

**Texas Water Resources Institute
Annual Technical Report
FY 2017**

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 during fiscal year 2017 managed 63 active projects with more \$15,900,000 in funds. 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. Those projects included collaborations with 20 internal Texas A&M System departments and centers and 38 external entities. In 2017, the institute was awarded 24 new TWRI-lead projects with direct funding of \$5,583,103.

TWRI works closely with agencies and stakeholders to provide research-derived, science-based information to help answer diverse water questions and produce communications to convey critical information and 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 USGS graduate student research projects in 2017-2018 conducted by one graduate student at Rice University and one at Texas Tech University. In addition, four Mills Scholarships were awarded to Texas A&M University students.

Avantika Gori, Department of Environmental Engineering at Rice University. Advisor: Dr. Philip Bedient. Research: Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability.

Asef Mohammad Redwan, Civil, Environment & Construction Engineering at Texas Tech University. Advisors: Drs. Kayleigh Millerick and Audra Morse. Research: Effects of Salinity on DOC Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems.

Sierra Cagle, Department of Wildlife and Fisheries Sciences at Texas A&M University. Advisor: Dr. Daniel Roelke. Research: An Experimental Approach to Understanding the Mechanism Underlying Site Specific Salinity Thresholds Linked to Fish Killing Pymnesium Parvum Blooms in Texas Reservoirs.

Ajinkya Deshpande, Department of Ecosystem Science and Management at Texas A&M University. Advisor: Dr. Georgianne Moore. Research: Relating Riparian Health to River Hydrodynamics and Climate Using Dendrochronology and Tree Ring Carbon Isotope Composition.

Jennifer Morton, Department of Wildlife and Fisheries Sciences at Texas A&M University. Advisor: Dr. Charles Randklev. Research: Determining Drought Tolerances of Freshwater Mussels in Texas and the Implications for Environmental Flows.

Wan-Yi Wei, Water Management and Hydrological Sciences at Texas A&M University. Advisors: Dr. Clyde Munster and Fouad Jaber. Research: Low Impact Development Research.

Transboundary Aquifer Assessment Program (TAAP): TX Water Resources Institute Effort

Basic Information

Title:	Transboundary Aquifer Assessment Program (TAAP): TX Water Resources Institute Effort
Project Number:	2016TX513S
USGS Grant Number:	
Sponsoring Agency:	U.S. Geological Survey
Start Date:	9/15/2016
End Date:	10/14/2017
Funding Source:	104S
Congressional District:	15, 16, 23, 28, 34
Research Category:	Not Applicable
Focus Categories:	Groundwater, None, None
Descriptors:	None
Principal Investigators:	John C. Tracy, Zhuping Sheng, Rosario SanchezFlores

Publications

There are no publications.

Transboundary Aquifer Assessment Program

Technical Report

2016-2017

Summary of Deliverables

- Geologic Correlation between Mexico and Texas
 - o Activities involved
 - Field work and data collection in the border region, particularly the Allende-Piedras Negras Transboundary Aquifer
 - Attended a various meetings with the public and private water sector in Mexico to obtain groundwater data (well data)
- Development of the transboundariness approach
 - o Sanchez, R. & Eckstein, G., 2017, Aquifers Shared Between Mexico and the United States: Management Perspectives and Their Transboundary Nature: Groundwater, April 2017, DOI: 10.1111/gwat.12533
- Integration of a Texas-Mexico transboundary aquifer initial assessment report delivered to Conagua and IBWC/CILA representatives.
 - o This report includes:
 - Homogenization of geological formations across de border
 - Identification and classification of potential aquifer formation units and their corresponding water quality assessments
 - Identification and development of effective aquifer areas. An approach that can be applied both at international and domestic levels.
- Integration of the conceptual model of Allende-Piedras Negras Aquifer and groundwater levels scenarios using MODFLOW

Important Meetings and Conferences

- 2017 World Water Conference at Cancun, Mexico. Presented in two special sessions on transboundary aquifers and Moderator of a Session on Environmental Programs in the border region
- TAAP Meeting at El Paso with TAAP members and IBWC/CILA
- UCOWR, presentation on the transboundariness approach and TAAP current research
- TAAP Meeting at Tucson with TAAP members, follow up and current research

Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability

Basic Information

Title:	Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability
Project Number:	2017TX510B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	TX002
Research Category:	Climate and Hydrologic Processes
Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	Philip B. Bedient, Avantika Gori

Publication

1. Gori, A., Blessing, R., Juan, A., Brody, S., Bedient, P. Characterizing urbanization impacts on floodplain through integrated land use, hydrologic, and hydraulic modeling. *Journal of Hydrology* (under review).

Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability

Project Number: 2017TX510B (06-M1701864)

Primary PI: Avantika Gori

Co-PI: Philip Bedient

Abstract:

In the United States, fluvial flood risk is managed by the National Flood Insurance Program (NFIP), which delineates areas that have a 1% chance of flooding each year (i.e. the 100-year floodplain). However, there is a disconnect between NFIP risk delineation, and observed flood losses that can be attributed in part to changing land cover impacts on watershed response. Development within and adjacent to riverine floodplains exacerbates losses by increasing peak discharge, shortening the time to peak, and altering the extent of the floodplain. This paper proposes a novel methodology for evaluating the impacts of future development on the 100-year floodplain by considering both regional trends in development and site-scale development policies. The framework advanced in this paper integrates future development scenarios from a machine learning land use projection model with distributed hydrologic modeling and coupled 1D/2D unsteady hydraulic modeling to produce future floodplain estimates. Current site-scale detention requirements are represented within the hydrologic model to evaluate the regional effectiveness of these policies under future development conditions in 2050. Results indicate that the 100-year floodplain can expand by 25% as a result of projected development in 2050 using current stormwater mitigation policies. This study serves as a step forward in understanding how incremental land use changes can significantly alter the reality of flood risk in urbanizing watersheds, and how to increase flood resilience through land use policy.

Problem and Research Objectives:

In the US, fluvial flood risk is characterized and managed through the National Flood Insurance Program (NFIP), which delineates a regulatory 100-year floodplain (the area that has a 1% chance of flooding each year), known as the Special Flood Hazard Area (SFHA). However, there is often a disconnect between the SFHA and observed flood damage (NRC, 2014) that can be attributed in part to outdated floodplain maps, which do not take into account changing land cover impacts on watershed response (Blessing et al., 2017). For example, one study found that over 60% of floodplain maps were at least 10 years old (Birkland et al., 2003). In high-growth areas like Houston, TX (located along the upper Texas Gulf coast) substantial land development can occur within a span of 10 years that can significantly alter the hydrologic behavior and undermine the SFHA's capability to accurately represent current flood risk. Since NFIP map revisions cannot keep pace with changing watershed conditions, development may be occurring in areas that are vulnerable to flooding but have not been designated as SFHAs yet. This results in development policies that are reactionary rather than proactive. The consequences of this approach have been evident in Harris County, TX, where development restrictions have typically been implemented in response to major flooding events, rather than keeping pace with urbanization trends. This paradigm poses a critical challenge to planners and engineers who seek to design long-term flood management strategies in the face of future development uncertainty.

In order to evaluate the long-term effectiveness of flood management infrastructure and quantify evolving riverine flood risk, it is necessary to integrate land use projection modeling with hydrologic and hydraulic modeling. Although there have been many studies documenting the increase in peak flows and runoff volumes associated with historical urbanization (Doubleday et

al., 2013; Rose and Peters, 2001; Sheng and Wilson, 2009; Vogel et al., 2011), these impacts do not uniformly translate to increases in floodplain extent (Wheater and Evans, 2009). There is still limited understanding of floodplain sensitivity to increases in overland runoff rates and volumes, since topographic factors, stream characteristics, and the presence of existing flood infrastructure influence the ability of a watershed to accommodate or attenuate increases in overland flow.

There has also been little research conducted on the regional effectiveness of site-scale development policies to offset future impacts of urbanization. These policies, such as on-site detention/retention requirements, aim to mitigate the impacts of development at the site-scale. Although there have been some studies examining the local runoff response of these site-scale detention features (Mogollón et al., 2016), there has been no consideration of their efficacy at the regional scale.

This study aims to address the limited understanding of watershed sensitivity to future development and the regional impacts of site-scale mitigation by developing an integrated framework to quantify floodplain increases under a range of future development conditions. By linking land use projection modeling with hydrologic/hydraulic analysis, this paper provides a comprehensive approach to floodplain management that effectively considers the crucial feedback loop between anthropogenic activities, environmental response, and natural hazard management. First, a land use projection model for the region is developed to characterize the likelihood of development in 2050, and ultimately produce future development scenarios. These scenarios are represented within a distributed hydrologic model to evaluate the impact of urbanization patterns as well as site-scale development requirements on 100-year overland flows. Flow hydrographs are linked to an unsteady hydraulic model to assess development impacts on

water surface elevations, and ultimately produce current and future 100-year floodplain depths and extents. Floodplain results are analyzed to characterize watershed response to future development, identify potentially vulnerable regions of the watershed, and provide information about the effectiveness of existing policies in mitigating future flood risk. This framework is applied to a case study watershed in northwest Harris County that has experienced rapid development in recent years, has been highly vulnerable to riverine flooding, and is expected to continue developing rapidly in the future.

Materials/Methodology

Study Area

The Cypress Creek watershed is located north of the city of Houston in northwest Harris County, along the upper Texas Gulf Coast (Figure 1). The watershed encompasses a 692 km² drainage area, features over 400 km of open drainage channels, and contains a population of 347,334 (HCFCD, 2017). The watershed is currently partially developed, with the majority of developed land located on the east side of the watershed. The western portion of the watershed is primarily composed of agricultural and natural prairie land (Figure 1). Cypress Creek serves as the primary drainage conduit for the watershed, draining east to west until flowing into the San Jacinto River. The stream is slow-draining since it has largely remained in its natural state, with vegetation lining the banks and natural meanders. However, due to the flat topographic slopes in the southwestern portion of the watershed and the limited conveyance capacity of the stream, water spills over the watershed divide and into the neighboring Addicks Reservoir watershed during high-intensity rain events (HCFCD, 2017). Inter-basin overflow can occur during rain events greater than a 5-yr magnitude (14.7 cm in 24hr), and result in significant volumes of overflow

during higher intensity events (HCFCD, 2017). This complex hydraulic phenomenon is somewhat unique and poses a challenge for modeling the rainfall-runoff response of the watershed, since overflow rates depend on both rainfall intensity and downstream water surface elevations. Thus, traditional 1D models have been unable to simulate the runoff dynamics during extreme rain events and are unable to accurately represent the 100-year floodplain in this portion of the watershed.

The Cypress Creek watershed has experienced several major flooding events over the last few years that have inundated thousands of homes and resulted in substantial economic losses. During a storm event in April 2016, for example, over 2000 homes were flooded in the Cypress Creek watershed alone, and peak water elevations throughout the watershed far exceeded previous records (Lindner and Fitzgerald, 2016). More recently, during Hurricane Harvey, thousands of residents in the watershed experienced severe inundation over a period of several days (Sebastian et al., 2017), leaving hundreds stranded in their homes. These recent extreme precipitation events highlight the vulnerability of the watershed to repetitive flooding.

These recent flood events in the Cypress Creek watershed are even more concerning when considering the rapid development simultaneously occurring in the area. From 2000 to 2010, the population of the watershed grew by 70% on average, while development rates in the western portion were as high as 390% in one zip code (Zheng, 2011). The impact of this development is twofold: 1) new development is occurring inside areas already vulnerable to flooding and 2) the accompanying increase in impervious surface further exacerbates flood risk.

Land Use Projection Model

This study utilizes output from a pattern recognition based model, known as a multi-layer perceptron artificial neural network (MLPNN) (Pijanowski et al., 2002). The MLPNN model for the Houston-Galveston region was set up and validated by Dr. Russell Blessing from Texas A&M Galveston. The ability of ANNs to generalize across regions is particularly useful for land cover modeling. More specifically, ANNs can address the oftentimes complex interacting nature of land use change drivers that operate over different spatial and temporal scales (Lambin et al., 2003). Spatially, drivers of change can be local or global, and temporally they can operate in subtle and graduate fashion (e.g. climate change) or they can exhibit the rapid changes due to major events (e.g. hurricanes and floods) (Lambin et al., 2003). In this study, an ANN is used to determine the potential of a given location to transition from a non-built classification to built (i.e. urban expansion) using regional drivers of change and historic land cover change dynamics.

A full description of the model set up and validation can be found in the forthcoming article (Gori et al., 2018). Essentially, the model is trained using historical land cover data from the NLCD from 2001 and 2006. Historical drivers of development are investigated and ultimately four drivers are shown to sufficiently explain regional urbanization patterns in the Houston-Galveston region: existing land cover type, distance to existing development, distance to downtown, and distance to schools. The model is validated using NLCD 2011 land cover data to ensure accurate prediction.

Transition potentials for 2050, or the likelihood that an area will become developed in the year 2050, are generated by the model. This yields a map of probability of development as well as a

map depicting the model's "best guess" for 2050. Land use scenarios are developed by utilizing both maps to stipulate 15% less development than predicted by the best guess estimate for a low development scenario, and 15% more development than predicted for a high development scenario. These two development scenarios are modeled within a distributed hydrologic model.

Hydrologic Model

This study utilizes Vflo®, a physics-based, distributed hydrologic model, to simulate the rainfall-runoff process. Vflo® solves conservation of mass and momentum equations using a finite-element approach, and represents the physical characteristics of a watershed in gridded-cell format (Vieux and Bedient, 2004). In the model domain each grid cell contains parameters that represent elevation, soil type, land cover characteristics, and a flow direction that is defined based on relative elevation compared to surrounding cells. Grid cells can be designated as overland or channel cells, and channel cross sections can be extracted from digital elevation data. The model performs rainfall-runoff calculations within each grid cell, and overland flow between cells is routed via the Kinematic Wave Analogy (KWA), which is a simplification of the 1D Saint-Venant equations. A full description of the KWA derivation is documented in (Vieux & Vieux, 2002). Infiltration is calculated at each grid cell using the Green & Ampt Equation, which depends on soil parameters of hydraulic conductivity, wetting front suction head, effective porosity, and soil depth (Rawls et al., 1983). In this study, Modified Puls routing is utilized to model channel flow since it is more suitable for representing channel storage in mild-sloped watersheds (Vieux and Bedient, 2004).

Distributed models are particularly useful for representing spatially-diverse land cover characteristics and modeling land cover evolution through time since calculations are made at the grid cell level. In contrast, traditional lumped modeling methods often rely on empirical parameters derived at a subbasin-scale, which may not be able to accurately represent localized development changes (Blessing et al., 2017). Vflo® has been successfully utilized to model development scenarios, low impact development features, and flood mitigation infrastructure (Doubleday et al., 2013; Fang et al., 2010; Juan et al., 2017). Additionally, Vflo® was chosen because it has been widely applied and validated in the Houston region for both inland and coastal watersheds (Blessing et al., 2017; Ray et al., 2011; Vieux and Bedient, 2004).

Model Set up and Calibration

Vflo® model setup requires detailed elevation, soil type, and land cover information. The model domain was delineated based on the Harris County Flood Control District (HCFCD) watershed boundary and utilized a grid cell resolution of 91 m (300 ft), which was determined based on a maximum model size of roughly 100,000 cells. 2008 LiDAR Digital elevation (DEM) data was obtained from the Houston-Galveston Area Council (HGAC), and was utilized in the model to determine the slope of each cell and the overland flow direction grid, and to extract cross-section profiles for channel cells in the model. Soil type information was obtained the Texas Natural Resources Information System (TNRIS), and processed in ArcGIS according to Rawls et al., (1983) to obtain estimates of hydraulic conductivity, effective porosity, wetting front capillary pressure head, and soil depth.

Land cover data to represent current conditions in the watershed was obtained at 30 m resolution from a 2011 dataset within the National Land Cover Database (NLCD). Vflo® is able to represent land cover/use through a Manning's roughness coefficient and a percent imperviousness applied at each grid cell. Roughness coefficients indicate the amount of frictional losses between flowing water and ground surface, and impact the velocity of overland flow (Kalyanapu et al., 2009). Consequently, natural areas of high vegetation or forest will have higher roughness coefficients and lower flow rates, while concrete or pavement areas will have low roughness and high flow rate. Land cover categories from NLCD are converted to Manning's roughness coefficients based on Kalyanapu et al (2009), and impervious percentages are designated based on NLCD guidelines (NLCD, 2011).

The hydrologic model was calibrated using two significant rainfall events, one on April 17th 2016 and the other occurring on May 26th 2016. The first event in April 2016 was an extreme precipitation event that dropped over 38 cm in 12 hrs on some parts of the watershed, and resulted in the Tax Day flood described in the Study Area section (Lindner and Fitzgerald, 2016). This storm exceeded a 500-yr frequency event in the western portion of the watershed and a 100-yr frequency on average throughout the study area (Lindner and Fitzgerald, 2016). The second storm occurring on May 26th 2016 resulted in 12.7-17.8 cm across the watershed, corresponding to roughly a 10-yr frequency event. These two events were chosen because they represent a range of frequency storm magnitudes, and because they occurred during the same time period. This latter point is important in order to isolate and calibrate to the most recent development conditions.

Five USGS streamflow gages along Cypress Creek were used as calibration points (Figure 3a). The average peak flow difference and Nash-Sutcliffe Efficiency across the three gages was 2.1% and 0.80, and -1.2% and 0.74, for the April 2016 and May 2016 storms respectively (with negative values indicating under-prediction by the Vflo® model). Based on these performance metrics and the overall shape and timing of the comparison hydrographs, the authors believe these are satisfactory calibration results. Figure 3a shows hydrograph comparisons at the middle gage location, which is the most reliable gauge (based on rating curve measurements) in the watershed, and Figure 3b shows a comparison of modeled peak streamflow vs observed.

In order to ensure accurate comparison between current and future conditions, a 100-year design storm was applied to the current conditions Vflo® model to generate 100-year flow hydrographs. The 100-year rainfall hyetograph for this region corresponds to 31.5 cm in 24 hrs, and was applied according to the Soil and Water Conservation Society (SWCS) guidelines for a Type-III 24 hr storm event, which is the same rainfall methodology applied by Harris County floodplain managers in modeling a 100-year event (Storey et al., 2010).

Site-Scale Detention Modeling Methodology

Although roughness coefficients from Kaylanapu et al (2009) are used to represent frictional losses for current development in the watershed, these values were not applied to represent future development. These values assume no on-site detention measures, and thus represent development impacts under a no mitigation scenario. Instead, this study derives new roughness values based on development criteria from the HCFCD, which is the primary floodplain

regulatory agency in Harris County, and the topographic conditions of the Cypress Creek watershed.

According to HCFCD's Policy, Criteria, and Procedure Manual (Storey et al., 2010), new developments must adhere to peak discharge rate restrictions that are defined for a 10-year and 100-year storm event. For developments smaller than 2.59 km², a simple Site Runoff Curve can be used to determine the maximum allowable peak discharge. For developments larger than 2.59 km², more rigorous hydrologic and hydraulic modeling is needed to determine the appropriate on-site detention requirements. As a point of reference, the size of each grid cell in the Vflo® model is 0.008 km². For the purposes of this study it was assumed that all new developments would be the size of a single Vflo® grid cell, so on-site detention could be modeled using the Site Runoff Curve equations to constrain the maximum discharge rate. These curves are determined based on the following equation:

$$Q = bA^m$$

Where Q is peak flow rate, A is development area, b is a factor based on impervious percent of the development, and m a factor based on the size of the development. For development areas less than 0.08 km², m is equal to one and the equation simplifies to a linear relationship. Using this equation, each grid cell in the Vflo® model that is projected to become developed in 2050 should have a peak discharge of less than 0.14 m³/s. This methodology for calculating and applying the maximum discharge rate to each individual cell is appropriate because given the linear nature of the Site Runoff Curves, a group of developed cells would have a combined peak discharge that is still in compliance with the detention requirements for their collective area. For

example, a new development the size of ten Vflo® grid cells has a maximum allowable discharge ten times that of an individual developed cell.

In order to achieve compliance with these detention requirements, a sub-grid parameterization was employed so that on-site detention features within a given cell could be represented by adjusting the overland roughness across the entire cell. Since calculated flow rates within the Vflo® domain depend on both the slope and roughness of the cell (Vieux, 1990), both of these parameters were examined when calculating a new representative roughness for on-site detention features. This process is outlined in figure 4 and involved the following steps: 1) calculating the distribution of overland slope values for all new development cells in the watershed, 2) selecting a representative slope value (s_0) based on the distribution, 3) determining a representative roughness (r_0) for a cell with slope s_0 which produces a 100-year peak flow of $0.14 \text{ m}^3/\text{s}$, and 4) applying the new r_0 to all cells within the watershed and checking a random sample of 100 cells to ensure that compliance is achieved.

Since steeper slope values produce higher flow rates, s_0 was chosen to be greater than 90% of cells within the watershed. Based on the distribution of slope values (figure xx), 90% was chosen as the threshold because the distribution has a heavy tail, with a few high slope outliers. Next, r_0 was determined by applying a 100-year rainfall hyetograph to a single cell with slope s_0 , and increasing the roughness until the peak discharge was reduced to $0.14 \text{ m}^3/\text{s}$. The new r_0 was determined to be 0.2, compared to 0.0678 under a no mitigation scenario (Kalyanapu et al, 2009). This representative roughness was applied to all newly developed cells within the watershed and the 100-year peak flow for a random sample of 100 cells was tested to ensure

compliance across the watershed. Of the 100 cells tested, 89 complied with peak flow requirements, and only 11 exceeded the peak flow threshold. However, most of these cells were within 5% of the required peak flow and all cells were within 10% of the requirement. Thus, this performance was deemed acceptable for modeling site-scale detention.

Hydraulic Model

For this project, hydraulic analysis was conducted using a hydraulic model, HEC-RAS (Hydrologic Engineering Center – River Analysis System), developed by the U.S. Army Corps of Engineers. This model has been used in a wide variety of applications, including floodplain assessment, flood insurance studies, and dam breach analysis (Bass et al., 2017; Butt et al., 2013; Knebl et al., 2005; McLin et al., 2001). The primary function of HEC-RAS is to calculate water surface elevations at channel cross sections or modeled storage areas of interest for any given flow rate. The latest version of the software, Version 5.0.3 (Brunner, 2016), is capable of computing water surface profiles by performing one-dimensional (1D), two-dimensional (2D), or combined 1D/2D hydraulic calculations, based on energy and momentum equations.

In this study, the effective hydraulic model of Cypress Creek watershed developed by HCFCD was used as reference. This model is a 1D-steady model, and is used as the basis for generating the 100-yr FEMA floodplain. The model generates a static water surface profile (i.e., maximum water surface elevation) along the entire channel based on peak discharges inputted at specific channel cross sections. While a 1D-steady model is useful for floodplain assessment and floodway encroachment studies, it is insufficient to model the hydraulic performances of intricate systems where volume and timing are crucial, such as the Cypress Creek overflow area. In order to simulate the hydrodynamics at this particular location, the effective HCFCD model

was modified and converted to a 1D/2D unsteady hydraulic model. The main advantage of an unsteady model compared to a steady model is that it can simulate the water surface profiles of entire storm hydrographs instead of just peak flows, which provides a better understanding of the system's flow and stage response over time. This is crucial for modeling the overflow area in Cypress Creek, because the overflow dynamics depend on both stage hydrograph timing and peak.

The HEC-RAS model was validated using the same two precipitation events that were used to calibrate the hydrologic model. There were a significant number of high water marks obtained for these events in addition to peak water levels recorded at gauges along Cypress Creek.

Maximum water surface elevations modeled in HEC-RAS were compared to these high water marks for both the April 2016 and May 2016 storms. Additionally, for the April 2016 storm there were several high water marks recorded in the overflow area, which were used to ensure a good match between modeled overflow depths and observed depths. The average peak stage difference was -0.01 m and -0.3 m for the April 2016 and May 2016 storms respectively, with negative values indicating model under-prediction, and a comparison between modeled water depth and observed depth for both storms is shown in figure 5. Although the model slightly under-predicted stage for the May 2016 event, it produced good results for the April 2016 event, which is close to a 100-year magnitude.

Principal Findings

Future Development in Cypress Creek

As shown in figure 6, the Cypress Creek watershed is currently partially developed, with a majority of the watershed composed of agricultural and natural lands. Development projections

for 2050 predict that new development will occur in areas adjacent to existing development, such as the undeveloped lands located in the middle and eastern portion of the watershed, and new development trends will push westward into areas currently dominated by natural and agricultural land cover. A comparison of current land use, 2050 low development, and 2050 high development shown in figure 6 illustrates the trend of westward development, and shows that the primary difference between the low and high development scenarios is the amount of development located in the western portion of the watershed.

Table 1 indicates that development in 2050 is projected to grow by 37%-54.5%, becoming the dominant land use type within the watershed. While developed land sees the largest gains in 2050, natural lands are projected to experience the highest losses, decreasing by 54%-61%. Agricultural lands remain relatively constant, shrinking by only 11%-24%. These results suggest that future development within the Cypress Creek watershed could disproportionately impact natural land, such as forests and wetlands, compared to pasture and crop land. Figure 6 demonstrates this trend further, showing that large areas of natural land are projected to become developed in 2050.

Floodplain Extent Increase

Figure 7 illustrates the extent of the 100-year floodplain under each of the three scenarios: current conditions, 2050 low development, and 2050 high development. A comparison of the three floodplains illustrates that increases in floodplain extent are moderate along the middle and downstream portion of the watershed, but are more severe in the upstream portion, which is magnified in figure 7A. This magnified area corresponds to the inter-basin overflow area, where

Cypress Creek spills over its banks and into the neighboring Addicks Reservoir watershed.

Figure 7B shows a portion of the midstream of Cypress Creek. In this region, floodplain increases are much less severe than in the overflow area.

Table 2 shows the change in 100-year floodplain extent and increase in inundated residential parcels between 2050 development scenarios and current conditions. The 100-year floodplain extent is projected to increase by 8.4-12.5% across the watershed, which corresponds to an increase in inundated area of 9-13 km². The impact to residential parcels is more severe, ranging from 12.3-18.8% increase compared to current conditions. Across the watershed, this corresponds to an additional 361-550 impacted parcels. These estimates only include existing residential parcels, and do not take into account newly developed parcels in 2050. Thus, it is likely that Table 2 under-estimates the true increase in residential flood risk across the watershed. Instead, it represents existing parcels that could become designated as special flood hazard areas (SFHAs) in the future due to growth of the floodplain extent.

Table 3 displays similar flood risk statistics as Table 2 for the overflow area alone. Within the overflow area, the floodplain extent is projected to increase by 16.4%-23%, and increase the number of inundated parcels by 21%-25%. These impacts are considerably greater than results across the entire watershed.

Significance

The results indicate that the 100-year floodplain can expand by nearly a quarter of its original size as a result of nearly four decades of projected urbanization in the Cypress Creek watershed.

In general, across the watershed, a percent increase in development translated into about a 0.23% increase in the extent of the floodplain. However, floodplain sensitivity to projected development was found to be highly variable, which was driven in large part by spatially varying watershed characteristics and the heterogeneous pattern of future development. The overflow area in particular was much more sensitive to future urbanization, with impacts two times more severe than across the entire watershed. Even under a low development scenario, the floodplain is projected to increase by more than 20% in the overflow area, indicating that this region is highly sensitive to urbanization impacts. This impact likely would not have been as evident without the coupled 1D/2D unsteady hydraulic model that more accurately represents the complex hydrodynamics of the overflow area.

Another key finding is that the impact that development has on floodplain extent is location specific. Small increases in upstream urbanization can have large impacts on downstream floodplain extent due to specific physical characteristics of the downstream area. For example, although the majority of projected urbanization in 2050 (Figure 6) occurs in the middle and downstream portion of the watershed, the largest floodplain impacts are observed in the upstream overflow area. Under current conditions, 6% of land upstream of the overflow area is developed, and by 2050 increases to only 10% under a low development scenario. Yet, this small increase in upstream development results in a 20% increase in floodplain extent. In contrast, the middle and downstream portion of the watershed appear to be fairly resilient to increases in development, since they are able to accommodate large increases in future development without substantial increases in floodplain extent.

The difference in floodplain impacts between the overflow area and the middle/downstream portions of the watershed is also mediated by changes in slope and channel storage capacity. In the overflow region, the ground slope is mild and there is little storage capacity outside the channel. This results in a wide floodplain extent even under current conditions, since relatively small increases in water elevation result in large increases in inundation extent. Furthermore, since Cypress Creek already has limited storage capacity in this location (described in section 2), increases in runoff volume resulting from new development cannot be effectively stored or conveyed through the channel. Instead, excess runoff volume spills over the channel banks and drains through the overflow area, resulting in substantial increases to the 100-year floodplain in this area. In contrast, the middle and downstream portion of the channel has a large amount of overbank storage, which is able to constrain the floodplain extent. Previous studies have also shown that the presence of overbank storage capacity can improve flood wave attenuation by storing excess floodwater (Castellarin et al., 2011; Woltemade and Potter, 1994).

In addition to understanding overall watershed sensitivity to development, and identifying vulnerable locations, this study also evaluated the effectiveness of existing detention requirements to mitigate impacts from future development. Based on floodplain extent results, it is clear that on-site detention policies are unable to completely mitigate the impacts of future development. Previous studies have argued that on-site detention systems that are dispersed across a watershed can better alleviate the impacts from new development compared to large regional detentions systems, because they are better able to replicate pre-development hydrologic response (McCuen and Rawls, 1979). However, these systems are generally most effective for intermediate storms rather than extreme precipitation events (Konrad and Burges, 2001).

Roughness coefficients were increased substantially to replicate the effect of on-site detention standards for this area that were intended to preserve pre-development hydrologic conditions. However, the impact of increased imperviousness overwhelmed the study's on-site detention proxy resulting in increases in floodplain extents that disproportionately affected specific areas. These results suggest that in addition to limiting peak flow rates with on-site detention other hydrologic characteristics should be considered such as limiting runoff volume with on-site retention. Furthermore, the method presented in this study could be used to determine the necessary level of site-scale mitigation necessary achieve no adverse impacts at a regional scale. Development policies should be crafted by examining multiple spatial scales in order to properly quantify the cumulative impacts of development, and set mitigation criteria that produces no adverse impacts across the entire watershed.

The application of an integrated framework for land use projection modeling and hydrologic/hydraulic modeling to the Cypress Creek watershed highlights its usefulness for quantifying the impacts of future development trends and development policies. By taking into account both where development occurs regionally and how development is managed at the site-scale, this methodology is able to more accurately delineate areas of future risk. Specifically within the overflow area, which exhibits complex hydrologic effects, distributed hydrologic modeling coupled with 1D/2D hydraulic modeling methods are able to effectively represent evolving flood risk. Floodplain managers and engineers could utilize a similar framework to evaluate the long-term effectiveness of flood infrastructure or different development policies under nonstationary land use. Specifically, by considering a range of possible development

conditions, decision-makers can understand the threshold level of development at which negative impacts are observed, and plan mitigation strategies based on this threshold.

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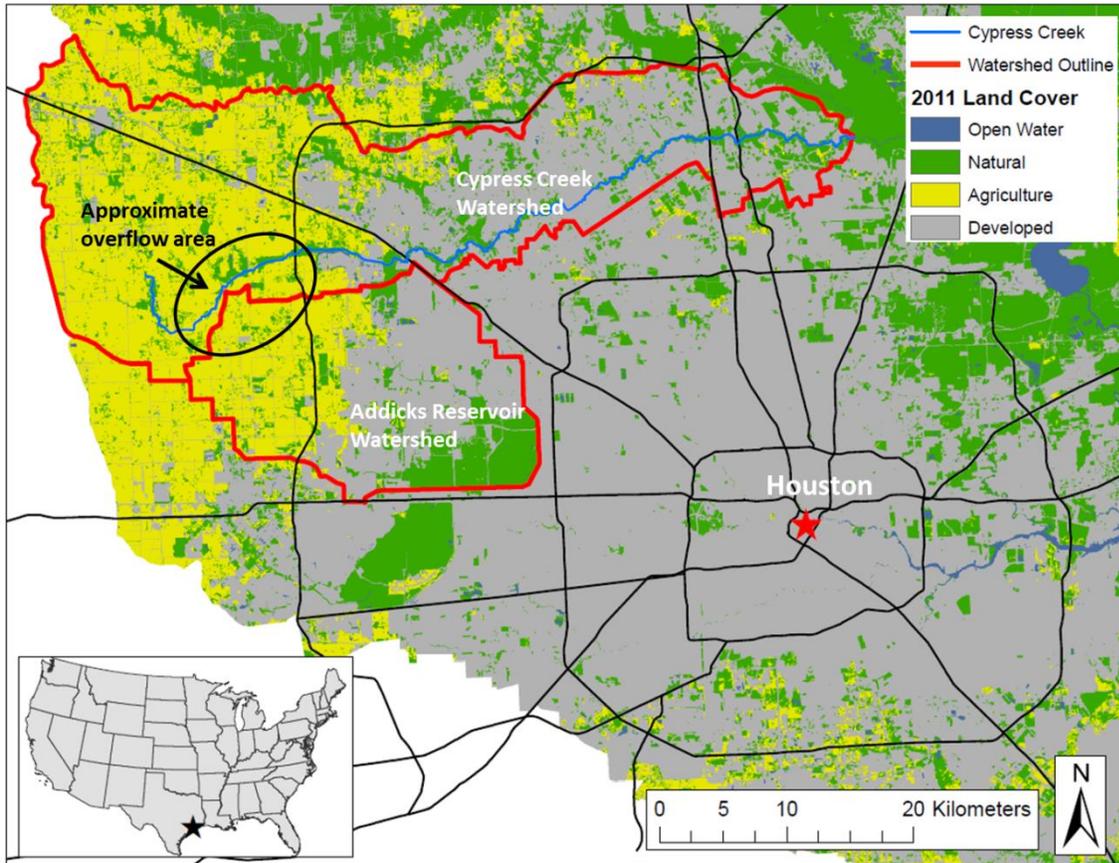


Figure 1: Cypress Creek watershed study area and regional land use

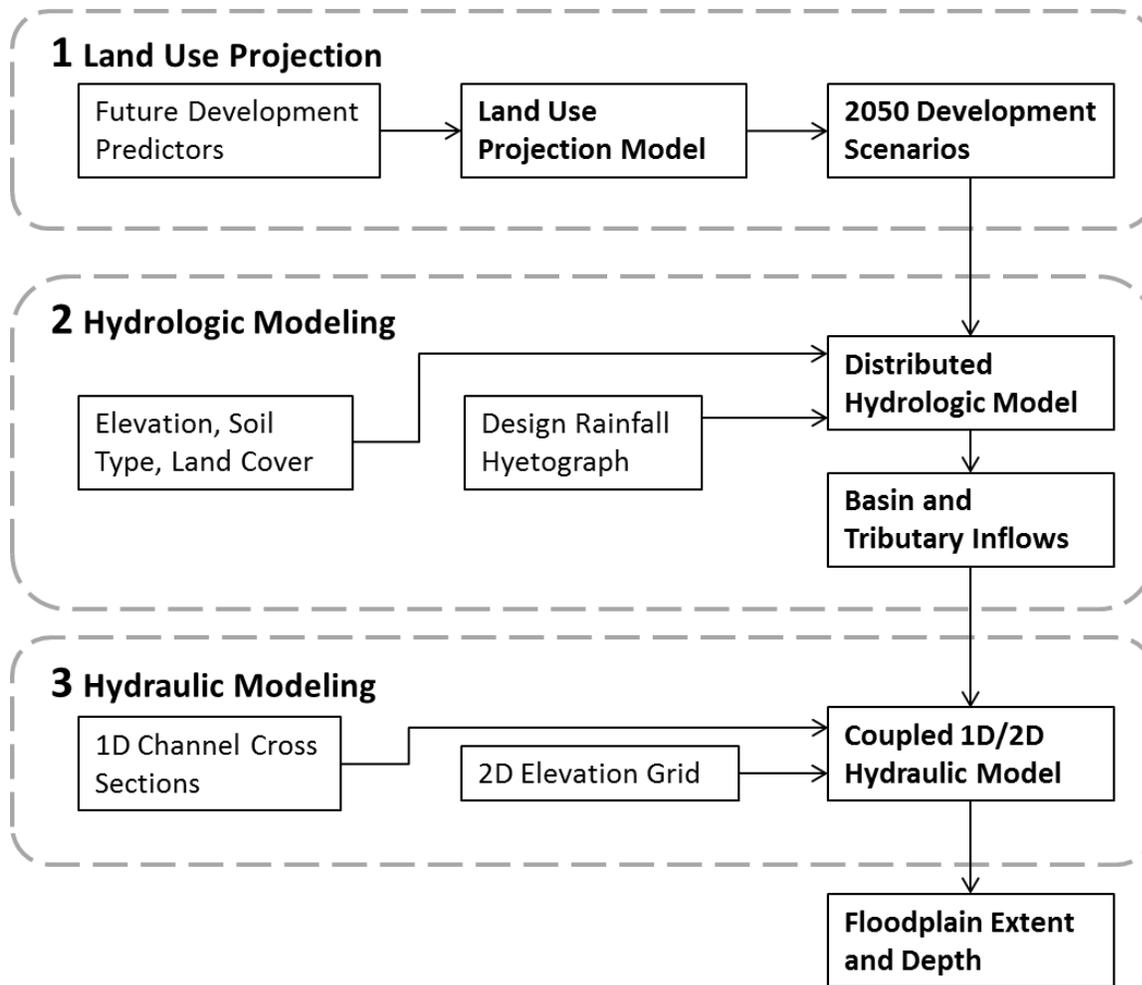


Figure 2: Integrated modeling framework overview

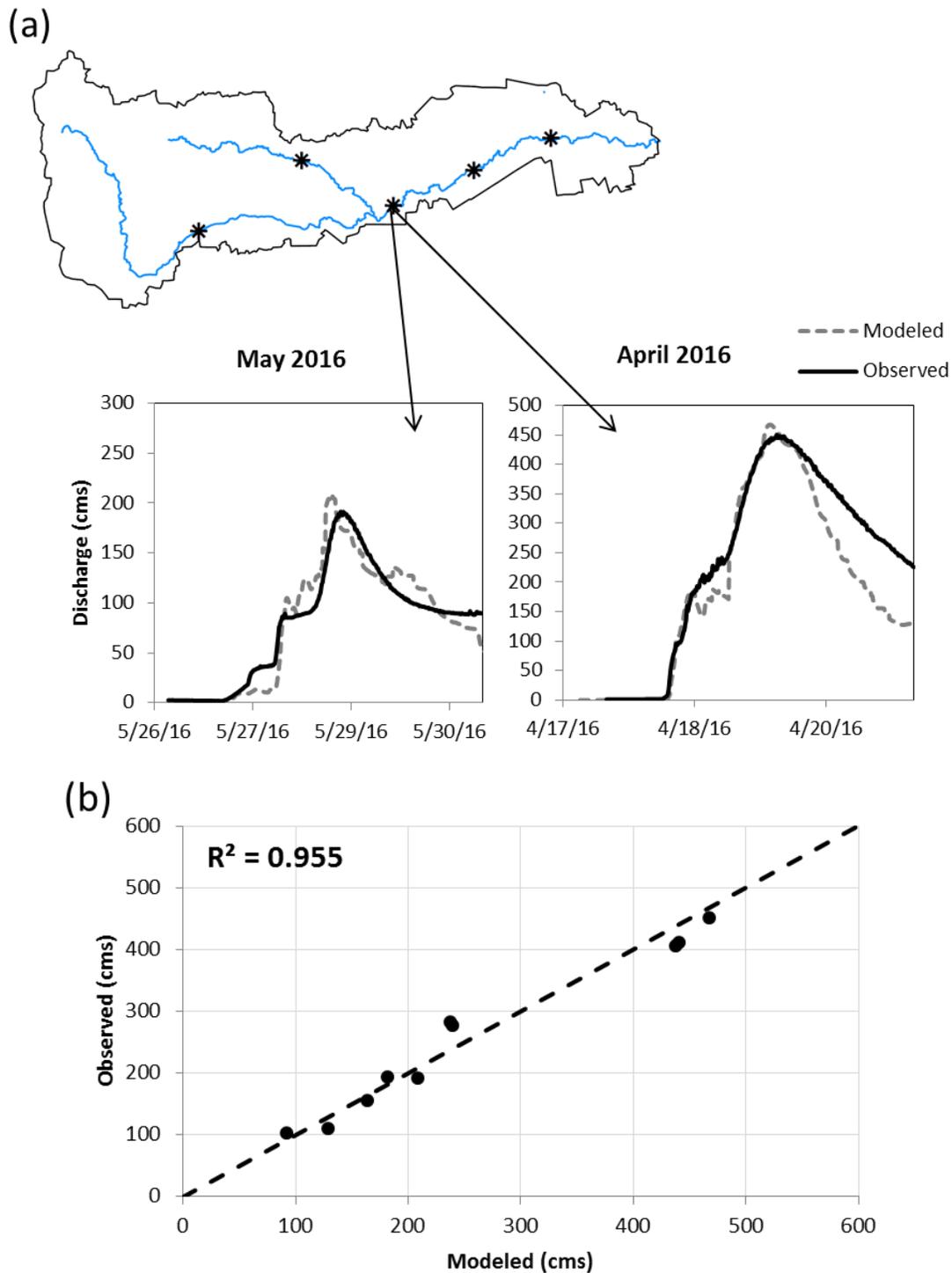


Figure 3: (a) Location of flow calibration points and hydrograph comparisons for a sample location in the middle of the watershed (b) modeled vs observed peak flow across all gages and storms

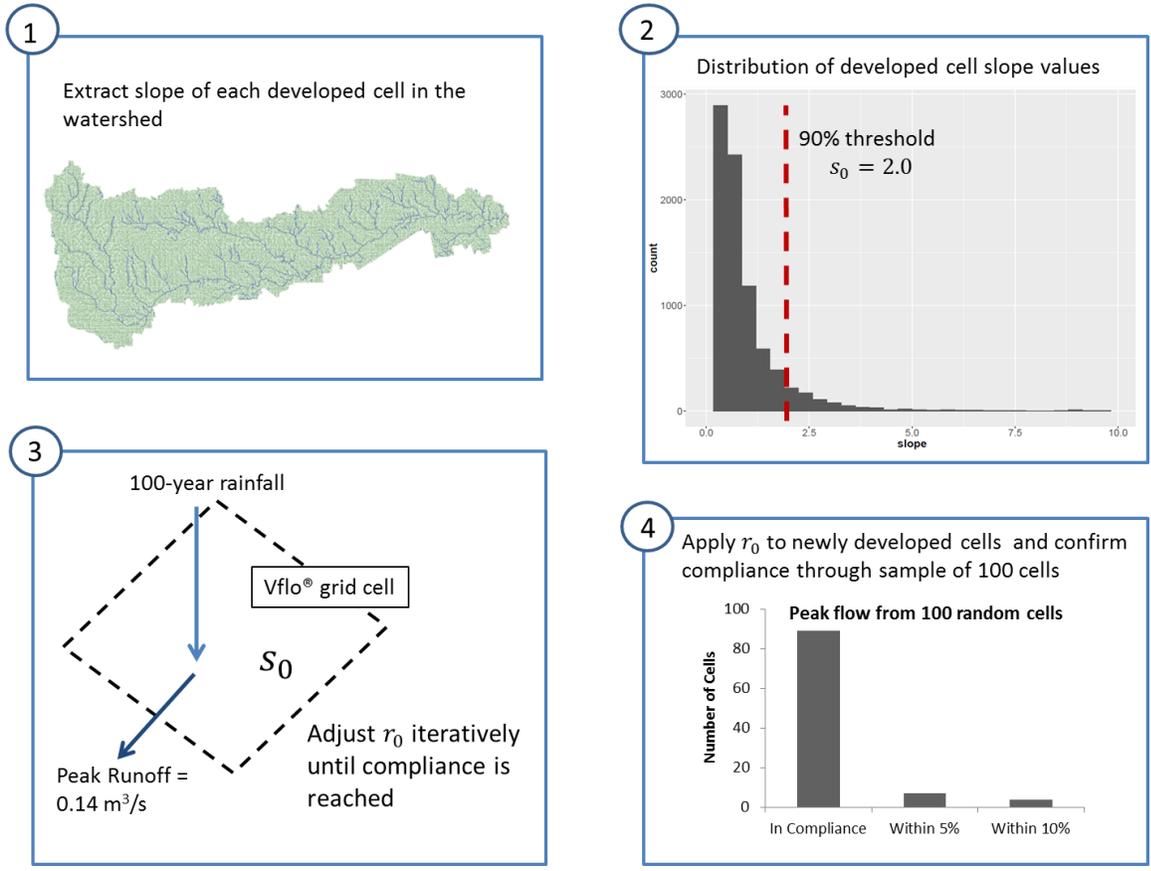


Figure 4: Process flowchart for determining representative roughness value to model on-site detention features of new development

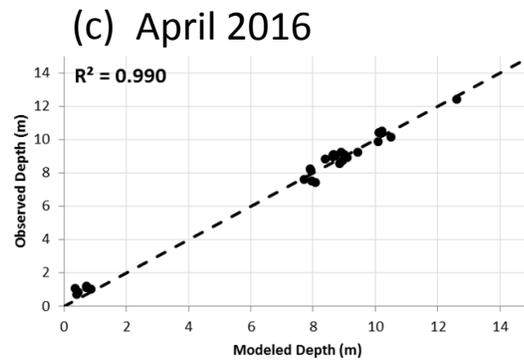
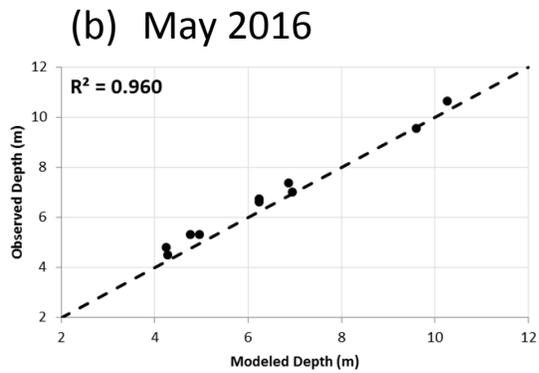
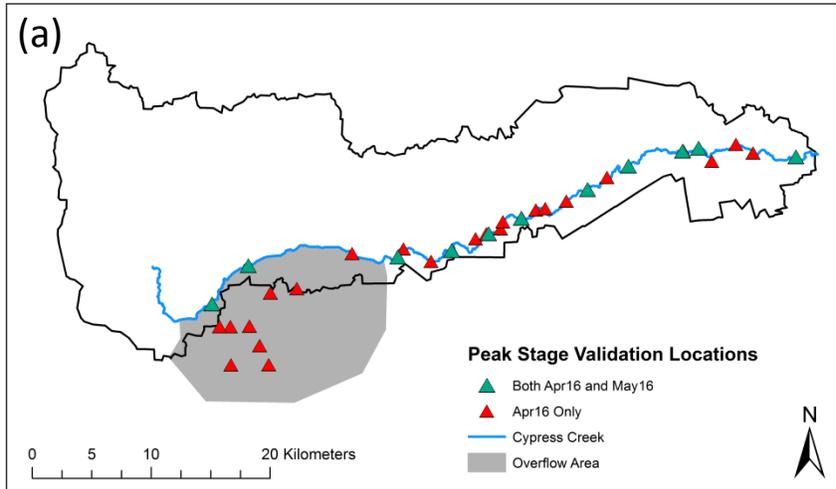


Figure 5: (a) peak stage validation locations (b) modeled vs observed peak stage for May 2016 event (c) modeled vs observed peak stage for April 2016 event

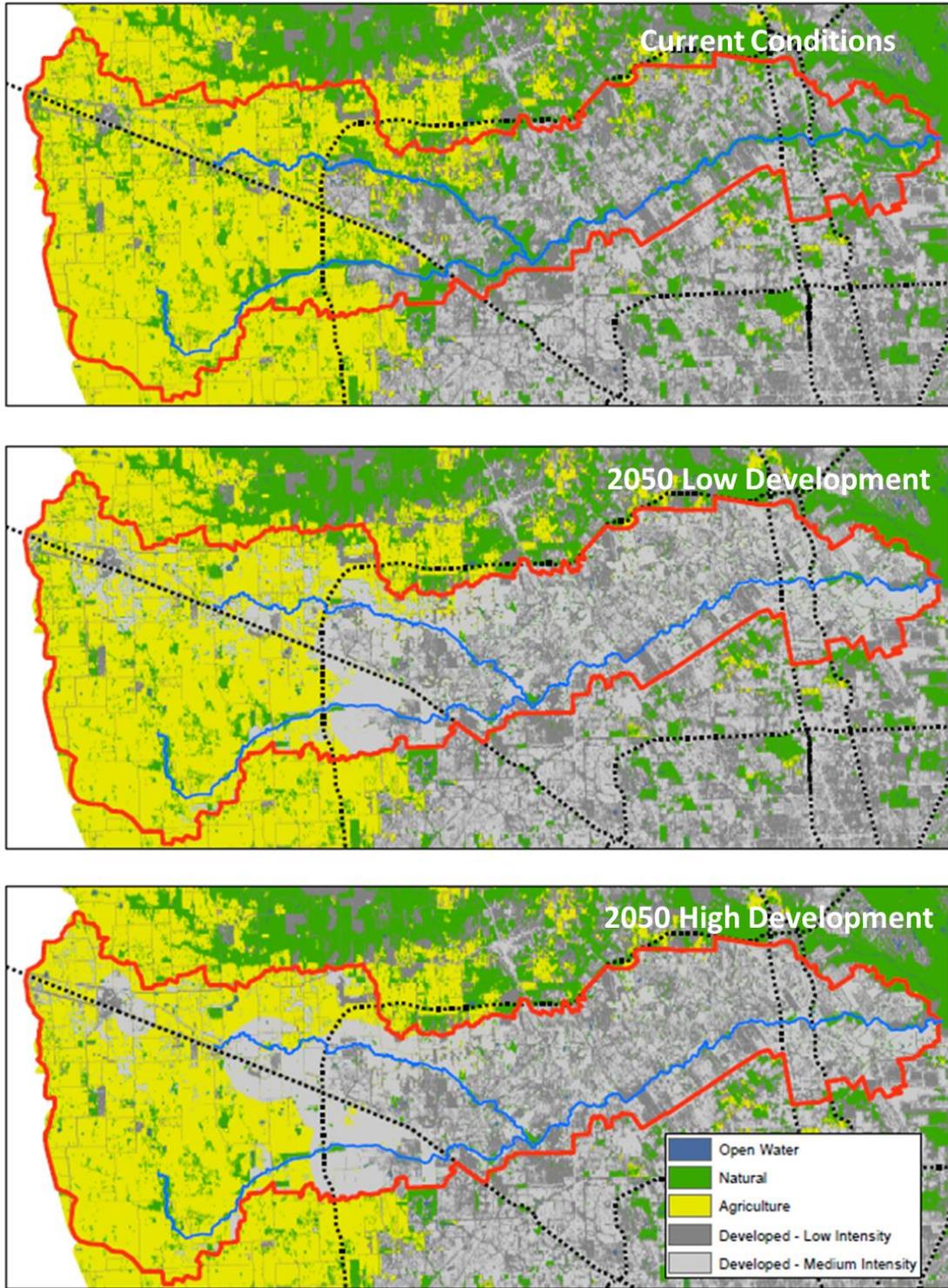


Figure 6: Land use evolution in Cypress Creek watershed for current conditions (top), 2050 low development scenario (middle), and 2050 high development scenario (bottom)

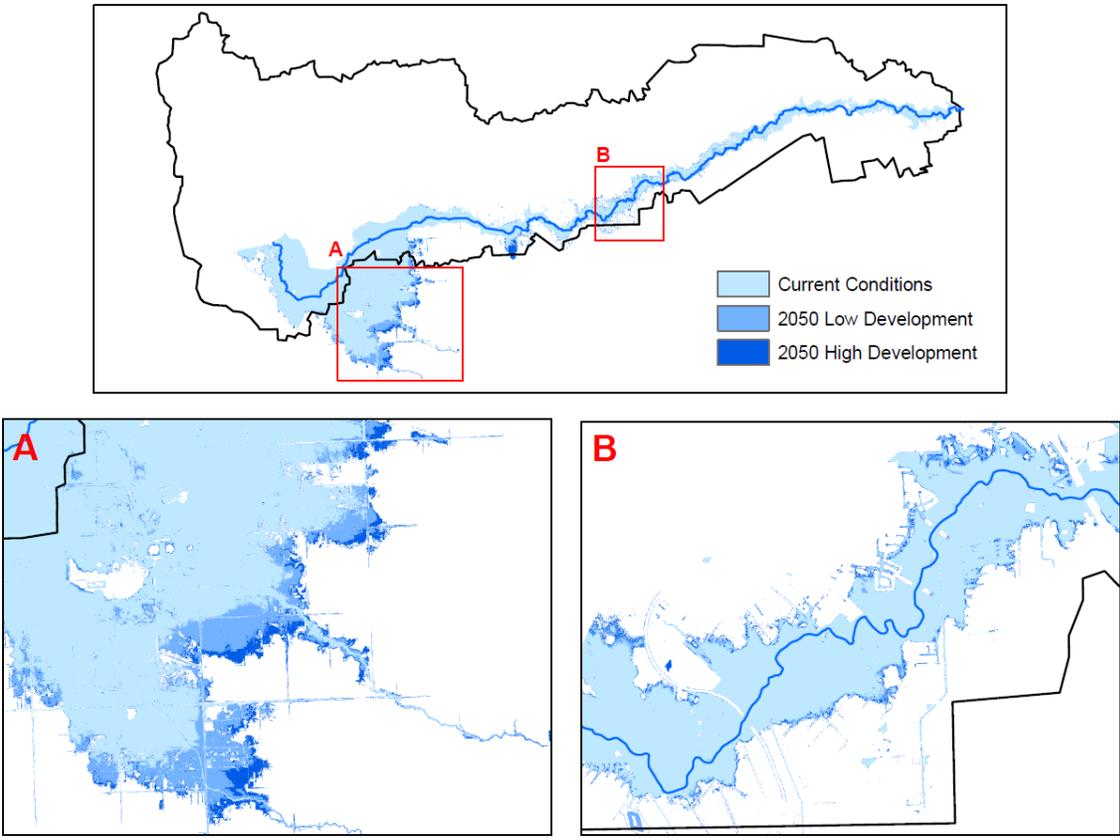


Figure 7: Current and 2050 projected 100-year floodplain comparisons

	Developed	Natural	Agriculture
2011	38.7%	17.6%	43.7%
2050 (low)	53.0%	8.0%	38.9%
2050 (high)	59.8%	6.8%	33.4%
Percent change from 2011 (low)	37.0%	-54.5%	-11.0%
Percent change from 2011 (high)	54.5%	-61.4%	-23.6%

Table 1: Percent changes in land use type between 2050 projections and current conditions

	2011	2050 (low)	2050 (high)
Floodplain Extent (km)	106.5	115.5	119.8
Percent Increase	-	8.4%	12.5%
Inundated Parcels	2926	3287	3476
Percent Change from 2011	-	12.3%	18.8%

Table 2: Floodplain extent increase and increase in inundated parcels for entire Cypress Watershed

	2011	2050 (low)	2050 (high)
Floodplain Extent (km)	38.5	44.8	47.3
Percent Increase from 2011	-	16.4%	23.0%
Inundated Parcels	413	499	515
Percent Increase from 2011	-	20.8%	24.7%

Table 4: Floodplain extent increase and increase in inundated parcels for overflow region of Cypress Creek watershed

Effects of Salinity on Dissolved Organic Carbon (DOC) Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems

Basic Information

Title:	Effects of Salinity on Dissolved Organic Carbon (DOC) Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems
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There are no publications.

REPORT

Title Effects of Salinity on Dissolved Organic Carbon (DOC) Removal in Combined Biological Activated Carbon/Reverse Osmosis Systems.

Project Number 2017TX511B

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Abstract

Reverse osmosis (RO) is one of the most practiced technologies used for salinity removal and is necessary for areas such as West Texas where surface waters are rich in salts. Membrane fouling is a major drawback of RO and results in increased operating costs. This can be mitigated in wastewater systems by pretreating water with biological activated carbon (1), but it is unknown whether biological activated carbon (BAC) is an appropriate pretreatment strategy for partially saline surface waters intended for RO and potable use. We propose a combined BAC-RO system to study: i) the effects of varying salinity concentrations on DOC removal in BAC and ii) how BAC permeate influences membrane flux and organic fouling in downstream RO systems. This work evaluates BAC using small-scale glass columns packed with activated carbon and measures influent/effluent organic carbon concentration and size distribution. Both synthetic and actual West Texas surface water were used for these preliminary studies, allowing for a better understanding of how salinity influences BAC system performance. Future work will evaluate BAC permeate filtration through RO membranes.

Problem and Research Objectives

Critical State Water Problem. Surface water is a significant water resource within the State of Texas. Use of surface water is expected to increase as groundwater resources are depleted, and the Texas Water Development Board (TWDB) estimates that surface water will comprise ~45 % of total water supplies in the state by year 2070 (2). Waters in West Texas can be partially saline, with sulfate (SO_4^{2-}) present as the dominant anion (3). The extent of salinity in water determines its application (*e.g.* drinking water, livestock, industrial usage, irrigation, etc.). As surface water usage in West Texas increases, so will issues associated with salinity. Additionally, surface waters are likely to contain high levels of dissolved organic carbon (DOC).

Salinity is roughly equivalent to total dissolved solids (TDS). The Texas Commission on Environmental Quality (TCEQ) has established a secondary drinking water standard for TDS of 1,000 mg/L, which is higher than EPA's (500 mg/L). This reflects the higher saline waters typical of Texas. Several rivers in Texas exceed these limits, including the upper portions of the Red, Wichita, Colorado, Brazos, and Rio Grande, located in the western part of the state (TDS = 5,000 mg /L or more). These regions have recommended water management strategies to address salinity issues (4).

Reverse osmosis (RO) is a high-pressure filtration process that removes minerals, monovalent and divalent salts, pathogens, and organic contaminants. It is the most common technique for salt removal, but organic fouling of the membranes is still a major issue, limiting its efficiency. Fouling is usually due to accumulation or adsorption of organic matter in the membrane micropores and surfaces, which results in declining flux, increasing operating pressures, and increasing energy costs. Fouling is problematic for RO systems treating West Texas surface water, because these waters are high in both TDS (requiring RO treatment) and DOC (responsible for RO fouling). A current research priority of the TWDB is to minimize fouling by implementing pretreatment strategies before RO. One proposed treatment, biological activated carbon (BAC), is a low energy pretreatment strategy applied upstream of RO units that removes DOC via microbial oxidation. BAC has excellent removal efficiency in wastewater treatment systems, mitigating membrane fouling (1), but it is unknown how salinity may affect DOC oxidation in waters intended for potable use. **This study is the first step in evaluating the impact of salinity upon DOC removal in BAC systems upstream of RO units treating West Texas surface water.**

The objectives of this research are to:

Evaluate the effects of salinity on carbon removal in small-scale BAC column experiments.

Water of varying salinity levels was passed through biological activated carbon filters operated in parallel. Artificial and natural water sources were evaluated. Influent and BAC permeate waters were collected and analyzed for DOC.

Evaluate the effects of salinity on DOC size distribution in small-scale BAC column experiments.

Water of varying salinity levels was passed through biological activated carbon filters operated in parallel. Artificial and natural water sources were evaluated. Influent and BAC permeate waters were collected and analyzed size distribution of natural organic matter (NOM).

Materials/Methodology

Bench top experiments were conducted in Dr. Millerick's environmental microbiology laboratory using glass columns. Methods and procedures are described below.

Biological Activated Carbon (BAC) Columns: Eight glass columns (25 mm inner diameter, 150 mm height) operated in parallel served as upflow columns. A glass fiber filter separated the influent line from the column. The first 25 mm of column height was packed with Teflon pieces (~5 mm in diameter). Activated carbon (Calgon 400) comprised a height of approximately 100



Figure 1: BAC columns for TWRI project.

mm. The last 25 mm of column height was again packed with Teflon pieces, and a second glass fiber filter was added to the end of the column prior to the effluent line. Completed BAC columns (prior to covering with black felt) can be seen in Figure 1.

To equilibrate columns, Water 1 (see below) was diluted 1:1 with deionized (DI) water and pumped through each of the columns via Peristaltic pump at a flow rate of 0.8 mL/min. This flow rate resulted in an empty bed contact time (EBCT) of ~ 27 minutes per column. To prevent photosynthetic growth, columns, feed lines, and reservoirs were covered in black felt. Columns were allowed to equilibrate for 57 days prior to experimentation.

Source Water: Column experiments were conducted using the following two different waters.

Water 1: Surface water collected downstream of Ransom Canyon in Slaton, TX, as shown in Figure 2. The collection point is where water flowing from Buffalo Springs Lake intersects Hwy 400; pH \approx 8.5. 20 L of this surface water was collected weekly and stored at 4 °C prior to use. The TOC of this water was 8.1 mg/L carbon.

Water 2: Distilled, deionized water containing 30 mM NaHCO₃ buffer; pH \approx 8.1. This water was prepared daily.

Feed Water Preparation:

Water 1 (natural water) was filtered via vacuum extraction using a glass fiber disk filter to remove large particles. This water was then diluted 1:1 with DI water, producing a finished water of ~ 4 mg/L carbon.



Figure 2: Hwy 400 Sampling Location

Water 2 (buffered DI water) was amended with 4 mg/L carbon. Carbon was amended as wheat grass extract. Briefly, wheat grass extract was prepared by packing wheat into a 2 L bottle, filling void spaces with boiling water, and sealing. Sealed bottles were placed on a platform shaker at 150 rpm and allowed to equilibrate overnight. After equilibration, samples were filtered via vacuum extraction using a .45 μm disk filter and stored at 4 °C. The TOC of this extract was approximately ~ 427 mg/L carbon. This was spiked into buffered DI water for a final concentration of ~4 mg/L carbon.

Biological Activated Carbon (BAC) Experiments:

The eight columns received feed water (described in Table 1) at a flow rate of 1 mL/min.

Table 1: BAC Column Descriptions

Column	Name	Feed Water	Amendments
Column 1	Natural – Control	Water 1	25 mg/L HOCl (disinfectant)
Column 2	Natural – No Salt	Water 1	None
Column 3	Natural – Low Salt	Water 1	1 g/L K ₂ SO ₄ ; 1 g/L KCl
Column 4	Natural – High Salt	Water 1	4 g/L K ₂ SO ₄ ; 4 g/L KCl
Column 5	Artificial – Control	Water 2	25 mg/L HOCl (disinfectant)
Column 6	Artificial – No Salt	Water 2	None
Column 7	Artificial – Low Salt	Water 2	1 g/L K ₂ SO ₄ ; 1 g/L KCl
Column 8	Artificial – High Salt	Water 2	4 g/L K ₂ SO ₄ ; 4 g/L KCl

Feed water was stored in 2.5L bottles (reservoirs). Reservoirs were exchanged daily with fresh, feed water prepared in cleaned bottles. Feed water was stored 4 °C until 4 hours prior to use, when it was brought to room temperature.

Columns were backwashed approximately every 2 weeks. Columns were backwashed for 30 minutes at 5 mL/minute using column-specific amended waters, as described in Table 1.

Sample Collection and Analysis:

Samples were collected twice a week at the reservoirs, at the column inlet, and at the column effluent. The following analyses were performed:

Dissolved Organic Carbon (DOC): Water samples were filtered through PTFE filters, acidified to remove inorganic carbon, and analyzed on a Vario TOC Select (Elementar).

Natural Organic Matter (NOM): Changes in natural organic matter size and composition were quantified with high performance size exclusion chromatography using an HPLC (Agilent 1200) equipped with a UV-Diode array detector and a size exclusion column (SEC). Polystyrene sulfonate sodium salt standards were used for quantification.

Salinity: Salinity in surface water samples prior to amendment with salts was measured as conductivity using a probe (HACH). Surface water samples had a conductivity of approximately 1544 $\mu\text{S}/\text{cm}$ at 21 °C.

Anions: Concentrations of common anions (Cl^- , SO_4^{2-} , PO_4^{3-} , NO_3^- , NO_2^- , Br^- , F^-) were measured using ion chromatography (IC; Dionex) equipped with AS14A column for separation.

Principal Findings

Overall, the work summarized below describes a study in progress – biological growth occurred much more rapidly than anticipated and was prolific throughout the columns and feed lines. While data show that organic matter changed in speciation, discrepancies between DOC speciation in reservoirs and column influents suggest that much of the biodegradation occurred within the feed lines and not within the activated carbon portion of the filtration columns. This could also be observed visually – despite black felt, discoloration due to biofilm formation in the feed lines could be observed for all eight columns (including columns receiving chlorinated water). For this reason, this project had to be taken off-line early so that feed lines could be cleaned. Initial attempts at cleaning feed lines by pumping chlorine through them were unsuccessful, so instead lines and columns were cleaned with a concentrated solution of percarbonate to remove residual biofilms (this was successful). Now sterile, this project is in the beginning stages of restart, and we anticipate finishing this project later this year.

Most of our useful data was obtained through size exclusion chromatography (SEC) chromatograms, which provide a relative size distribution of DOC. Instead of including each of these chromatograms, below is a summary of our data and observations we made prior to taking the columns off-line:

Water Quality: Anionic concentrations in undiluted Water 1 at the time column equilibration began were as follows (all units in mg/L): $\text{Cl}^- = 4.0$, $\text{F}^- = 2.6$, $\text{NO}_2^- = 2.5$, $\text{NO}_3^- = 3.05$, $\text{PO}_4^{3-} = 4.9$, and $\text{SO}_4^{2-} = 13.72$. This sulfate concentration was significantly lower than we had expected and is lower than other values reported for this region, but was consistent with other sulfate concentrations in Water 1 during the equilibration period (Fall 2017). The sampling location of Water 1 is downstream of the effluent discharge location of the Lubbock South Wastewater Treatment Plant and is adjacent to several agricultural fields, which may partially explain elevated concentrations in phosphate and fluoride. Elevated phosphate may have increased the likelihood of the line fouling that was observed.

Use of Wheat Extract as a DOC Source: Wheat extract was selected as a DOC source over Suwannee River Natural Organic Matter because of the quantities required (columns each required 1,440 mL of feed water per day, at a carbon concentration of 4 mg/L). We prepared our wheat extract as described in another column study, which described a mother solution of ~ 80 mg/L carbon. Our solution, at 427 mg/L carbon, was five times as concentrated. SEC results suggest that most of this was readily biodegradable, as concentrations and size distributions decreased rapidly when these samples were brought to room temperature. We originally selected wheat extract as a DOC source believing that it would mimic DOC from a natural water source; however, this substrate was considerably more biodegradable than the naturally occurring DOC obtained in Water 1. More tests need to be conducted on wheat extract to identify the assimilable organic carbon (AOC) portion and to better understand its makeup, as all low molecular weight compounds in this matrix became undetectable via SEC when passed through feed lines and columns. These preliminary SEC results suggest that waters containing wheat extract may better mimic carbon in wastewater (rather than water), may lead to over-ripening over long-term experiments, and may not well-mimic carbon in natural surface water bodies.

Decreased Flow during Experimental Phase: Flow was maintained using peristaltic pumping, which assumes no pressure buildup. Flow fluctuation was observed in several of the columns, likely due to the biofilm buildup in the flow lines. This was particularly pronounced right before the columns were taken off-line in Columns 6, 7, and 8, which contained wheat extract but no chlorine. This suggests that i) backwashing should be conducted more frequently, ii) lines may need to be replaced, not simply backwashed, in this system and iii) the concentrations of wheat extract may be inappropriate for this system.

Disinfectant Dosage: SEC results for influent and effluent water samples in Columns 1 and 5 (intended as sterile controls) suggest DOC transformation despite chlorination. This suggests that the biofilm created in these columns over the 57-day equilibration period was partially resistant to chlorinated flow-through waters and that DOC may be consuming free chlorine, reducing its potency. A more aggressive treatment for the sterile control columns is needed between equilibration and the start of experiments, and free chlorine will need to be consistently confirmed to better maintain sterility.

Significance

This is a very attractive project, given its probable applications. It is also versatile in a sense that in the future, it will test two uniquely significant systems (BAC and RO) and their combined

effect. This project originally intended to study both the BAC and RO systems (and we have a miniature RO system for future work), but the work described here suggests that the BAC system must be better understood prior to investigating the RO system.

Our preliminary results show significant changes in DOC speciation as a result of the biofilms we grew, and future work will build upon this to better understand how this may affect BAC-RO system. The materials purchased under the TWRI/USGS fund were used to construct a reusable flow-through system that we will keep using as we complete this study.

We will begin re-equilibration of the columns shortly. The following are amendments we intend to make with this second trial:

- Provide a longer equilibration time (closer to 6 months) for columns, as this would increase biofilm stability, and quantify ATP as a relative measurement of biofilm maturity (fluctuations in carbon concentration indicated that our biofilm may have still been in growth phase).
- Focus solely on natural waters, as wheat extract may be too artificial for this system, and may encourage wastewater-like fouling.
- Investigate more aggressive sterilization treatments for columns intended as abiotic controls.

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TAAP: Identifying and Assessing the Condition of Transboundary Aquifers between Texas and Mexico

Basic Information

Title:	TAAP: Identifying and Assessing the Condition of Transboundary Aquifers between Texas and Mexico
Project Number:	2017TX516S
USGS Grant Number:	
Sponsoring Agency:	U.S. Geological Survey
Start Date:	9/25/2017
End Date:	9/24/2018
Funding Source:	104S
Congressional District:	15, 16, 23, 28, 34
Research Category:	Not Applicable
Focus Categories:	Groundwater, None, None
Descriptors:	None
Principal Investigators:	Rosario SanchezFlores, Zhuping Sheng, John C. Tracy

Publications

1. Sanchez, R., L. Rodriguez, and C. Tortajada, 2018, Transboundary aquifers between Chihuahua, Coahuila, Nuevo Leon and Tamaulipas, Mexico, and Texas, USA: Identification and Categorization, Journal of Hydrology, Regional Studies, Special Edition on Transboundary Aquifers, DOI.org/10.1016/j.ejrh.2018.04.004.
2. Sanchez, R, L. Rodriguez, and C. Tortajada, 2018, The Transboundariness Approach and Prioritization of Transboundary Aquifers between Mexico and Texas, Ambio, DOI: 10.1007/s13280-018-1015-1.
3. Sanchez, R, and G. Eckstein, 2017. Aquifers Shared Between Mexico and the United States: Management Perspectives and Their Transboundary Nature, groundwater, Vol. 55, Issue 4, pp. 495-505. DOI: 10.1111/gwat.12533. Online at: <http://onlinelibrary.wiley.com/doi/10.1111/gwat.12533/abstract>.

TAAP progress report

May 2018

PI: Rosario Sanchez

Co-PIs: Zhuping Sheng and John Tracy

(i) A comparison of actual accomplishments to the objectives of the Agreement established for the budget period and overall progress in response to the performance metrics.

Objective 1:

* Collect borehole data (geological field work) to confirm the hydrogeological transboundary linkages of transboundary aquifers with limited data.

Progress

- Field work and data collection in the border region, particularly the Allende-Piedras Negras Transboundary Aquifer. Preliminary report with conceptual model developed using MODFLOW will be ready by December 2018 and expected publication by Fall 2019.
- Geological correlation of transboundary formations, initial classification based on aquifer potential and water quality. Publication of results in the *Journal of Hydrology, Regional Studies, Special Edition on Transboundary Aquifers* in May 2018. <https://doi.org/10.1016/j.ejrh.2018.04.004>
- Homogenization of geological formations across the border
- Development of geological (stratigraphic) data based from Mexico and Texas. Publication of results in the *Journal of Hydrology, Regional Studies, Special Edition on Transboundary Aquifers* in May 2018. <https://doi.org/10.1016/j.ejrh.2018.04.004>
- Integration of a Texas-Mexico transboundary aquifer initial assessment report delivered to Conagua and IBWC/CILA representatives. An official letter of response by Conagua was delivered recognizing our report as the first of its kind for both countries and the basis for future research.

Objective 2:

* Develop assessment tools and evaluate, update, upgrade, and refine the existing Hueco Bolson groundwater flow model, with an emphasis on the interaction of surface water and groundwater and impacts of agricultural irrigation (crop patterns, crop acreage and irrigation scheduling), and assess impacts of different groundwater development scenarios.

Progress:

- Coordinate with the Texas Water Sciences Center (TX WSC), the Hueco Bolson Groundwater Model by the USGS, and GAM model by El Paso Water Utility, the conversion from the previous version of the MODFLOW (96) to MODFLOW-2005 or to a later version.
- Communication and collaboration with Mexican partners via IBWC/CILA has been initiated
- Develop SOW for binational cooperation on data exchange and numerical model development. Official meeting to be held in May 22, 2018 for final details.
- Collecting and compiling groundwater well profiles in El Paso and Hudspeth counties in coordination with USGS El Paso Office. Preliminary results will be presented at official meeting in Ciudad Juarez.

Objective 3:

- * Develop a conceptual hydrogeochemical framework for the Hueco Bolson Aquifer.

Progress:

- Conceptual hydrochemical framework for the Hueco Bolson Aquifer is being developed through data exchange and communications with USGS El Paso office about water quality and geochemistry of groundwater, brackish water intrusion and probably solute transport model towards the end of the project.

Objective 4:

- * To develop a framework to assess the physical conditions, transboundary nature, and opportunities for cooperation for ill-defined aquifers bordering Texas and Mexico. Then to use this information to develop binational criteria for identifying the vulnerability of transboundary groundwater resources.

Specific Objectives:

1. To develop protocols to identify transboundary aquifers method for prioritization of transboundary aquifers.

Progress:

- Development of the transboundariness approach first published by Sanchez, R. & Eckstein, G., 2017, *Aquifers Shared Between Mexico and the United States: Management Perspectives and Their Transboundary Nature: Groundwater*, April 2017, DOI: 10.1111/gwat.12533
- Publication of peer reviewed paper at *AMBIO Journal* in February 2018, that applies the transboundariness approach (priorization of transboundary aquifers) first introduced by

Sanchez & Eckstein 2017, to the identified hydrogeological units between Mexico and Texas. DOI 10.1007/s13280-018-1015-1

- Integration of database of lithological and water quality data from all the available wells in the border region between Mexico and Texas to propose a more refined delineation of Effective Aquifer/Formation Areas. Data set has been completed and GIS analysis has been performed. Expected results by May 2019.
2. **Objective:** Network workshops, binational academic programs, binational groundwater research with faculty and stakeholders from both sides of the border with the objective to develop common criteria over transboundary water sharing. Engage the scientific, agency and lay communities impacted by water use from transboundary aquifers along the United States and Mexico border, and provide them with resources to understand the extent and management of this water resource.

Progress:

- MOU between TWRI and IMTA (Mexican Institute for Water Technology). To be signed by July 2018.
- MOU between TWRI and SGM (in progress) focused on the updating groundwater availability model of the Hueco Bolson aquifer. Official meeting to be held in May 22 including IBWC/CILA.
- AWRA Conference 2018 on Groundwater Resources, hosted by TWRI in Fort Worth. Participants will be from various transboundary aquifers along the border binationally and internationally.

3. **Objective:** Develop framework to assess the physical conditions, transboundary nature, and opportunities for cooperation for ill-defined aquifers bordering Texas and Mexico.

Progress:

- *Website development:* <http://transboundary.tamu.edu> has been created and is currently under construction. It is expected to be launched in July 2018 during the AWRA Conference in Fort Worth. The objective is to create a portal for data sharing information and network building.

Objective 5:

* Evaluate and develop strategies for protecting and managing more efficiently groundwater resources from a regional (transboundary) scale with a local (rather than binational) perspective.

Progress:

- Field work started in November 2017 to interview groundwater stakeholders in the border region to identify groundwater governance mechanisms and management practices that could be used to propose models of cooperation and ultimately management.

- Preliminary results to be presented at the AWRA Conference in Fort Worth in July 2018.

Objective 6: Develop binational criteria for groundwater vulnerability, groundwater quality assessments, soil salinity and contamination remediation alternatives.

Progress:

- Currently working on the development of matrix for vulnerability of shallow groundwater (DRASTIC or index method), characterization of brackish water, salinization of soil and water and other contaminants of interest in the Hueco Bolson Aquifer
- Developing a geochemistry analysis on the Allende-Piedras Negras Aquifer to confirm the connectivity of the geological units using correlation of similar geochemical processes. Preliminary results will be presented at the AWRA Conference in Fort Worth.

(ii) The reasons why established goals were not met, if appropriate.

Nothing to report.

(iii) Additional pertinent information including, when appropriate, analysis and explanation of cost overruns or high unit costs.

Nothing to report.

(iv) An outline of anticipated activities and adjustments to the program during the next budget period.

- Effective Formation Areas assessments should be ready by Fall 2019 and adapted for domestic and binational use
- Connectivity of the Allende-Piedras Negras aquifer should be ready by Fall 2019 (both geological and geochemistry approaches)
- MOU in place between TWRI and IMTA
- Website transboundary.tamu.edu in place

c) Between the required reporting dates, events may occur which have significant impact upon the project or program. In such cases, the Recipient shall inform the USGS as soon as the following types of conditions become known:

Nothing to report.

(i) Problems, delays, or adverse conditions which will materially impair the ability to meet the objective of the Agreement. This disclosure must include a statement of the action taken, or contemplated, and any assistance needed to resolve the situation.

Nothing to report.

(ii) Favorable developments which enable meeting time schedules and objectives sooner or at less cost than anticipated or producing more or different beneficial results than originally planned.

Goals have been met and have actually been superseded by additional projects and research objectives: geochemistry analysis of the Allende-Piedras Negras Aquifer and the Effective Formation Areas database that has the potential to be used in additional technical and managerial assessments domestically and binationally. Also, the website development will have the additional ability to store shareable data and to create a binational water network.

Information Transfer Program Introduction

In 2017, the Texas Water Resources Institute (TWRI) 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. TWRI also publishes an online peer-reviewed journal in conjunction with a nonprofit organization. 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 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 project-specific websites and keeping the information current contained within the websites.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2017TX509B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	TX017
Research Category:	Not Applicable
Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	John C. Tracy, Danielle Kalisek, Lucas Gregory, Troy A Berthold

Publications

1. Gutierrez, Victor, Kevin Wagner, and Allen Berthold, 2018, Delivering Education Programs Focused on Stakeholder Needs to Address Agricultural NPS in the Arroyo Colorado Watershed FY 2014 CWA 319(h)(TR-490), Texas Water Resources Institute, Texas A&M University, College Station, TX, 59 pages.
2. Berthold, Allen, George Di Giovanni, Elizabeth Casarez, and Jude Benavides, 2017, Bacterial Source Tracking to Support Adaptive Management of the Arroyo Colorado Watershed Protection Plan: Final Report (TR-494), Texas Water Resources Institute, Texas A&M University, College Station, TX, 50 pages.
3. Wagner, Kevin, Terry J. Gentry, Maitreyee Mukherjee, George D. Di Giovanni, Elizabeth A. Casarez, Joy A. Truesdale, 2017, Texas' Bacterial Source Tracking Program for Fiscal Year 2015 (TR-496), Texas Water Resources Institute, Texas A&M University, College Station, TX, 28 pages.
4. Gregory, Lucas, Katelyn Lazar, Anna Gitter, Terry Gentry, Kirby Peddicord, 2017, Navasota River Below Lake Limestone Watershed Protection Plan (TR-497), Texas Water Resources Institute, Texas A&M University, College Station, TX, 69 pages.
5. Boellstorff, Diane, Drew Gholson, Danielle Kalisek, John W. Smith, Ryan Gerlich, Kevin Wagner, Anish Jantrania, and Travis Miller, 2017, Statewide Delivery of the Texas Well Owner Network (TWON) (TR-498), Texas Water Resources Institute, Texas A&M University, College Station, TX, 19 pages.
6. James, Andy, Brian Hays, and Kevin Wagner, 2017, Continued Coordinating Implementation of the Leon River Watershed Protection Plan (TR-499), Texas Water Resources Institute, Texas A&M University, College Station, TX, 29 pages.
7. Wagner, Kevin, Rehanon Pampell, Daren Harmel, and Terry Gentry, 2017, Improving Runoff Water Quality from Small Pork Production Facilities using Vegetative Treatment Areas (TR-501), Texas Water Resources Institute, Texas A&M University, College Station, TX, 32 pages.
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9. Flores, Jaime, Kevin Wagner, Lucas Gregory, Jude A. Benavides, Tim Cawthon, 2017, Update to the Arroyo Colorado Watershed Protection Plan (TR-504), Texas Water Resources Institute, Texas A&M University, College Station, TX, 141 pages.

Information Transfer

10. Wolff, Aubry, Diane E. Boellstorff, and T. Allen Berthold, 2017, Residential Customer Characterization for Urban Water Conservation Planning, Texas A&M AgriLife Extension Service Publication ESC-044, College Station, TX: Texas A&M University, 24 pages.
11. Wolff, Aubry, Diane E. Boellstorff, and T. Allen Berthold, 2017, Evaluating Customer Water Use to Create Effective Conservation Programs, Texas A&M AgriLife Extension Service Publication ESC-043, College Station, TX: Texas A&M University, 4 pages.
12. Wagner, K., R. Pampell, and R.D. Harmel, 2017, Vegetative Treatment Areas: Reducing Soil, Nutrient and Bacteria Runoff from Small Hog Farms (EM-122), Texas Water Resources Institute, Texas A&M University, College Station, TX, 2 pages.
13. Gregory, L.F., R. Karthikeyan, J.A. Aitkenhead-Peterson, T.J. Gentry, K.L. Wagner, and R.D. Harmel, 2017, Nutrient Loading Impacts on Culturable E. coli and Other Heterotrophic Bacteria Fate in Simulated Stream Mesocosms, Water Research 126 (2017) 442e449.

**Texas Water Resources Institute
Information Transfer Activities
March 1, 2017 – February 28, 2018**

In 2017, the Texas Water Resources Institute (TWRI) continued its outstanding communication efforts to produce university-based water resources research and education outreach programs in Texas.

TWRI 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 at 2,207.

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. There are 3,466 subscribers (total for hard copy and online) and approximately 700 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 678 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 3,233 Twitter followers, and TWRI had 430,360 impressions (number of times our tweets were seen). TWRI has 1,153 Facebook page likes; 401 Instagram followers and 293 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 led to 59 news releases with 100 mentions in the media.

In cooperation with research scientists and extension education professionals, the institute published eight 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 updating the sites' information. The institute is currently assessing its website content and layout in preparation for updating the overall website template and project websites in the coming year. The revamped website will better display our institute, project information, results and materials in the face of constantly changing technology and the limited time that viewers spend on each page.

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	0	0	0	0	0
Masters	7	0	0	1	8
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	0	1	8

Notable Awards and Achievements

Publications from Prior Years

1. 2012TX458B ("Evaluation of invasive aquatic species in Texas") - Conference Proceedings - Edgerton, Elizabeth, 2017, The Effects of Diffused Aeration on Fish Habitat in Small-Scale Ponds, in 37th International Symposium of the North American Lake Management Society, North American Lake Management Society, Madison, WI, p. 41.
2. 2013TX461B ("Evaluation of invasive aquatic species in Texas") - Conference Proceedings - Edgerton, Elizabeth, 2017, Get Your Water to Movin': Different Methods of Aeration, Pond Boss Conference and Expo 2017, Pond Boss, Sadler, TX, p. 13.