-coagulated water as compared to the other biofilter trains. The sand biofilter showed removal only of atenolol, but at less than 10%. For TrOC removal, the ferric biofilter train, which had the lowest influent DOC, appears to have better removal. Further sorption studies will be made to determine how much is due to biodegradation versus sorption. The bench-scale columns will continue to be operated under optimized coagulation conditions and their performance will continue to be assessed to see if the trend continues. Additionally, the NOM fractionation will be analyzed for all three cases to compare similarities and differences.

To date this study suggests that optimized ferric chloride coagulation appears to have better removal of a greater variety of TrOCs. Ferric chloride may be more beneficial to use during treatment since some studies have shown it removes a greater amount of NOM and thus through flocculation and sedimentation reduces particle loading and backwashing of the biofilters

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

Basic Information

Title:	Connecting Climate Variability with Water Supply Reliability: A Case Study in the Trinity River Basin, Texas
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Focus Category:	Water Supply, Floods, Drought
Descriptors:	None
Principal Investigators:	Gang Zhao, Huilin Gao

Publication

1. Zhao, Gang, Huilin Gao (2016), Connecting Climate Variability with Water Supply Reliability, in American Geophysical Union, Fall Meeting 2016, San Francisco, California: Abstract #H33M-08.

REPORT

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

Project Number: 2016TX501B

Principal Investigator (PI):

Gang Zhao, Graduate Student, Texas A&M University

Email: zeternity@tamu.edu; Telephone: (979)587-4367

Co-PI:

Huilin Gao, Assistant Professor, Texas A&M University

Email: hgao@civil.tamu.edu; Telephone: (979)845-2875

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.

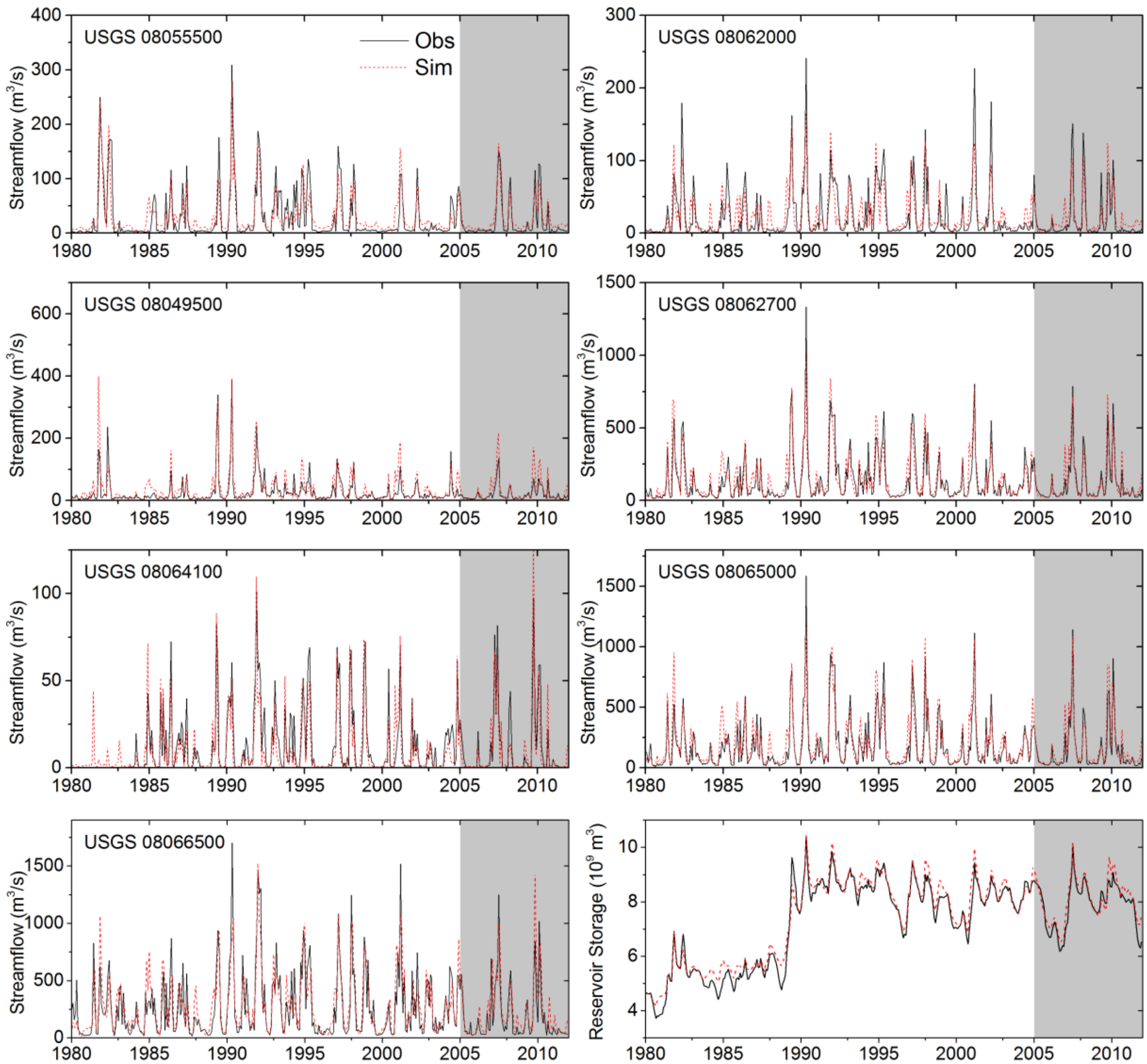

Figure 1. DHSVM calibration and validation results for 7 streamflow gauges and total reservoir storage for 16 reservoirs in TRB.

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.

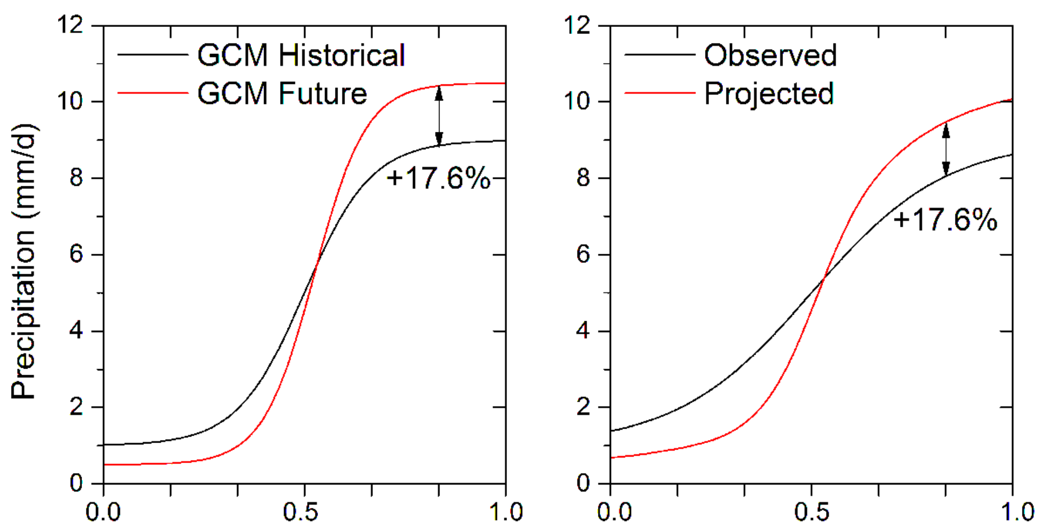

Figure 2. Quantile mapping technique to match the accumulative distributions of original GCM outputs to observation.

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.

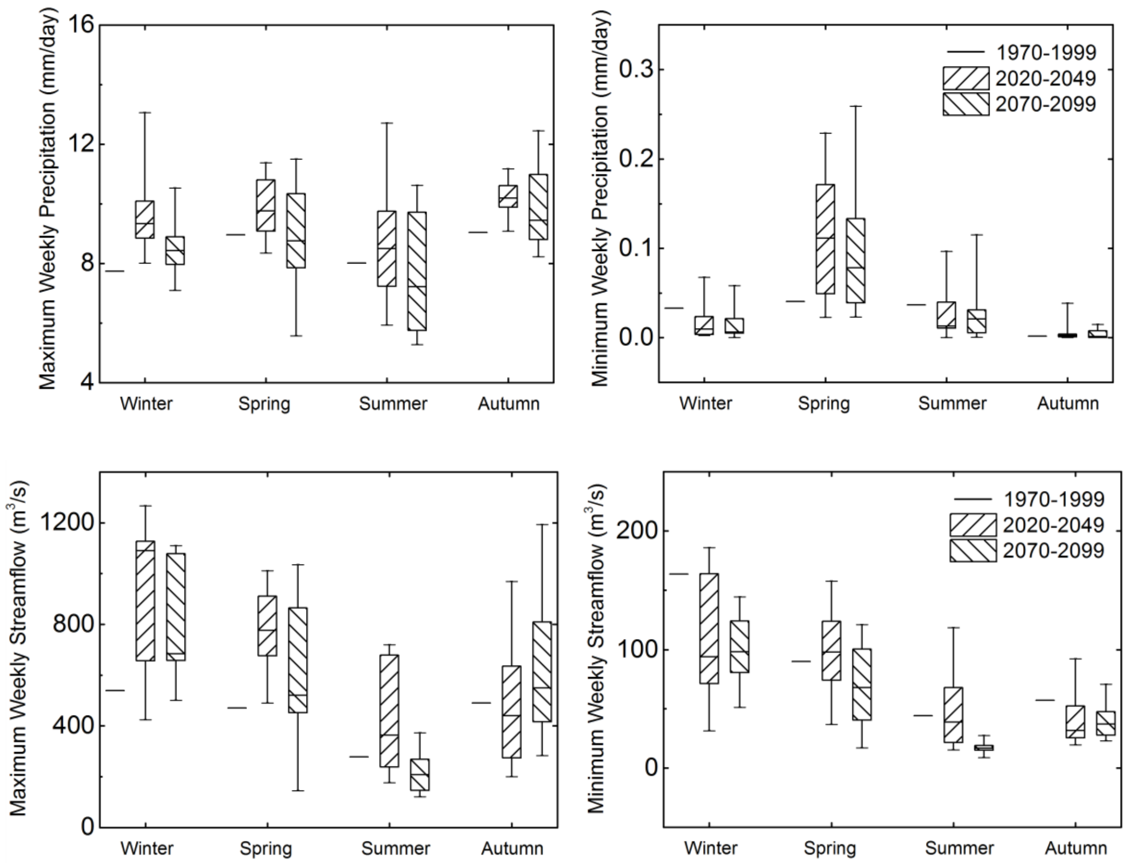

Figure 3. Seasonal precipitation and naturalized flow extremes at the outlet of Trinity River Basin

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.

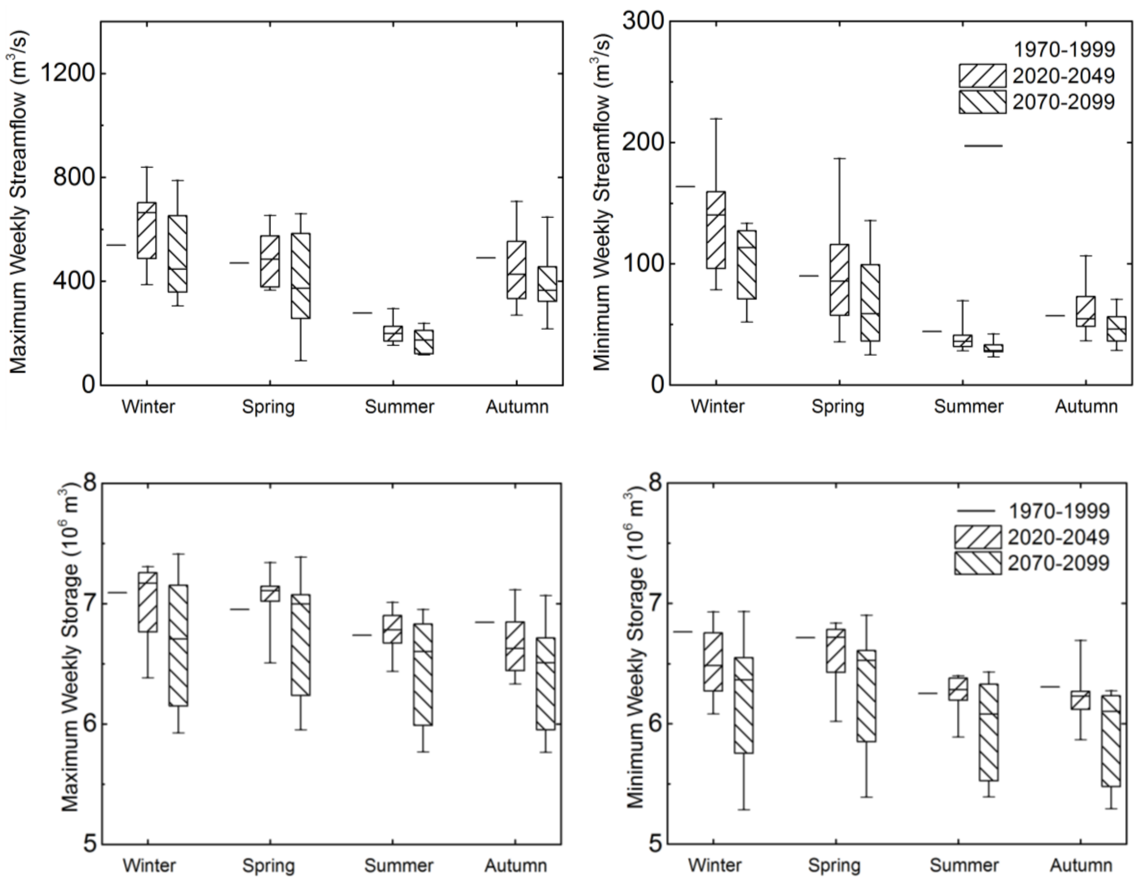

Figure 4. Seasonal regulated flow extremes at the outlet of Trinity River Basin and reservoir storage extremes for the entire basin.

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.

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Zhao, G., Gao, H., Naz, B. S., Kao, S. C., & Voisin, N. (2016b). Integrating a reservoir regulation scheme into a spatially distributed hydrological model. Advances in Water Resources, 98, 16-31.

Information Transfer Program Introduction

In 2016, the Texas Water Resources Institute continued its outstanding communication efforts to produce university-based water resources research and education outreach programs in Texas.

The institute publishes a monthly email newsletter and a semi-annual institute magazine. The institute also publishes an online peer-reviewed journal in conjunction with a nonprofit organization. Additionally, social media is used, as appropriate, to publicize information.

TWRI works to reach the public and expand its audience by generating news releases as well as informational fact sheets. The institute also publishes technical reports and educational publications in cooperation with research scientists and extension education professionals.

Finally, TWRI continues to enhance its web presence by posting new project-specific websites and continually updating the information contained within the current websites.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2016TX499B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	17
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	John C. Tracy, Leslie H Lee, Kevin Wagner, Kathy Wythe, Danielle Kalisek

Publications

1. Gregory, Lucas F.; R. Karthikeyan, Terry J. Gentry, R. D. Harmel, J. Aintkenhead-Peterson, K.L. Wagner, R. Lopez, 2016, Bacteria growth, persistence and source assessment in rural Texas landscapes and streams, (TR-489), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 48 pages.
2. TWRI; IRNR, 2016, Final Report: Fair Oaks Ranch Water Policy Analysis, (TR-492), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 48 pages.
3. Di Giovanni, George D.; Elizabeth A. Casarez, Joy A. Truesdale, Terry Gentry, P. Wanjugi, Emily Martin, Kevin Wagner, 2016, Expansion and Evaluation of Texas' Bacterial Source Tracking Program (TR-492), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 108 pages.
4. Truong, Amy Uyen; Richard White, Forrest Cobb, and Roel Lopez. 2016. The Drought Survivability Study Report (TR-495), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 77 pages.
5. Wagner, Kevin; Terry J. Gentry, Maitreyee Mukherjee, George D. Di Giovanni, Elizabeth A. Casarez, and Joy A. Truesdale. 2016. Texas BST Program Refinement, Expansion, and Use – FY15 (TR-496), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 35 pages.
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7. Wolff, Aubry; Diane Boellstorff, T. Allen Berthold, 2016, Utility Customer Profile Guide for Water Conservation Planning, (EM-120), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 24 pages.
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along the Mexico-US Border: An initial assessment. Journal of Hydrology, 535:101-119.
11. Sanchez-Flores, R.; A. Conner, R.A. Kaiser. 2016. The regulatory framework of reclaimed wastewater for portable reuse in the United States. International Journal of Water Resources Development, DOI 10.1080/07900.
12. Wagner, Kevin; Nikki Dictson, Lucas Gregory, Drew Gholson, Clare Entwistle, Kirstin Hein, Diane Boellstorff, Allen Berthold, Chelsea Hawkins, Aubry Wolff, Brian Jonescu. 2016. Texas Water Resources. Texas Master Naturalist, Edited by Michelle M. Haggerty and Mary Pearl Mueth.
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15. Wythe, Kathy. 2017. Ramsey Park parking lot doubles as environmental filter for water quality. TheAGMAG, Volume 3, Issue 3, January/February 2017.

Texas Water Resources Institute
Information Transfer Activities
March 1, 2016 – February 28, 2017

In 2016, the Texas Water Resources Institute continued its outstanding communication efforts to produce university-based water resources research and education outreach programs in Texas.

The Institute produces a monthly email newsletter and a semi-annual institute magazine. The Institute also publishes an online peer-reviewed journal in conjunction with a nonprofit organization and uses social media to publicize information.

Conservation Matters, a monthly email newsletter, covers the latest research and education news about land, water and wildlife in Texas and beyond state lines. Newsletter subscriptions are up to 2,460.

txH₂O, a 30-page glossy magazine, is published two times a year and contains in-depth articles that spotlight major water resources issues in Texas, ranging from agricultural nonpoint source pollution to landscaping for water conservation. Subscribers are at 2,418 for hard copies and 1,157 for email copies and approximately 600 more magazines are distributed.

The Texas Water Journal is an online, peer-reviewed journal devoted to the timely consideration of Texas water resources management and policy issues from a multidisciplinary perspective that integrates science, engineering, law, planning and other disciplines. The journal has published 10 articles. It currently has 718 enrolled users, although registration is not required to view the journal.

The Institute uses social media to promote the institute as well as water resources research and education news from throughout the state. The Institute currently has 3,014 Twitter followers, and TWRI tweets had an average of 50,825 monthly impressions, up from 41,121. TWRI has 1,055 Facebook page likes; 304 Instagram followers and 289 Pinterest followers. TWRI also maintains two project-specific Facebook page.

Working to reach the public and expand its audience, the Institute generates news releases and collaborates with Texas A&M AgriLife Communications writers for them to produce news releases about projects as well. The Institute also prepared informational fact sheets. TWRI projects or participating researcher efforts had at least 96 mentions in the media.

In cooperation with research scientists and extension education professionals, the Institute published six technical reports and two educational material publications, which provide in-depth details of water resource issues from various locations within the state.

TWRI continues to improve its online content, hosting and maintaining project-specific websites and continually updating the sites' information. The institute currently maintains 24 active program websites. It also hosts 28 more websites, archived in the TWRI site, that are completed projects or other programs.

TWRI Program Sites:

Arroyo Colorado	arroyocolorado.org
Attoyac Bayou Watershed Protection Plan Development	attoyac.tamu.edu
Automated Metering Initiative	arlingtontxwater.org/
Bacteria Fate and Transport	bft.tamu.edu
Carters Creek Watershed Water Quality	cartersandburton.tamu.edu
Copano Bay Water Quality Education	copanobay-wq.tamu.edu
Communications Team Support	twri.tamu.edu/what-we-do/support/communications/
Groundwater / Surface Water Interactions	waterinteractions.tamu.edu
Leon River Watershed Protection Program	leonriver.tamu.edu
Little River Water Quality	littleriver.tamu.edu
Matagorda Basin	matagordabasin.tamu.edu
MyWater Web Portal and AMI	mywater.tamu.edu
Navasota River Water Quality Improvement	navasota.tamu.edu/
Ogallala Aquifer Program	Ogallala.tamu.edu
Student Scholarships for Water Resources Research	twri.tamu.edu/what-we-do/educate/scholarships/
Texas Bacterial Source Tracking Support	twri.tamu.edu/what-we-do/support/bacterial-source-tracking/
Texas BST Infrastructure Support	texasbst.tamu.edu
Texas Water Resources Institute	twri.tamu.edu
Texas Watershed Planning	watershedplanning.tamu.edu
Texas Well Owner Network	twon.tamu.edu
Tres Palacios Creek Water Quality	matagordabasin.tamu.edu
Natural Resources Training Program	nrt.tamu.edu
Watershed Monitoring Support	twri.tamu.edu/what-we-do/support/watershed-monitoring/
Watershed Planning Support	twri.tamu.edu/what-we-do/support/watershed-planning/

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	6	0	0	0	6
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

2015TX482B: The work conducted under this grant directly contributed me securing my current position as a postdoctoral researcher at the University of Georgia.

Publications from Prior Years

1. 2015TX482B ("Evaluating the Efficacy of a Long-Term Residential Water Conservation Program in College Station, TX") - Articles in Refereed Scientific Journals - Landon, Adam C., Gerard T. Kyle, Ronald A. Kaiser, 2016, An Augmented Norm Activation Model: The Case of Residential Outdoor Water Use, Society & Natural Resources, DOI: 10.1080/08941920.2016.1239294. Link: http://dx.doi.org/10.1080/08941920.2016.1239294.
2. 2014TX469B ("Increasing Water Security through Horizontal Wells") - Articles in Refereed Scientific Journals - Blumenthal, Benjamin J., Hongbin Zhan, 2016, Rapid computation of directional wellbore drawdown in a confined aquifer via Poisson resummation, Advances in Water Resources, 94, 238-250.