# Texas Water Resources Institute
# Annual Technical Report
# FY 2015

# 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 2015 managed 43 active projects with $10,570,890 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 2015 the Institute was awarded 18 new TWRI-lead projects with direct funding of $3,331,850.

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 for two graduate student research projects in 2015-2016 conducted by one graduate student at Texas A&M University and one at the University of Texas.

Adam Landon, of Texas A&M University's Water Management and Hydrological Science department, evaluated the efficacy of a long-term residential water conservation program in College Station, TX.

Dora Frances Sullivan-Gonzalez, of the University of Texas' Department of Environmental and Water Resources Engineering, studied hollow fiber membrane air stripping for removal of carbonate species in produced water from hydraulic fracturing.

# Evaluating the Efficacy of a Long-Term Residential Water Conservation Program in College Station, TX

## Basic Information

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|---|---|
| **Title:** | Evaluating the Efficacy of a Long-Term Residential Water Conservation Program in College Station, TX |
| **Project Number:** | 2015TX482B |
| **Start Date:** | 3/1/2015 |
| **End Date:** | 2/28/2016 |
| **Funding Source:** | 104B |
| **Congressional District:** | 17 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Conservation, Education, Economics |
| **Descriptors:** | None |
| **Principal Investigators:** | Adam Landon, Ronald Kaiser, Gerard Kyle |

## Publications

1. Landon, A.C., G.T. Kyle, R.A. Kaiser, 2016, Predicting Compliance with an Information-based Residential Outdoor Water Conservation Program, Journal of Hydrology, 536, 26-36.
2. Landon, A.C., 2015, Evaluating Residential Water Conservation Attitudes, Behaviors, and Demand Management Policy Effectiveness in College Station, TX, "Ph.D. Dissertation", Water Management and Hydrological Science, Texas A&M University, College Station, TX, 115 pp.

# REPORT

**Title** Evaluating the Efficacy of a Long-Term Residential Water Conservation Program in College Station, TX.

**Project Number** 2015TX482B

**Primary PI** Adam C. Landon

**Other PIs** Ronald A. Kaiser; Gerard T. Kyle

## Abstract

This research details the evaluation of water savings associated with the administration of an information-based residential demand management policy in College Station, TX. The authors draw on a quasi-experimental design to attribute a causal effect to the treatment. The results indicate that the information-based program was successful in reducing the water use of households that received messages, and that the savings increase over time with each repetition of the messages. However, heterogeneity exists in the treatment effect based on household baseline water use (e.g., in the period before the messages were administered). The results are discussed in the light of developing effective residential demand management policy, and changing consumer behaviors.

## Problem and Research Objectives

*Background*

Conservation has been identified as a critical component of ensuring an adequate future water supply in the state of Texas (Water for Texas, 2012). However, beyond stressing the potential contributions of conservation in closing anticipated gaps in supply and demand, the exact mechanisms through which to achieve these needed reductions in water use remain poorly defined. The residential sector is one area where significant reductions in water use stand to made. The Environmental Protection Agency (2013), for instance, estimates that as much as half of all the water used outdoors, for lawn and landscaping irrigation, is wasted as a function of leaking infrastructure, over watering, and miss-direction. Improving the efficiency of water use in lawn and landscaping irrigation, therefore, can result in significant water savings (Endter-Wada et al., 2008; White et al., 2004).

Achieving these potential reductions in water use requires upgrades in technology, but potentially more importantly, significant changes in the behaviors of water users (Schultz et al., 2014; Schultz, 2011). In an attempt to manage demands for outdoor water, and leverage behavior change among water customers, utility mangers have designed and implemented a host of policy interventions (Olmstead and Stavins, 2009; Kenney et al., 2008; Campbell et al. 2004). These interventions range from progressive block rate price structures and financial incentives for technical retrofits (Arbúes et al., 2004), to persuasive educational messages and public information campaigns that stress the merits of conservation (Syme et al., 2000). Although the savings associated with conservation pricing structures and technological upgrades are relatively well understood in the literature, the potential savings associated with information-based instruments are context specific and comparatively understudied (Syme et al., 2000). Evaluating the ability of information-based instruments to reduce water use and change the behaviors of residential water users, however, is necessary in order to meet long-term goals for water use, water supply, and conservation in the residential sector. This is especially important given that information and education polices are among the most commonly employed strategies in municipal conservation programs (Mickelson et al., 2000). Additionally, market based mechanisms are infeasible in many communities owing to the political climate and the social acceptability of rate increases.

Over the last several years, water managers in the City of College Station Texas have undertaken a residential demand management campaign featuring a number of the policy instruments mentioned above including block rate pricing structures, rebates for technological upgrades, audits of irrigation systems, and especially persuasive educational messages designed to improve the efficiency of outdoor water use within the service area.

*Research Objectives*

The objective of this research was to determine the water savings associated with the persuasive information-based messages implemented as a part of the College Station residential water conservation program. This educational program has consisted of providing personalized feedback on water use to a subset of the city's largest consumers of water in the form of a "water budget". The water budget is composed of two key pieces of information, 1) a comparison of the customers' water use to an "efficient" standard determined as a function of their lawn's water needs and climatic conditions, and 2) a comparison of their water use to the water use of their neighbors. These comparisons, along with accompanying information on how to reduce outdoor water use, are designed to give customers a benchmark against which to judge their behavior, and when appropriate conform to societal expectations regarding water use (Shultz et al., 2014; McKenzie –Mohr, 2000; Cialdini et al. 1990; Festinger, 1954). Although the impacts of general conservation education programs have been reported with mixed success in the literature (Schultz et al., 2002; Michelsen et al. 2000), social norms and social marketing approaches (McKenzie-Mohr, 2000), like the one implemented here, have shown promise in achieving behavior change among resource users (Schultz et al., 2014).

## Materials/Methodology

*Description of the water budget program*

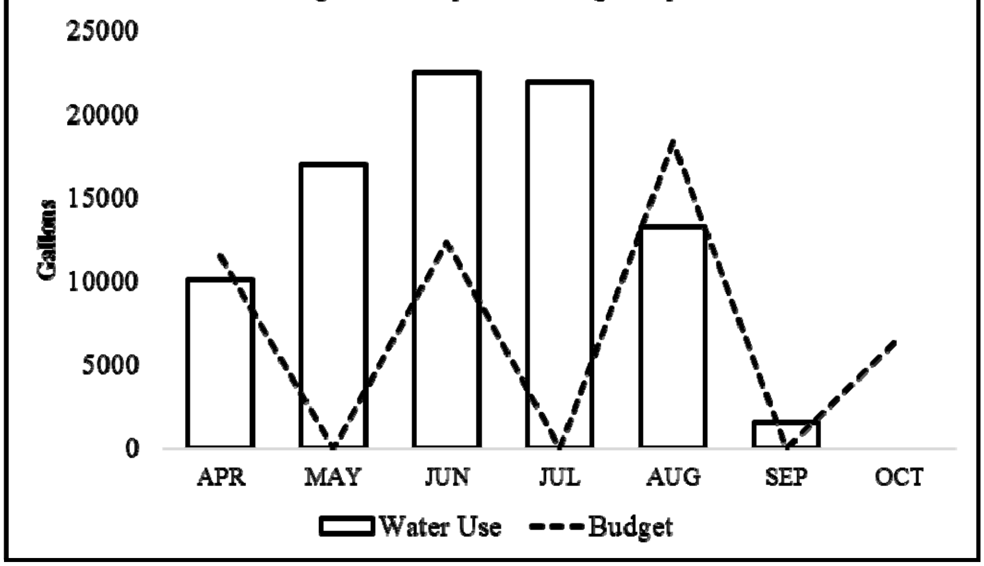
Households were selected for inclusion in the water budget program (e.g., receive the communications) if they were located in a neighborhood with average household irrigation season (April to October) water use in excess of 100,000 gallons, during the period 2008-2011. All households in the neighborhood received the communication if the neighborhood fell under this condition, regardless of their individual consumption. Households in these neighborhoods (n=5,565) have received the water budget communication at the beginning of the irrigation season each year since 2012. An example of the water budget graph presented to participants is shown in Figure 1. The solid bars represent household water use for that month, and the dotted line represents the water budget, or what would have been an efficient application (e.g., enough to keep their lawn healthy) of irrigation water given the climatic conditions during that period of time. Water budgets are provided at a one year time lag. For example, at the beginning of the 2014 irrigation season households received feedback on their 2013 water use.

Following White et al. (2004) the water budget was calculated as a monthly water balance of precipitation and evapotranspiration over a given area of lawn:

$$\textbf{Eq. 1.}\ \text{WB (gal)}_{\text{month}} = \text{Irrigable Area (ft}^2\text{)} * [(K_c * \text{PET (in)} - \text{P (in)})] *.6\ (\text{gal/ft}^2)$$

Where WB is the monthly water budget in gallons, Irrigable Area is the area of the household parcel subject to irrigation (derived from GIS files), $K_c$ is a crop coefficient, PET is potential evapotranspiration in inches, P is precipitation in inches, and .6 is a conversion factor of inches to gallons. Social comparisons (not pictured) were conducted at the neighborhood scale for both total outdoor water use per square foot of lawn, and neighborhood water use compared to the budget.

**Figure 1.** Example Water Budget Graph




*Analysis*

To assess the efficacy of the water budget program we drew on monthly household water use records for the City of College Station spanning from 2008 to 2014 (n=8,816). Our analysis was limited to single family detached homes with complete water use records spanning the length of the study. We used a fixed-effects difference-in-difference approach to compare the monthly irrigation season water use between households that received the water budget communications to those that did not, in the periods before (2008-2011) and after (2012-2014) they were administered. We limited the pseudo control group (e.g., households that did not receive the messages; n=4,561) to the same range of demographic characteristics as the treatment group (e.g., households that received the communications; n=4,255) including lot size, home value, and home age drawn from publicly available county tax assessment records, in order to ensure the validity of the comparisons. To account for unobserved household level variables influencing demand we estimated a fixed-effect for each household. We also controlled for monthly climate variables, including total precipitation and average daily maximum air temperature, which have been shown to influence demand (Arbúes et al., 2003). Climate data were drawn from a combination of three weather stations operational at different periods of time (from 2008-2014) within the city. Monthly household irrigation season water use was modeled following:

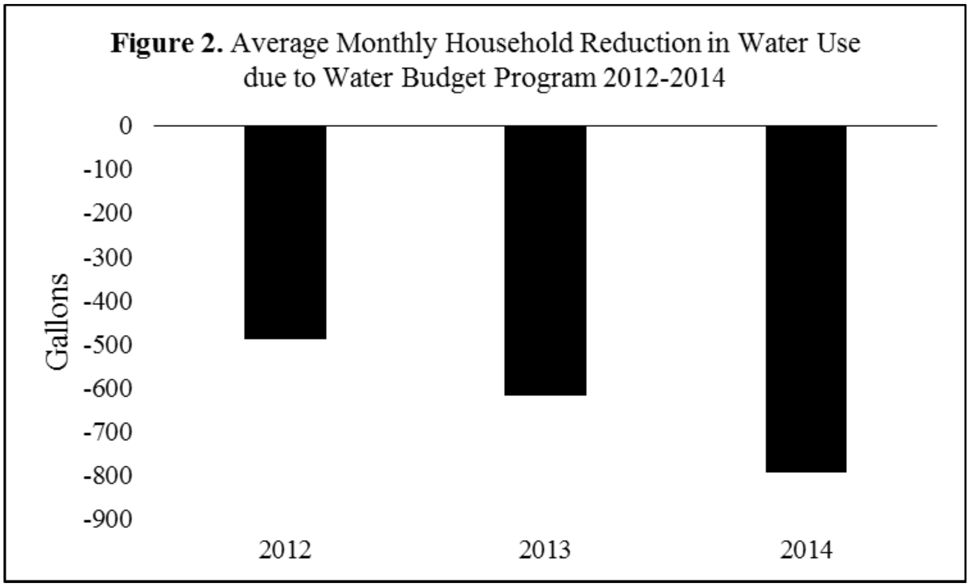
**Eq. 2.** $$WU_{it} = \beta_1 P_t + \beta_2 T_t + \beta_3 TG_i + \beta_4 TP_t + \beta_5 TG_t * TP_t + a_i + u_{it}$$

Where WU is monthly household water use, P is total precipitation in month t, T is average daily maximum air temperature in month t, TG is a dummy variable representing the ith household's membership in the treatment group, TP is a dummy variable representing months during the treatment period, and TG*TP is an interaction of treatment group and treatment period which yields the difference-in-difference estimate (treatment effect), $a_i$ and $u_{it}$ are error terms.

In addition to estimating the total water savings attributed to the program we conducted additional analyses to determine changes in the strength of the treatment effect over time, and variation in the treatment effect by the level of baseline household water use (e.g., pre-2012), split into roughly equal thirds. To do this we ran separate models to estimate a treatment effect for each year of the program 2012, 2013, and 2014, and for each year by each of the three water use groups (e.g., bottom 33% of households, middle 33% of households, and top 33% of water using households). We hypothesized that the treatment effect would be strongest among the top water using households, and have little or no effect on the bottom two thirds.

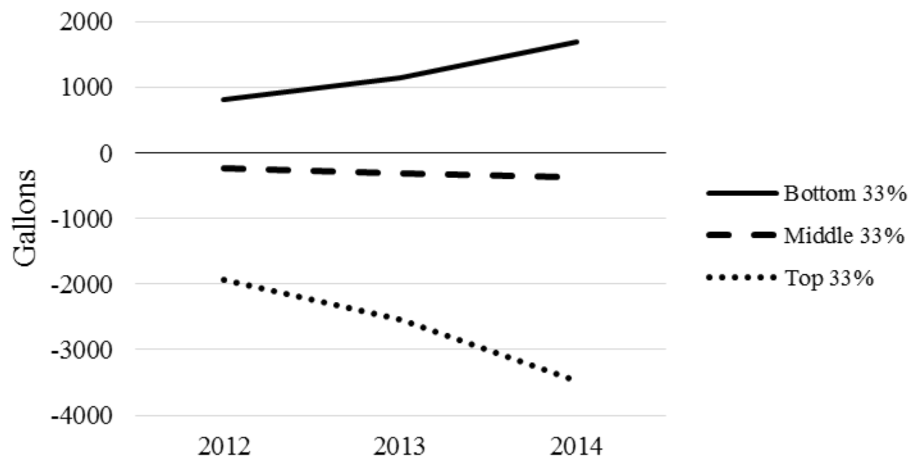
## Principal Findings

Results indicate that the water budget program yielded an average monthly reduction in household irrigation season water use of 649 gallons (t=-6.49, p<.001). Over the course of the program 2012 – 2014 this amounts to a savings of roughly 76 million gallons, or 233 acre feet, for the entire treatment group (n=5,565). However, there was quite a bit of heterogeneity in the strength of the treatment effect over time. Our results demonstrate an increased strength in the treatment effect each year with repetition of the water budget messages (Figure 2). In 2012 the estimated water savings associated with the water budget program were 489 gallons per household per month (t=-4.56, p <.001), 618 gallons per household per month in 2013 (t=-5.20, p <.001), and 794 gallons per household per month in 2014.




Similarly, we found significant variation in the treatment effect by water use groups (Figure 3). Households that fell in the top one third of water using households in the period before the water budget program began, exhibited the largest reductions in water use; 2,659 gallons per household per month ($t=-15.74$, $p<.001$). Households falling within the middle one third of water users during the baseline period exhibited limited response to the water budget messages, reducing their consumption by an average of 307 gallons per month ($t=-2.52$, $p<.001$). Last, households falling within the bottom one third of water users actually responded to the water budget messages by increasing their consumption, on average 1,220 gallons per month ($t=11.39$, $p<.001$). This was an unexpected result. However, past work in the psychology and economics literatures has demonstrated that social norms messages can cause increases in undesirable behaviors when respondents are below the norm that they are being compared to, and the message that they receive does not adequately demonstrate the acceptability of being below the norm (Schultz et al., 2007; Alcott, 2011). This is referred to as the "boomerang effect", and has implications for the use of social norms messages in resource conservation. Similar to results for the entire treatment group, treatment effects increased in strength for each of the water use subgroups over time (Figure 3).

**Figure 3.** Average Monthly Household Reduction in Water Use due to Water Budget Program 2012-2014 by Water Use Group




## Significance

The results of this work have implications for the administration of education and information-based policy instruments in residential demand management. First, we empirically demonstrate that information-based messages can indeed influence the water use behaviors of residential consumers. Our results parallel other studies that have used a similar social norms based approach (Ferraro and Price, 2013). However, this is one of only a few studies to demonstrate that the effects of norms-based messages can increase with message repetition over time. Future work should seek to examine the cost effectiveness of information-based messages, and determine ceiling effects in their ability to influence consumer behavior. Second, we found differential effects on water savings based on household initial water use. In fact, the lowest users actually increased their consumption. Conservation programs seeking to influence consumer behaviors through social norms approaches, like the on detailed here, must be careful to construct messages in a way that make expectations clear, and consider carefully who the messages are sent to. Our results, for instance, indicate that the program would have yielded greater savings, and cost less to administer, if the bottom one third of consumers did not receive the messages at all.

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# Hollow fiber membrane air stripping for the removal of carbonate species in produced water from hydraulic fracturing

## Basic Information

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|---|---|
| **Title:** | Hollow fiber membrane air stripping for the removal of carbonate species in produced water from hydraulic fracturing |
| **Project Number:** | 2015TX483B |
| **Start Date:** | 3/1/2015 |
| **End Date:** | 2/28/2016 |
| **Funding Source:** | 104B |
| **Congressional District:** | 25 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Treatment, Water Quality, Wastewater |
| **Descriptors:** | None |
| **Principal Investigators:** | Dora Frances Sullivan-Gonzalez, Benny Freeman, Lynn Katz, Desmond F Lawler |

## Publication


1. Sullivan-González, Dora Frances, 2015, Volatile Contaminant Removal Through Air Stripping, "MS Departmental Report," Civil, Architectural and Environmental Engineering, Cockrell School of Engineering, University of Texas, Austin, Tx, 36 pgs.

# REPORT

**Title:** Hollow fiber membrane air stripping for the removal of carbonate species in produced water from hydraulic fracturing

**Project Number** 2015TX483B

**Principle Investigator:** Dora Frances Sullivan-González, University of Texas at Austin, Department of Environmental and Water Resources Engineering, Master's student, dfsg@utexas.edu, (662) 832-3103, Dept. of Civil, Architectural and Environmental Engineering, 301 E. Dean Keeton St; Austin, TX 78712

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**Abstract:**

Approximately 5.66 million $m^3$ of wastewater per year is produced by hydraulic fracking; the "flowback" water constitutes about 10-30% of the water used in the fracking process. The ideal situation would be to treat and reuse the flowback water to reduce disposal costs and the demand for fresh water, but such treatment is difficult due to high saline content and presence of oils and other organics. In their pilot study, Miller et al. addressed the use of ultrafiltration (UF) and reverse osmosis (RO) membranes modified with a polydopamine coating to treat produced water from the Barnett shale gas basin in Texas. This research examined the use of a hollow fiber (HF) air stripping membrane unit for $CO_2$ removal as an intermediate step in this treatment train to improve the desalination performance of reserve osmosis. The overall goal of the research was to evaluate removal of volatile contaminants in the HF membrane air stripper as a function of synthetic water composition. The research utilized the Liqui-Cel® Membrane Contactor as it has proven success for air stripping of volatiles and its baffled design prevents fiber bypassing and promotes enhanced liquid film mass transfer coefficients. An experimental system was designed and tested for both $CO_2$ and other volatile compounds and a model that more accurately captures the removal of volatile compounds from water in the Liqui-Cel Membrane Contactor was developed.

**Problem and Research Objectives**

The popularity of hydraulic fracturing, or fracking, over the past decade has increased the production of natural gas in North America and, consequentially, the need for improved technologies to treat the accompanying flowback water.[1] Fracking requires large volumes of water putting a strain on local freshwater demands and disposal practices. Approximately 5.66 million $m^3$ of wastewater per year is produced by fracking;[2] this "flowback" water constitutes approximately 10-30% of the water used in the fracking process.[1]

Disposing of the produced water can cost up to $4 per barrel including costs for transportation and injection wells.[1] Therefore, it is ideal to reuse the flowback water to reduce disposal costs and the demand for fresh water. However, challenges to produced water treatment occur due to the high saline content and presence of oils and other organics. According to Thiel et al., produced water samples from the Permian shale basin contained up to 183,000 mg/L of total dissolved solids (TDS), while Miller et al. reported produced water characteristics from the Barnett shale basin of up to 99,000 mg/L TDS.[2,1]

The rise of membrane technology for purification of flowback waters is attributed to their small energy footprint, high efficiency, and ability to be moved from one drill site to the next.[1] Recent advances in membrane research for flowback water treatment include the use of microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Alzahrani et al. reviewed the different types of membrane technologies to conclude that current practices have "high potential" for meeting the needs of the petroleum industry while future goals can target a standard reference for produced water characterization, treatment of produced water at its source by integrated membrane technologies to aim for "zero liquid discharge," and the recovery of by-products from produced water.[3] The biggest drawback to membrane technologies is their tendency to foul due to the constituents in the water being treated.

In their pilot study, Miller et al. addressed the use of ultrafiltration (UF) and reverse osmosis (RO) membranes modified with a polydopamine coating to treat produced water from the Barnett shale gas basin in Texas.[1] The polydopamine coating was used as a surface modification for the membranes to reduce the effects of fouling. The polyacrylonite hollow fiber UF membranes were further modified by grafting poly(ethylene glycol) to the polydopamine coating. The UF membranes removed organic material, specifically emulsified oils, from the flowback water while RO membranes desalinated the UF permeate. The surface modifications successfully decreased the resistance to mass transport in the UF membranes. The polydopamine coating did not affect the water flux or the transmembrane pressure of the modified RO membrane compared with the unmodified RO membrane; the surface modification did, however, increase the salt rejection of the modified RO membrane. In that study, the TDS in the RO feed ranged from $2x10^{-4}$ to $6.5x10^{-4}$ mg/L, which represented the salt concentration of the waters.

To improve the desalination performance of reserve osmosis, different pretreatment options are available.[4] Jamaly et al. recommend the use of UF or NF as part of the pretreatment membrane train to extend the lifetime of RO membranes because the UF/NF membranes can handle a salinity range > 35,000 ppm.[4] Considering the pilot study in the Barnett shale gas region, an intermediate step between UF for organic removal and RO for desalination could be used to remove carbonate species from the produced water to prevent precipitation and scaling of the RO membrane. Thiel and Lienhard reported that the carbonate species in the produced water were the most likely to scale membranes based on their saturation index.[2] Therefore the overall goal of this research was to evaluate the addition of a membrane a hollow fiber air stripping membrane contactor as RO pretreatment to remove $CO_2$ from produced waters. Liqui-Cel® Membrane Contactor systems have been used to remove $CO_2$ from water prior to secondary treatment by RO or electrodeionization to decrease the scaling effect of the carbonate species. The objectives of this research were to 1) construct a micro-module system that could be used to test the performance of the membrane contactor over a range of background waters and operating conditions; and, 2) to develop a model that could be used to predict performance in these systems.

**Materials/Methodology**

The research plan was divided into two phases consistent with the two objectives. In phase I, a model was developed that can be used to predict removal efficiencies of volatile contaminants in the current two-stage Liqui-Cel hollow fiber (HF) air stripping membrane contactor. Since most of the previous research conducted with this system employed an unbaffled membrane operated as a single-stage, countercurrent, air stripper with the liquid stream flowing through the lumen, modeling approaches developed based on this system were not appropriate for the current construction of HF membrane contactor. The redesigned Liqui-Cel® Extra-Flow module (Figure 1) from Membrana contains a shell-side baffle and a central tube feeder with air flow on the lumen-side. This design avoids the channeling seen in the previous, unbaffled model and increases the mass transfer coefficient compared to strictly parallel flow[7]. Thus, a two-stage efficiency model was developed as part of this research.

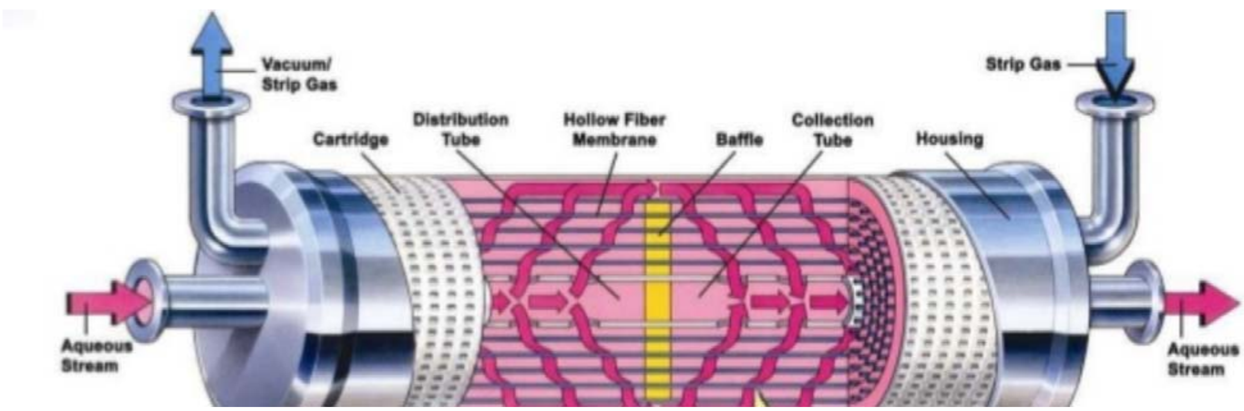


*Figure 1. Liqui-Cel® Extra flow design (Drawing from Liqui-Cel® Membrane Contactors, Membrana).*

The 1.7 x 5.5 MiniModule® PP X50 membrane contactor system from Membrana Contactors was used in this research and the experimental system developed for this research was constructed as part of this project (Figure 2). The module can accommodate a maximum flowrate of 2.5L/min, appropriate to handle a laboratory scale water flowrate of up to 0.8L/min. The hollow fiber membrane in this unit is hydrophobic polypropylene appropriate for $CO_2$ removal in a countercurrent flow setup with water on the shell side and either a vacuum or sweep gas on the tube side to remove $CO_2$ from the system. Air was used as the sweep gas in the experimental tests in this research. The synthetic water was prepared with Millipore water with varying concentrations of sodium chloride added for ionic strength up to 0.5M. The solutions were placed in 3 L Tedlar bags to prevent volatilization and the pH was adjusted to 5. Carbonate was added to the solutions using sodium bicarbonate and the initial bicarbonate concentration tested was 100 ppm. At pH 5 (the pH expected from upstream membrane processes), it was assumed that all of the carbonate was present at $H_2CO_3$* ($H_2CO_3 + CO_{2(aq)}$). Samples of the $CO_2$ concentration in the feed were taken prior to the beginning of the experiments. The liquid flow rate was set to 20 mL/min and air flow rates were determined based on the desired stripping factors. Initial testing used stripping factors from 10 to 20. The air flow rate was calibrated at the beginning and end of each experimental run using a bubble flow calibration device. Samples were taken in headspace free 40 mL vials at 10 minute intervals. Samples were stored at 4 ◦C for 24 hours or less and measured on a Shimadzu L total organic carbon analyzer for inorganic carbon. Additional experiments for model validation were also conducted in a similar manner using chloroform as a pH independent model compound. Chloroform analysis was conducted using GC/MS analyses.

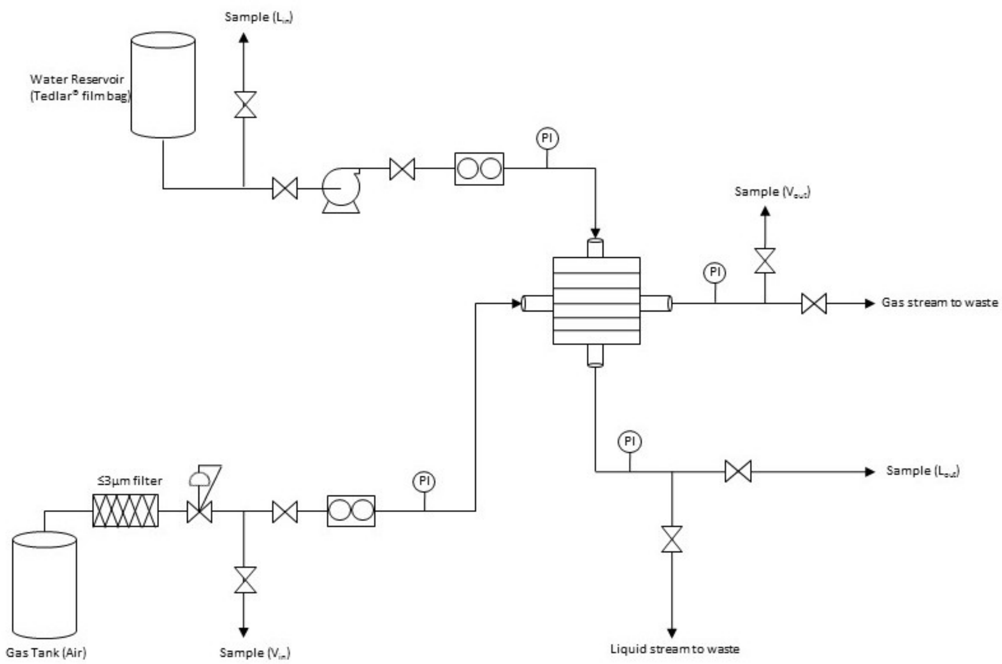


*Figure 2. Process flow diagram for the continuous flow experimental setup with the MicroModule for THM air stripping.*

## Principal Findings

### *Stage Efficiency Modeling*

The Liqui-Cel® Extra Flow module can be considered a stage device due to the physical attributes of the baffle. If either side of the baffle acts as one separation stage, then a stage efficiency model can be implemented to model the performance. Seibert and Fair designed experiments to formulate a stage efficiency modeling using a liquid-liquid extraction process[9]. The model is based on the Murphree efficiency of the system. Murphree efficiency typically describes the mass transfer efficiency at a particular stage in a separation process, where 100% efficiency is based on vapor and liquid phases leaving said stage in equilibrium in accordance with Henry's Law[8]. According to the model proposed by Seibert and Fair, the Murphree efficiency, $E_m$, can be calculated by:

$$E_m = \frac{\alpha}{1+\frac{\alpha}{2}} \tag{1}$$

where

$$\alpha = \frac{K_o A_i}{Q_t} \tag{2}$$

and

$$A_i = \frac{A_m}{1+N_{baffles}} \tag{3}$$

where $K_o$ is the overall liquid film or shell-side mass transfer coefficient of a system (m/s), $A_i$ is the contact area per stage ($m^2$), $Q_t$ is the tube-side volumetric flow rate ($m^2/s$), $A_m$ is the contact area per module ($m^2$), and $N_{baffles}$ is the number of baffles in the module[9]. The predicted overall efficiency of the module can then be calculated from the follow expression:

$$E_o = \frac{\ln[1+E_m(S-1)]}{\ln S} \tag{4}$$

where

$$S = \frac{HQ_G}{Q_L} \tag{5}$$

where S is the stripping factor, H is the Henry's law constant ($L_L/L_G$), $Q_G$ is the gas phase volumetric flow rate ($m^3/s$), and $Q_L$ is the liquid phase volumetric flow rate ($m^3/s$)[9]. The actual overall stage efficiency can be calculated using the Kremser equation:

$$N_{eq} = \frac{\ln\left[\left(\frac{C0}{C}\right)\left(1-\frac{1}{S}\right)+\frac{1}{S}\right]}{\ln S} \tag{6}$$

where $N_{eq}$ is the number of theoretical stages, $C_0$ is the initial concentration of contaminant to be removed, C is the final concentration of contaminant, and S is the stripping factor[8]. Dividing the number of theoretical stages by the number of physical stages in the module gives the actually efficiency of the separation process. The stage efficiency model was tested against several sets of data from the literature for volatile contaminants. Significant variability between measured and predicted efficiencies was observed; however, most of the experimental data was either collected using the unbaffled module configuration or using experimental conditions that were not consistent with the model (e.g. liquid phase flow on the tube side, vacuum application to the gas phased). Thus, the need for collecting data with the current module configuration is necessary for model validation.

*Preliminary Results from Hollow Fiber Membrane Contactor Experimental System*

Experimental data from the HF micro-module system demonstrated that removal of both $CO_2$ and chloroform were possible. Steady-state was achieved within 10 minutes of operation. Since the Henry's Constants for these two compounds varies over an order of magnitude, the contactor has significant potential for stripping a range of volatile contaminants. Under the conditions of the experiments, removals of $CO_2$ ranged from 65 to 75 percent which suggests that $CO_2$ membrane stripping is feasible. No significant differences were observed over the range of ionic strengths tested (up to 0.5M).

## Significance

The Liqui-Cel® Membrane Contactor system employed in this research has significant potential for removing dissolved gases from liquid streams. Removal efficiency appears to be independent of ionic strength which indicates that the process has potential for serving as an intermediate step for removing carbonate from water to prevent precipitation and scaling of the RO membrane. In particular, the contactor can provide an intermediate step between UF for organic removal and RO for desalination of produced water.

A Murphree stage efficiency model was developed based on previous research by Seibert[10]. The Murphree efficiency describes the efficiency of a single separation stage in the overall module based on how well mixed the vapor and liquid phases are before moving to the next stage. The overall efficiency of the module can be calculated from the Murphree efficiency. Thus, this stage efficiency model can be used to predict removals and develop design parameters once it is validated with a larger set of data from the experimental system.

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# Information Transfer Program Introduction

In 2015, 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 an institute magazine published two times a year. 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:** | 2015TX481B |
| **Start Date:** | 3/1/2015 |
| **End Date:** | 2/28/2016 |
| **Funding Source:** | 104B |
| **Congressional District:** | 17 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | None, None, None |
| **Descriptors:** | None |
| **Principal Investigators:** | Roel R Lopez, Danielle Kalisek, Leslie H Lee, Kevin Wagner, Kathy Wythe |

## Publications

1. Harmel, R., K. Wagner, E. Martin, D. Smith, P. Wanjugi, T. Gentry, L. Gregory, T. Hendon, 2016, Effects of field storage method on E. coli concentrations measured in storm water runoff, Environmental Monitoring Assessment 188:170.
2. Rajsekhar, Deepthi, Vijay P. Singh, 2015, Hydrological Drought Atlas for the State of Texas, (TR-475), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 162 pages.
3. Gregory, Lucas, Anna Gitter, Katelyn Lazar, 2015, Basin Approach to Address Bacterial Impairments in the Navasota River Watershed, (TR-476), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 91 pages.
4. Lacewell, Ronald D., Paul Harrington, 2015, Potential Cropping Benefits of UAV Applications, (TR-477), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 8 pages.
5. Berthold, T. Allen, Terry Gentry, 2015, Pathogen Risk to Human Health in Potable Water Related to Nonpoint Sources of Contamination: Colorado River Alluvium Case Study, River Segment 1428 Phase II Final Report, (TR-478), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 45 pages.
6. Dictson, N., Allen Berthold, Clare Entwistle, Hughes Simpson, Sky Lewey, 2015, Texas Riparian & Stream Ecosystem Education Program Final Report, (TR-479), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 32 pages.
7. Harrington, Paul, Ron Lacewell, 2015, Impacts of Institutions on Water Conservation Incentives in the Texas Rio Grande Valley, (TR-481), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 34 pages.
8. Jonescu, Brian, Lucas Gregory, Allen Berthold, Kevin Wagner, 2015, Arenosa Creek Surface Water Quality Monitoring Report, (TR-482), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 29 pages.
9. Harrington, Paul, Ronald D. Lacewell, C. Robert Taylor, 2015, Non-Traditional Agriculture: Path to Future Food Production, (TR-483), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 22 pages.
10. Gregory, L., J. Murray, C. Schulz, 2016, Carters Creek Total Maximum Daily Load Implementation Project: Watershed Source Survey and GIS Mapping: Task 3, (TR-484), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 24 pages.
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Implementation Project: Routine, Reconnaissance and Stormwater Monitoring Report: Tasks 4 and 5, (TR-485), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 42 pages.

12. Gregory, L., J. Murray, C. Schulz, 2016, Carters Creek Total Maximum Daily Load Implementation Project: Intensive Water Quality Monitoring Report: Task 7, (TR-486), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 36 pages.
13. Gregory, L., C. Schulz, 2016, Carters Creek Total Maximum Daily Load Implementation Project: Education and Outreach Report: Task 6, (TR-487), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 10 pages.
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15. Rafi, K., K. Wagner, T.J. Gentry, R. Karthikeyan, 2015, Distribution of E. coli levels and recreation use as factor of stream order in the Central Great Plains, Central Oklahoma/Texas Plains and South Central Plains Ecoregion, (TR-491), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 137 pages.
16. Jones, Chelsea; T. Allen Berthold, 2015, Considerations for adopting AMI and AMR, (EM-119), Texas Water Resources Institute, Texas A&M System, College Station, Texas, 31 pages.
17. Wagner, K., G. Di Giovanni, T. Gentry, 2015, Bacterial Source Tracking: Learn why Bacterial Source Tracking is the foremost tool for identifying sources of fecal pollution, (EM-111, revised), Texas Water Resources Institute, Texas A&M System, College Station, TX, 4 pages.
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**Texas Water Resources Institute**
**Information Transfer Activities**
**March 1, 2015 – February 28, 2016**

In 2015, 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 an institute magazine published two times a year. 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.

*$txH_2O$*, 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 2,363 for hard copies and 1,139 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 eight issues. It currently has 649 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 2,565 Twitter followers, and TWRI tweets had 41,121 monthly impressions, up from 37,000. TWRI has 651 Facebook page likes; 205 Instagram followers and 271 Pinterest followers. TWRI also maintains one 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 63 mentions in the media.

In cooperation with research scientists and extension education professionals, the Institute published 14 technical reports and one educational material publication, 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 22 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 and Burton Creeks 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 |
| MyWater Web Portal and AMI | mywater.tamu.edu |
| Navasota River Water Quality Improvement | navasota.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** | 0 | 0 | 0 | 0 | 0 |
| **Masters** | 2 | 0 | 0 | 0 | 2 |
| **Ph.D.** | 0 | 0 | 0 | 0 | 0 |
| **Post-Doc.** | 0 | 0 | 0 | 0 | 0 |
| **Total** | 2 | 0 | 0 | 0 | 2 |

# Notable Awards and Achievements

2015TX482B: The work conducted under this grant directly contributed to the student (Adam Landon) securing his current position as a postdoctoral researcher at the University of Georgia.

# Publications from Prior Years

1. 2014TX469B ("Increasing Water Security through Horizontal Wells") - Articles in Refereed Scientific Journals - Blumenthal, Ben; Zhan, Hongbin. 2016. Rapid Computation of Directional Wellbore Drawdown in a Confined Aquifer via Poisson Resummation. Advances in Water Resources.