Missouri Water Resources Research Center Annual Technical Report FY 2017

Introduction

Water Problems and Issues in Missouri

The water problems and issues in the State of Missouri can be separated into three general areas: 1) water quality, 2) water quantity, and 3) water policy. Each of Missouri's specific problems usually requires knowledge in these three areas. These three areas are part of the food, water, and energy nexus, which contributes in a major way to the urban and rural communities in the state.

Water Quality

With the large agricultural activity in the state, non-point source pollution is of major interest. In coordination with the other state water center programs in the Mississippi River basin, Missouri has placed high priority for research initiatives that address cyanobacterial blooms (also called harmful algae blooms or HABs) and their impact on water quality and water management decisions.

HABs are naturally occurring, however their frequency and intensity have been increasing. The increases have been tightly linked to anthropogenic inputs of nutrient into the aquatic system. Heightened agriculture production, discharges from sewer and wastewater management, and other urban runoff have amplified the amount of nutrients entering local and regional water systems beyond that naturally occurring in marine and freshwater ecosystems.

In these systems, excess nutrients create a greening effect with the growth of algae. This, in turn, can have large-scale negative implications for surface water and marine ecosystem structure and is a stressor on healthy ecosystem functionality. HABs is a broad topic that may encompass any of the following areas: HAB events,nutrient transport related to HABs, treatment and control technologies and their effectiveness, and social science related to HABs.

In addition several hazardous waste superfund sites exist in Missouri, and hazardous waste is still of a concern to the public. Research projects are still being proposed and funded through the Center to evaluate the quality of water sources in affected areas and improve the methods to protect them. Areas of research for the past ten years have included (but are not limited to): erosion, non-point pollution reclamation of strip mine areas, hazardous waste disposal, nutrient management, water treatment and disinfection byproduct controls, wastewater treatment and reuse coupled with algal bioenergy production, acid precipitation, anthropogenic effects on aquatic ecosystems and wetlands.

Water Quantity

Missouri has a history of variable rainfalls. Because of the several drought years and major floods, water quantity has become a major topic of concern. The drought in 2012 was particularly notable with all counties in the State of Missouri being declared drought disaster areas with diminished agricultural and economic activities. Research is needed to better understand droughts and flood conditions. Many reservoirs have been constructed in Missouri to address water shortage issues; research is needed to understand how the agricultural activities affect water quality and how to best manage reservoirs and regional land use as a system. Also, a critical aspect is that research is needed on water treatment/reuse coupled with nutrient management.

Water Policy

Policies and program need to be formulated that will ensure continued availability of water for designate uses, as new demands are placed on Missouri's water. The social and economic costs may no longer be acceptable levels if water becomes a major issue in cities and rural areas. Past droughts and possible low flows of the Missouri River have raised serious questions over states rights to water and priority uses. Better approaches for managing non-point source pollution need to be derived. Research areas in this program included drought planning, legal aspects, perception and values, economic analysis, recreation, land/water policy and legislation, and long-term effects of policy decisions.

Research Program Introduction

WATER PROBLEMS AND ISSUES OF MISSOURI

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Recent research activities include the following:

Stormwater Program

Federal regulations require MU, City of Columbia and Boone County to protect the quality of surface water from stormwater runoff. The Water Center has several projects to evaluate best management practices that will detain and filter the runoff. One project involves a diverse group from across campus to understand the best management practices for stormwater at the University of Missouri. The student team is laying groundwork to evaluate existing projects in preparation of data collection that will be used to inform future decisions. Allen Thompson, associate professor of biological engineering serves as principal investigator for the project. In addition, Bob Reed research associate professor, Enos Inniss, assistant professor and Robert Broz, extension assistant professor with agricultural engineering, round out the mentoring team.

Satellite Imaging Program

The project objective was to develop a satellite-imagery based algorithm to monitor suspended sediment concentration (SSC) along the Middle-Mississippi River (MMR) between the Missouri River and Ohio River confluences. The objective was achieved through the following tasks: (1) a critical review of previous work, (2) identification of available data for analysis, (3) methodology development, (4) validation of method transferability, (5) estimation of SSC at unmonitored tributaries along the MMR, (6) development of a local sediment budget, and (7) data preparation for integration into a publicly-available data portal.

Endocrine Disruptor Chemicals in Natural Waters

Many man-made chemicals for agricultural use are now widely dispersed and contaminate the environment. Some of these chemicals have significant potential to interfere with normal biological functions and cause adverse effects. Concerns over chemicals that disrupt the endocrine system in humans and wildlife have grown during the last two decades, leading to efforts to screen and test for endocrine disrupting chemicals, or EDCs.

In 1996 congress passed the Food Quality and Protection Act that mandated the United States Environmental Protection Agency (USEPA) develop screening and testing methods to detect environmental chemicals that interfere with the endocrine system. There is now a tremendous body of literature describing the highly significant negative impacts on the human body from EDC exposure. In fact, the Endocrine Society recently published a position statement. Results from animal models, human clinical observations, and epidemiological studies converge to implicate EDCs as a significant concern to public health.

Adverse reproductive health outcomes associated with EDC exposures are well documented, with reported effects on reproductive organs, body weight, puberty, and fertility. Unfortunately, conventional methods to detect organic compounds involve not only expensive instrumentation, but also a large number of separating analytical procedures, resulting in a complex, time-consuming, and laborious screening procedure. For these reasons, the development of novel approaches for easy and rapid detection of selected organic contaminants is highly desirable.

Molecular imprinting is a well-established technique used to synthesize molecularly imprinted polymers (MIPs) with specific molecular recognition nanocavities. Recently, researchers have developed an original procedure that combines molecular imprinting and colloidal crystal to prepare polymers with 3D, highly ordered, macroporous structures (inverse opals) and specific binding nanocavities for a rapid assay to detect organics in water. The high sensitivity and specificity observed in these polymeric systems is mainly due to the high surface-to-volume ratios of the structure that allow for a more efficient mass transport in submicrometer-sized pores and enhance surface reactions.

The combination of molecular imprinting techniques and photonic crystals derived from the self-assembly of silica nanoparticles used as templates allows for the optical detection of adsorption trace compounds due to changes of the wavelength at maximum intensity of the Bragg diffraction peak. This project will involve developing a highly sensitive and specific sensor based on a MIP array capable of simultaneously detecting total EDC concentration. To this end, porous MIP films will be fabricated and characterized from colloidal crystal templates; it will explore the selectivity and specificity of MIPs, and the potential interferences of structural analogues as well as natural water chemistry, characterized by natural organic matter and/or dissolved substances. Furthermore, the kinetics of contaminant attachment to the MIP films, as well as release conditions and mechanisms are investigated. The combination of molecular imprinting techniques and photonic crystals allows for the optical detection of adsorption trace compounds due to changes of the wavelength at maximum intensity of the Bragg diffraction peak.

Deployment of Algae Membrane Bioreactor for polishing Wastewater Effluent

Algal cultivation has been recognized by the U.S. National Academy of Science and Department of Energy as one of the most promising solutions for simultaneous wastewater treatment and value-added product production. Interdisciplinary collaboration to integrate the sensing and modeling with traditional treatment processing is likely to support highly efficient wastewater reuse and algal biomass production. We demonstrated a pilot-scale algae membrane bioreactor (A-MBR) operation in the Rocky Fork wastewater treatment plant (WWTP) of the Boone County Water District with cyber-physical system sensors. Effort will continue to quantify the algal productivity and nutrient removal efficiency in the field.

Satellite-Imagery Based Method for Water-Quality Monitoring and Sediment Budgeting along the Middle-Mississippi River and Its Tributaries Phase 2

Basic Information

Title:	Satellite-Imagery Based Method for Water-Quality Monitoring and Sediment Budgeting along the Middle-Mississippi River and Its Tributaries Phase 2
Project Number:	2017MO153B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Categories:	Sediments, Water Quality, Surface Water
Descriptors:	None
Principal Investigators:	Amanda Lee Cox, Abuduwasiti Wulamu

Publications

1. Pereira, Leticia S.F., Lisa C. Andes, Amanda L. Cox, and Abduwasit Ghulam, 2018. Measuring Suspended Sediment Concentration and Turbidity in the Middle Mississippi and Lower Missouri Rivers Using Landsat Data. Journal of the American Water Resources Association (JAWRA) 54(2): 440 450. https://doi.org/10.1111/ 1752-1688.12616
2. Pereira, Leticia S. F., Lisa C. Andes, Amanda L. Cox, and Abduwasit Ghulam, 2017. Measuring SuspendedSediment Concentration and Turbidity in the Middle Mississippi and Lower Missouri Rivers Using Landsat Data. Journal of the American Water Resources Association (JAWRA) 1 11. https://doi.org/10.1111/1752-1688. 12616
3. Pereira, L.S.F. (2016). Landsat Imagery Based Method for Characterization of Suspended-sediment Concentration along the Middle-Mississippi River and Lower Missouri River. M.S. Thesis, Saint Louis University, Department of Civil Engineering, St. Louis, MO.
4. Pereira, L.S.F., Andes, L.C., Cox, A.L., and Ghulam, A. (2016). Remote Sensing of Suspended Sediment Concentration along the Middle-Mississippi River Geological Society of America GSA North-Central Section 50th Annual Meeting, presented April 18-19, Champaign, MO.
5. Pereira, L.S.F., Andes, L.C., Cox, A.L., and Ghulam, A. (2016). Remote Sensing of Suspended Sediment Concentration along the Middle-Mississippi River 22nd Annual Graduate Student Association Research Symposium, presented April 22, St. Louis, MO.
6. Cox, A.L. (2016). Use of Remote Sensing to Monitor Suspended Sediment Concentrations in the Middle Mississippi River. presented as a webinar for the St. Louis Chapter of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE), December 15, St. Louis, MO.
7. Cox, A.L. (2016). Using Remote Sensing as a Surrogate Method for Suspended Sediment Concentration Measurements along the Middle-Mississippi River. Invited Speaker for the Joint Seminar Series of the University of Mississippi National Center for Computational Hydroscience and

Engineering and the U.S. Department of Agriculture Agricultural Research Service National Sedimentation Laboratory, October 25, Oxford, MS.

8. Cox, A.L. (2017). Measuring Suspended-Sediment Concentrations and Turbidity in the Middle-Mississippi and Lower-Missouri Rivers using Remote Sensing Technology. Invited Speaker for the Hydrosystems Lab Seminar Series at the University of Illinois, March 3, Urbana, IL.

SATELLITE-IMAGERY BASED METHOD FOR WATER-QUALITY MONITORING AND SEDIMENT BUDGETING ALONG THE MIDDLE-MISSISSIPPI RIVER AND ITS TRIBUTARIES

Final Report

USGS Grant G16AP00066
Missouri Water Resources Research Center

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Introduction

The project objective was to develop a satellite-imagery based algorithm to monitor suspended sediment concentration (SSC) along the Middle-Mississippi River (MMR) between the Missouri River and Ohio River confluences. The objective was achieved through the following tasks: (1) a critical review of previous work, (2) identification of available data for analysis, (3) methodology development, (4) validation of method transferability, (5) estimation of SSC at unmonitored tributaries along the MMR, (6) development of a local sediment budget, and (7) data preparation for integration into a publicly-available data portal. The following sections detail each of the completed tasks.

Task 1: A Critical Review of Previous Work

The Pereira et al. (2017) publication (attached) provides the critical review of previous relevant work.

Task 2: Identification of Available Data to be used in the Analysis

The Pereira et al. (2017) publication (attached) details the available data used in the analysis.

Task 3: Methodology Development and Task 4: Validation of Method Transferability

A journal paper, being finalized for submission to the AGU Water Resources Research Journal, includes the results of Task 3 and Task 4. The information from that paper is summarized in this section for Task 3 and Task 4.

Pereira et al. (2017) developed an empirical relationship between surface reflectance from Landsat satellites and SSC for the MMR. Three empirical SSC equations were developed for the following satellites: Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS). When applying the equations, several SSC values were predicted as negative values due to the linear form of the equations. Therefore, new empirical Landsat surface reflectance – SSC regression equations were developed and are included in this final report.

The SSC-Reflectance empirical relationships developed in Pereira et al. (2017) used band ratios of the near infrared (NIR) band to all visible bands for Landsat 7 ETM+ and 4-5 TM equations. Landsat 8 OLI/TIRS only used the band ratio of NIR to red band. The new equations in this report used band ratios of NIR to all visible bands.

A summary of the development and validation data groups used in the regression analyses is provided in Table 1. Measured SSC data from two USGS gauge stations (Thebes, IL on the Mississippi River and Hermann, MO on the Missouri River) were used as the dependent variable in the regression analysis. These two gauge stations were categorized as development group stations. The empirical relationship equations from the regression analysis were validated using measured SSC data from two other USGS gauge stations (Chester, IL on the Mississippi River and St. Charles, MO on the Missouri River), categorized as the validation group stations. The St. Charles gauge station was not used in the validation group for the Landsat 8 regression analysis because SSC collection ended in 2008, before Landsat 8 was launched. Pereira et al. (2017) included the St. Joseph, MO gauging station in the validation group; however, when performing the regression analyses, data from the St. Joseph station did not fit the regression trends well for all Landsat sensors. Although St. Joseph is also on the Missouri River, the station is located 350 river miles upstream of the Herman station on the Missouri River. This finding reflects the significance of spatial transferability on reflectance-SSC empirical relationships.

Table 1. Summary of Development Group and Validation Group USGS Water Quality Gauging Stations used in Development of the Regression Equations.

Group	USGS Gauging Station (Location - Gauge No.)	River - River Mile	No. of Data Points		
			L8 OLI/TIRS	L7 ETM+	L4-5 TM
Development	Thebes, IL - 07022000	UMR[a] - 44	15	122	151
Development	Hermann, MO - 06934500	MOR[b] - 98	22	41	17
Validation	Chester, IL - 07020500	UMR - 110	21	95	70
Validation	St. Charles, MO - 06935965	MOR - 28	0	14	13

Note. [a] *UMR: Upper Mississippi River;* [b] *MOR: Missouri River*

Landsat Tier 1 band surface reflectance for blue, red, green and NIR bands were used as independent variables in the regression analysis. Surface reflectance values were taken from sampling areas at the four development and validation group station locations. In MATLAB, rectangular sampling areas at Thebes, Hermann, Chester, and St. Charles were delineated. After the areas were delineated, images were removed from the dataset through a filter if any pixels within the sampling area were not classified as “water with low cloud confidence” by the Landsat pixel quality product. For the remaining images, the mean surface reflectance and standard deviation were calculated for each band (green, blue, red, and NIR).

The following chronological filters were used on each Landsat image to generate the final dataset: collection tier filter, pixel quality filter, blue band mean surface reflectance filter (removes images with cirrus cloud coverage in the sample area), and surface reflectance standard deviation filter (removes images with vessels in the sampling area). Blue band mean surface reflectance was used filter out the image if the value was higher than 4.5%, for L8 OLI/TIRS images, and 6.5% for L7 ETM+ and L4-5 TM images. Lastly, images were filtered out if the surface reflectance standard deviation for any band was greater was than 0.5%. Details of the development of these filter methods are provided in Pereira et al. (2017).

The final dataset consisted of Landsat band surface reflectance and USGS measured SSC. Each Landsat image product is representative of one date. The temporal range of each final data set varied among Landsat sensors. A summary of the Landsat data is provided in Table 1. Landsat 4-5 used data from almost 29 years with a date range of January 1983 to November 2011; Landsat 7 used data from nearly 18 years with a date range of August 1999 to July 2017; and Landsat 8 used data from almost four and a half years with a date range of March 2013 to July 2017.

The following power regression equation was used for the analysis:

$$SSC = \alpha * {X_1}^{\beta_1} * {X_2}^{\beta_2} * {X_3}^{\beta_3} + \varepsilon \tag{1}$$

where $\widehat{SSC}$ is predicted SSC in mgL^{-1}, α is the regression coefficient, ε is a constant term, X_1, X_2, and X_3 are band reflectance ratios Blue:NIR, Green:NIR, and red:NIR, respectively, and β_1, β_2, and β_3 are exponents of band reflectance ratios X_1, X_2, and X_3, respectively. The least squares fitting method was used to determine the best final form of Equation (1) for each Landsat sensor. The resulting surface reflectance-SSC empirical equations are provided in Table 2, and a summary of the associated R^2 and RMSE values is shown in Table 3.

Table 2. Reflectance-SSC Empirical Relationships for Landsat 8 OLI/TIRS, 7 ETM+, and 4-5 TM.

Landsat Sensor	Reflectance-SSC Empirical Relationship
8 OLI/TIRS	$SSC(mgl^{-1}) = 159.9 * \left(\frac{b2}{b5}\right)^{-0.1337} * \left(\frac{b3}{b5}\right)^{-5.182} * \left(\frac{b4}{b5}\right)^{3.663} + 87.67$
7 ETM+	$SSC(mgl^{-1}) = 111.3 * \left(\frac{b1}{b4}\right)^{-0.2684} * \left(\frac{b2}{b4}\right)^{-6.033} * \left(\frac{b3}{b4}\right)^{5.031} + 63.84$
4-5 TM	$SSC(mgl^{-1}) = 74.80 * \left(\frac{b1}{b4}\right)^{-1.387} * \left(\frac{b2}{b4}\right)^{-4.639} * \left(\frac{b3}{b4}\right)^{4.227} + 80.68$

Note: For Landsat 8 OLI/TIRS, b2, b3, b4, and b5 are blue, green, red, and NIR band surface reflectance respectively; and for Landsat 7 ETM+ and 4-5 TM, b1, b2, b3, and b4 are blue, green, red and NIR band surface reflectance respectively.

Table 3. Summary of R^2 and RMSE for three Reflectance-SSC Empirical Regression Equations.

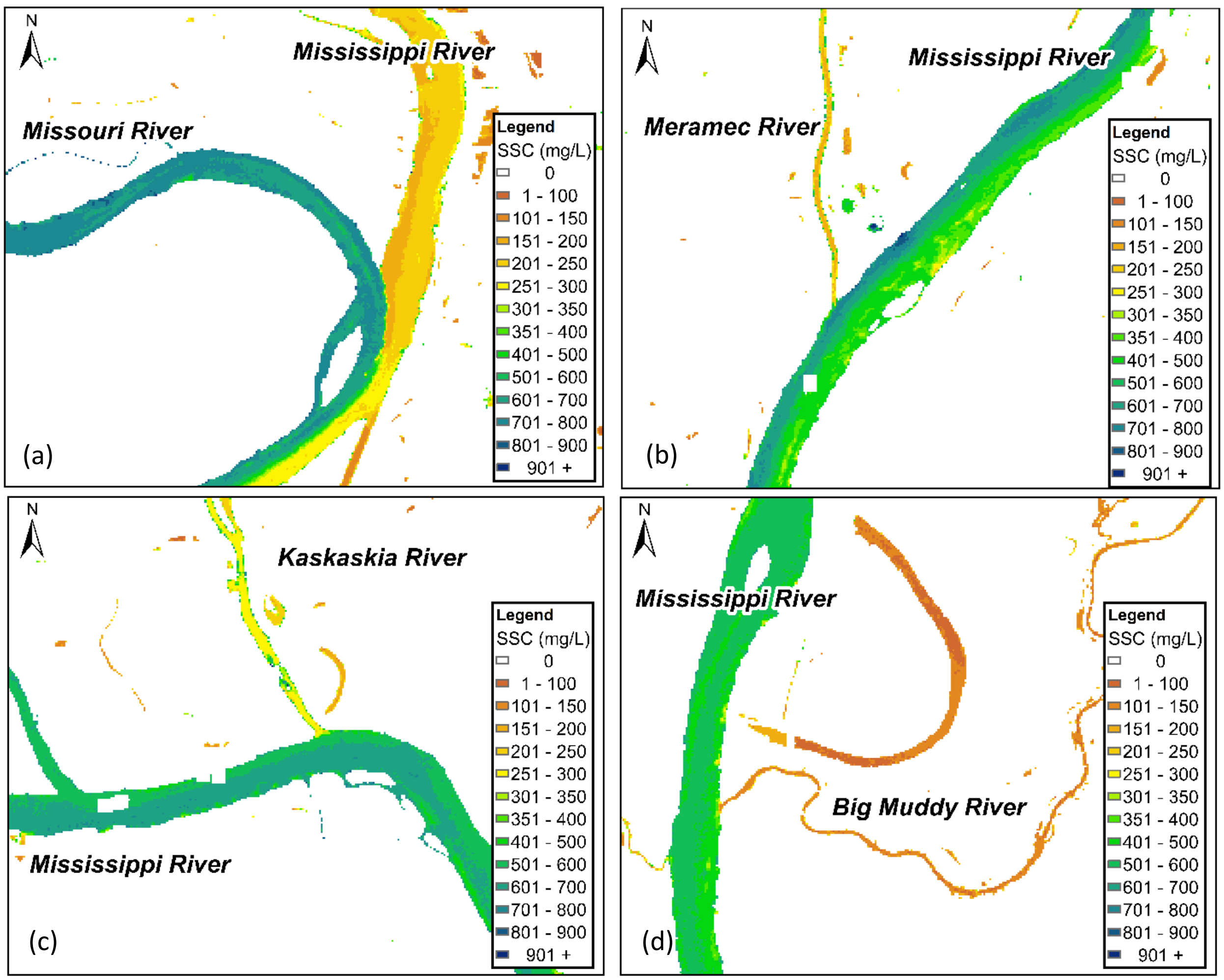
Regression		8 OLI SSC	7 ETM+ SSC	4-5 TM SSC
Range (mgl^{-1})		49-963	41-961	44-863
No. of Samples		58	272	251
Full Database	R^2_{Dev}	0.95	0.74	0.70
	R^2_{Val}	0.72	0.71	0.75
	R^2_{All}	0.87	0.73	0.72
	$RMSE_{Dev}$	37	82	85
	$RMSE_{Val}$	89	85	80
	$RMSE_{All}$	61	83	83
Reduced Database[a]	R^2_{Dev}	0.90	0.68	0.71
	R^2_{Val}	0.72	0.70	0.58
	R^2_{All}	0.81	0.70	0.68
	$RMSE_{Dev}$	38	73	70
	$RMSE_{Val}$	89	71	74
	$RMSE_{All}$	62	72	71

Note. [a]Excludes measured values greater than 600 mg/l.

Task 5: Estimation of SSC at Unmonitored Tributaries along the MMR

5.1 Sediment Rating Curves

Within the MMR, the Missouri River is the only tributary monitored for SSC. Seventeen unmonitored tributaries are located downstream between the Missouri River confluence and the Ohio River confluence. The reflectance-SSC regression models allowed prediction for three of the seventeen tributaries: Meramec, Kaskaskia, and Big Muddy. Example images of predicted SSC for these three tributaries and the Missouri River tributary are shown in Figure 1. Although Landsat has a spatial resolution of 30 meters by 30 meters, the mean channel width decreases during low flow conditions. For smaller tributaries, the Landsat pixel quality product could not detect water to get an accurate SSC prediction.



Note: Landsat predicted SSC from Landsat 8 satellite image on 09/12/2016.

Figure 1. Landsat Predicted SSC for Confluences along the MMR: (a) Missouri River, (b) Meramec River, (c) Kaskaskia River, and (d) Big Muddy River

5.1.1 Methods

Sediment rating curves were created using Landsat predicted SSC and USGS gauge station measured daily mean discharge. SSC data for each tributary were obtained using the reflectance-SSC relationship and the filtering techniques described in the Pereira et al (2017) paper. Sampling areas were created upstream approximately two channel widths from each confluence on the tributaries and on the Mississippi River upstream of the Missouri and Ohio River confluences (Figure 2). All Landsat sampling areas were 33,000 square meter rectangular areas. The Landsat sample area dimensions on the Mississippi River were 100 meters (W) by 330 meters (L). The median channel width of each tributary varied, therefore sample area dimensions for each tributary were as follows: 100 meter (W) by 330 meter (L) for the Missouri River, 60 meter (W) by 550 m (L) for the Meramec and Kaskaskia, and 30 meter (W) by 1100 meter (L) for the Big Muddy River.

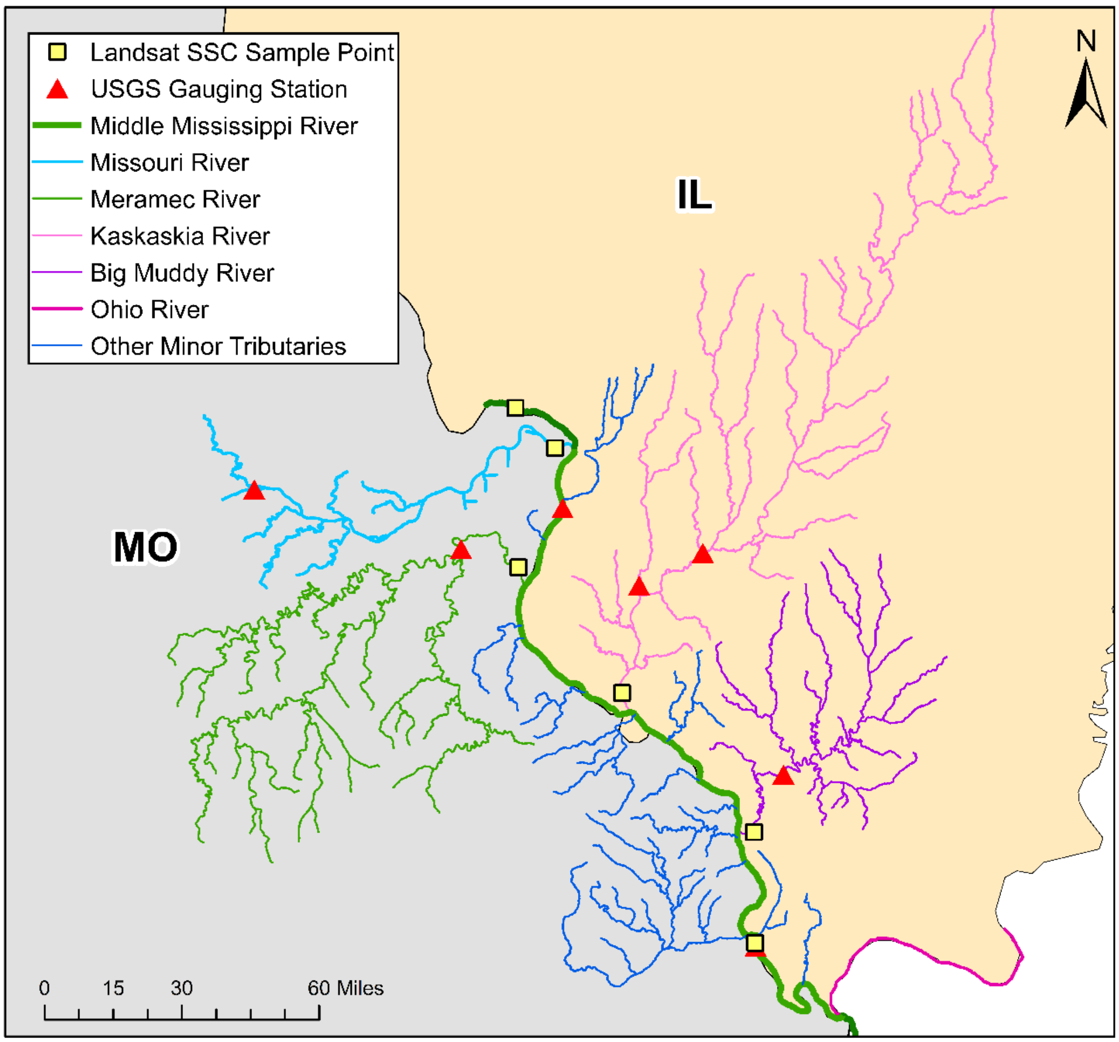


Figure 2. Landsat-Predicted SSC Sample Areas Locations and USGS Discharge Gauge Stations used to Develop the Sediment Rating Curves.

Daily mean discharge data were directly obtained from the USGS National Water Information System. The rating curve for the Mississippi River before the Missouri River and the Kaskaskia River rating curve used calculated daily mean discharge rather than direct USGS measured discharge. These discharges were calculated by subtracting the Missouri River at Hermann, MO gauge (06934500) discharge from the Mississippi at St. Louis, MO gauge (07010000) discharge, which gives an estimate of the Mississippi River discharge before the confluence with the Missouri River. The Kaskaskia River daily mean discharge was obtained by summing the daily mean discharge from the Kaskaskia River at Venedy, IL (05594100) and Silver Creek at Freeburg, IL (05594800). The Kaskaskia River at New Athens (05595000) USGS gauge station is located to the confluence; however, the earliest available daily mean discharge data during the period of Landsat measurement is in 2009, providing only 90 data points for regression development. Using the combination of discharge from the two gauging stations in the Kaskaskia basin provided a larger discharge data set of 286 data points. The remaining rating curves, Mississippi River before the Ohio River, Missouri River, Meramec River and Big Muddy River, used direct USGS daily mean discharge measurements from the gauging station that was both closest to each confluence and had the most available data. A summary of USGS discharge data used for developing the sediment rating curves is provided in Table 4.

Table 4. Summary of USGS Gauge Station Daily Mean Discharge Data used to Develop Sediment Rating Curve Regression Model.

River Rating Curve	USGS Gauging Station (Location - Gauge No.)	Data Date Range (MM/DD/YYYY - MM/DD/YYYY)	No. of Data Points[a]
Mississippi Before Missouri River	Saint Louis, MO – 07010000	09/03/1984 - 07/29/2017	324
	Hermann, MO – 06934500		
Mississippi Before Ohio River	Thebes, IL – 07022000	09/03/1984 - 06/19/2017	296
Missouri	Hermann, MO – 06934500	08/25/1984 - 06/26/2017	229
Meramec	Eureka, MO – 07019000	05/04/1986 - 06/27/2017	74
Kaskaskia	Venedy, IL (Kaskaskia River) - 05594100	11/22/1984 - 07/13/2017	286
	Freeburg, IL (Silver Creek) - 05594800		
Big Muddy	Murphysboro, IL – 05599490	05/25/1995 - 05/10/2017	21

[a]*Number of data points represent the amount of daily mean discharge measurements that correspond with Landsat measurement dates.*

The least squares method was used to find the best fit form of the rating curve equations for Mississippi River before Missouri River, Mississippi River Before Ohio River, and the four tributaries: Missouri, Meramec, Kaskaskia and Big Muddy Rivers. The following non-linear, power regression equation was used:

$$SSC = \alpha * Q^{\beta} + \varepsilon \quad (2)$$

where SSC is predicted SSC in milligrams per liter, α is the regression coefficient, Q is discharge in cubic feet per second, β is the power term for the discharge, and ε is the constant term.

5.2.2 Results

The resulting sediment rating curves are shown in Figure 3 and Figure 4, with each corresponding equation and R^2 value. The rating curves for the Mississippi River upstream of the Missouri River confluence and upstream of the Ohio River confluence are in Figure 3 with R^2 values of 0.404 and 0.503, respectively. The rating curves for the four confluences are in Figure 4 and the R^2 values range from 0.360 to 0.747.

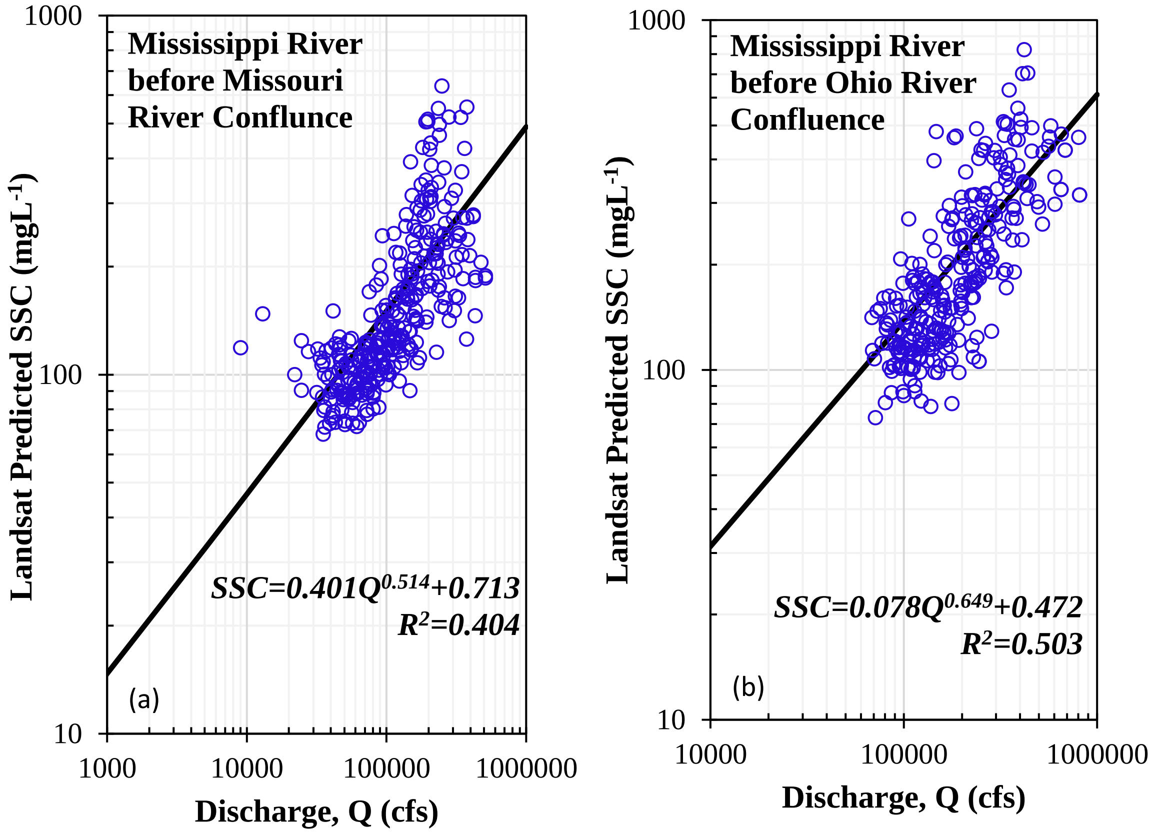


Figure 3. Sediment Rating Curves for the Mississippi River (a) before the Confluence with the Missouri River and (b) before the Confluence with the Ohio River.

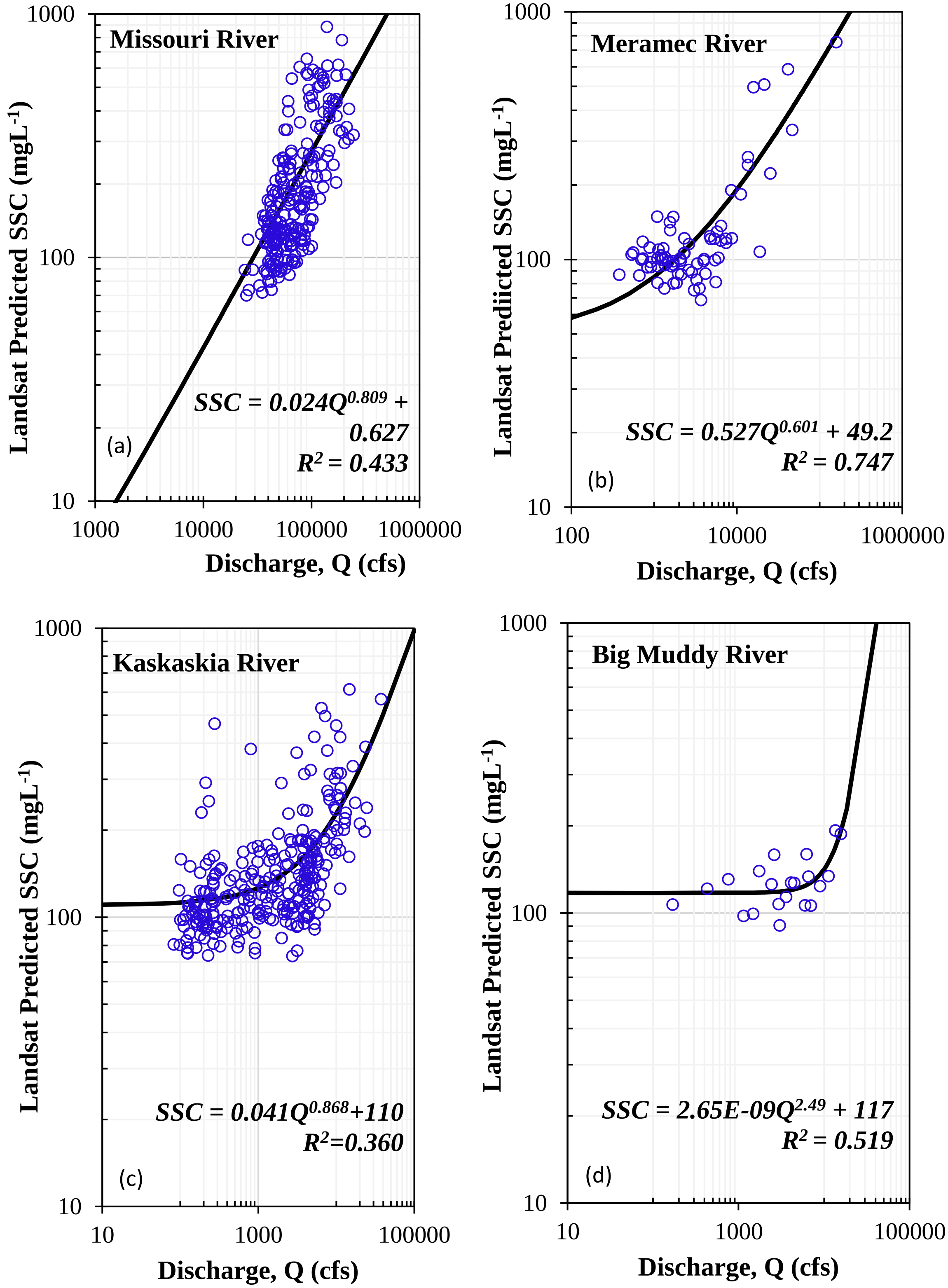


Figure 4. Sediment Rating Curves for the Four Largest Tributaries of the MMR: (a) Missouri River, (b) Meramec River, (c) Kaskaskia River, and (d) Big Muddy River.

Task 6: Development of a Local Sediment Budget

6.1 Methods

Suspended sediment concertation was estimated using the developed sediment rating curves and USGS Gauge station discharge (Section 5). Suspended sediment load (SSL) was calculated using the following equation:

$$SSL\ (tons/day) = SSC * Q * 0.0027 \quad (3)$$

where SSC is the SSC estimated using the sediment rating curve in mgL^{-1}, Q is USGS gauge station discharge in cfs, and 0.0027 is a conversation factor.

6.2 Results

The annual SSL from 1983 to 2017, shown in Figure 5, did not demonstrate any noticeable trends. Since the rating curves predict SSC based on discharge, the years with significant flood events are shown to have a high SSL in that year. The Missouri River individually contributed the most sediment of all the tributaries, followed by the Kaskaskia, Meramec and Big Muddy Rivers. For a majority of the period, the Missouri River SSL contribution was greater than the SSL from the ungauged tributaries and overland runoff SSL. The SSL contribution from ungauged tributaries and overland runoff was on average eleven times greater than the Kaskaskia, Meramec and Big Muddy River SSL contribution combined.

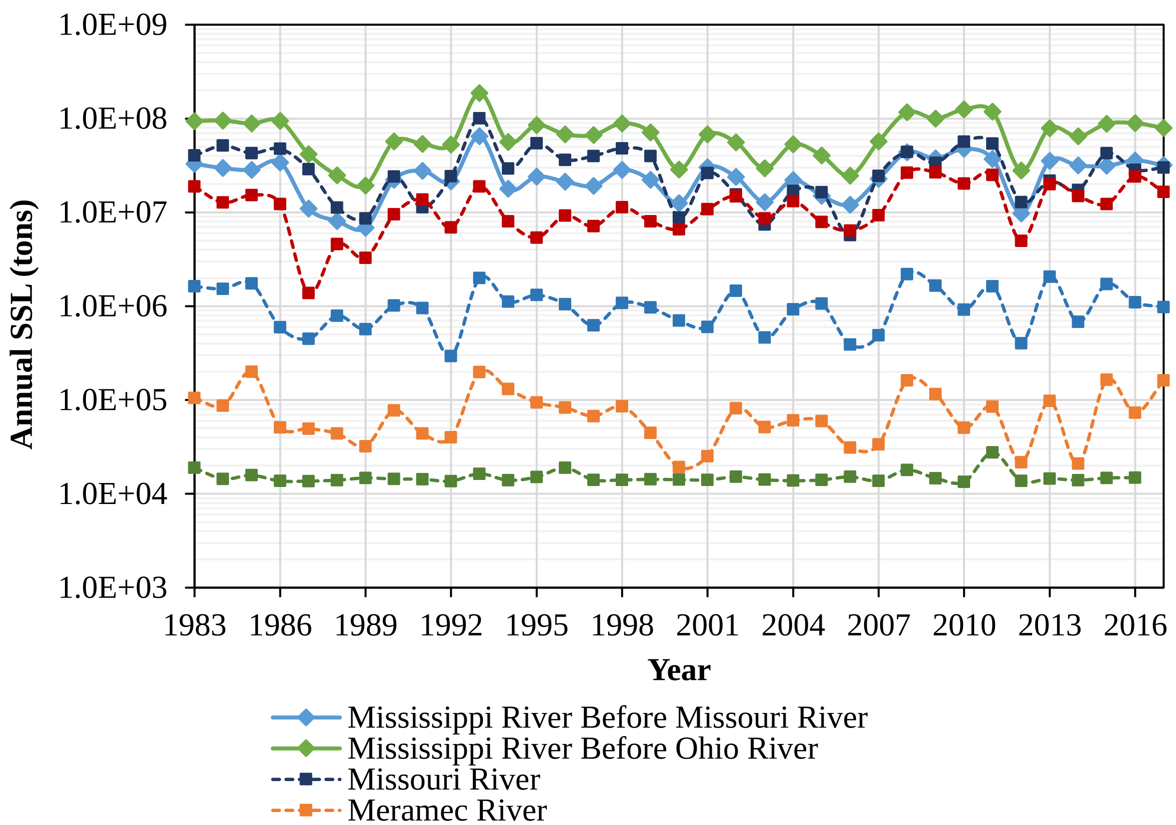


Figure 5. Annual Suspended Sediment Load in Tons from 1983 to 2017.

Average SSL from 1983 to 2017 for the Mississippi River before the Missouri River confluence, shown in Figure 6, was slightly less than the Missouri River before the confluence. The Kaskaskia River watershed is the largest of all the small tributaries and had the highest average SSL of the three ungauged tributaries. The Kaskaskia River average SSL was approximately 14 times greater than Meramec River and almost 70 times greater than the Big Muddy River. Average SSL at the downstream end of the MMR was nearly three times greater than the SSL upstream of the MMR. Average SSL contributions from the Missouri, Kaskaskia, Meramec and Big Muddy Rivers accounted for approximately 72% of the gains in the SSL in the MMR. Therefore, the remaining 28% of the total contributions were from the ungagged tributaries and overland runoff.

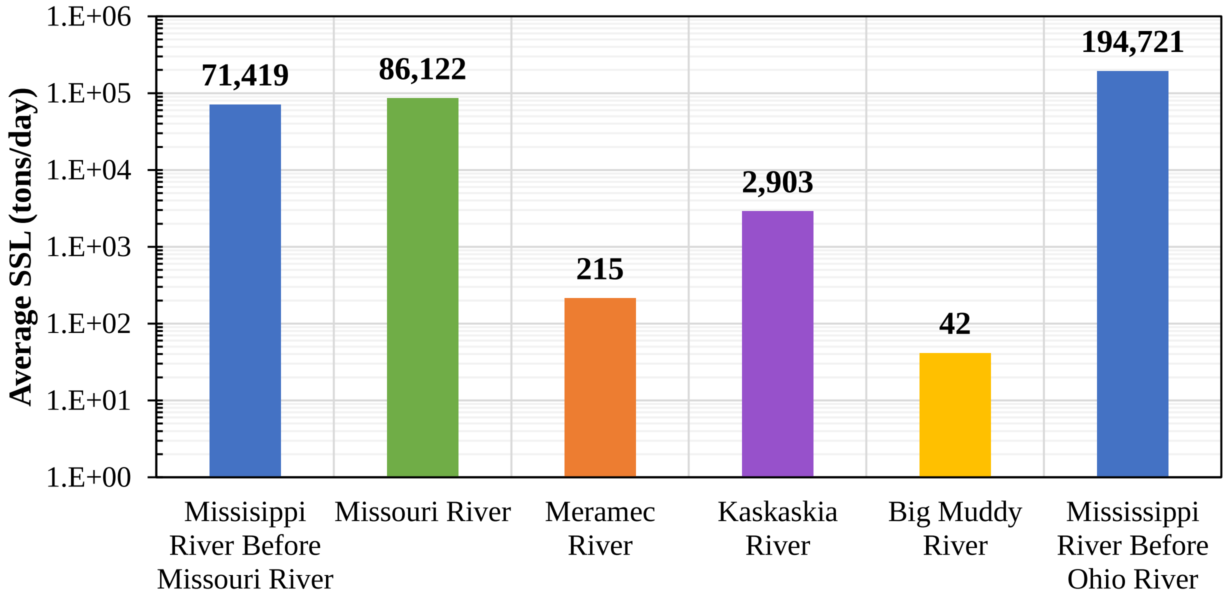


Figure 6. Average Suspended Sediment Load from 1983 – 2017 in tons per day.

The average monthly SSL from 2010 – 2017 for the Missouri River is shown in Figure 7 where the highest load in tons/day occurred during the spring and summer months with the peak average load in June. The average monthly SSL from 2010 – 2017 for the Meramec, Kaskaskia and Big Muddy Rivers is shown in Figure 8 where the highest SSL occurred in the winter and spring months, and the peak average monthly SSL was in May.

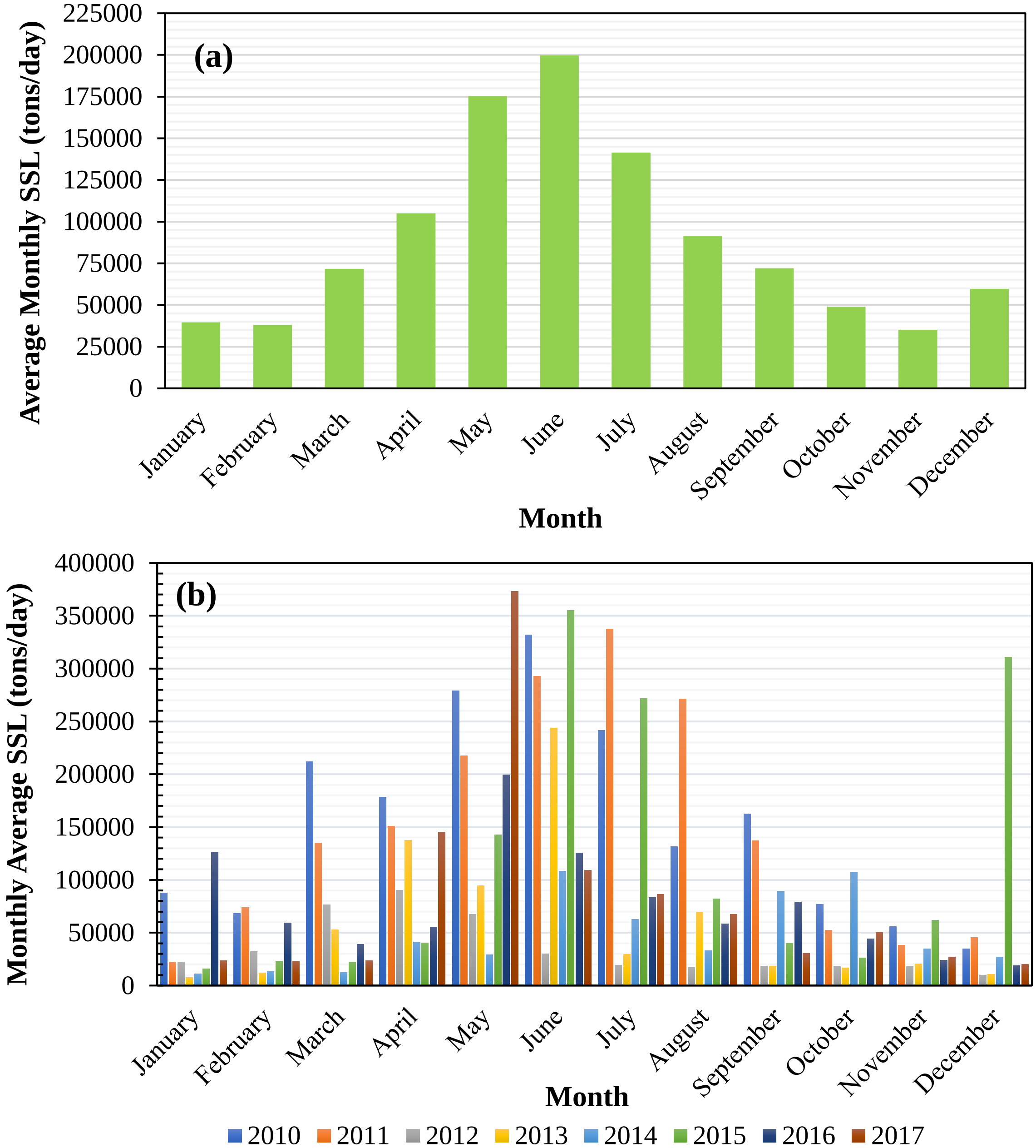


Figure 7. Missouri River Average Monthly SSL in tons per day (a) for the entire yearly period of 2010 – 2017 and (b) for each individual year 2010 – 2017.

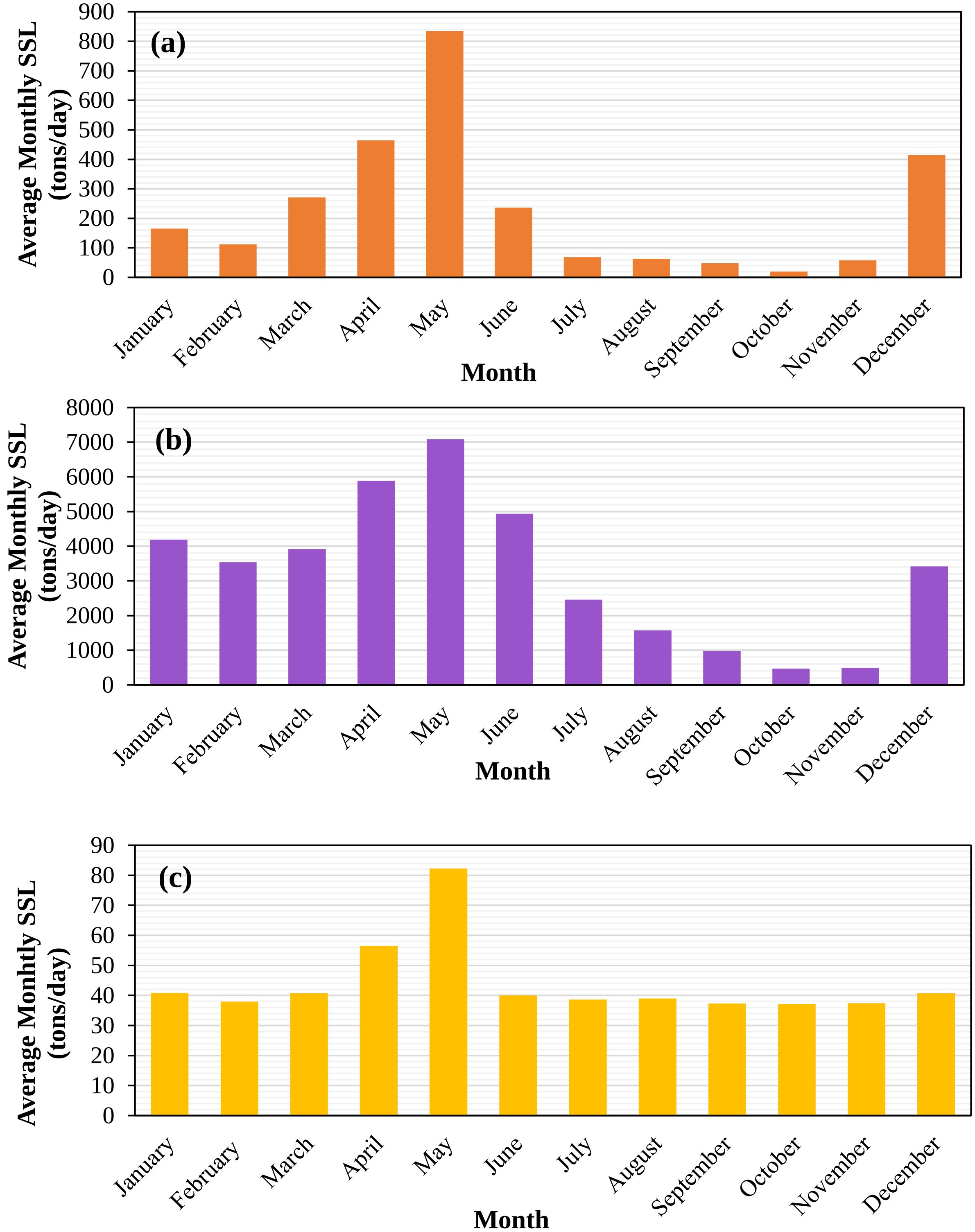


Figure 8. Average Monthly SSL in tons per day for the (a) Meramec River, (b) Kaskaskia River, and (c) Big Muddy River.

Task 7: Data for Integration into Publicly-Available Data Portal

Missing daily SSC data at four USGS gauge stations are provided in Appendix A to supplement the USGS records. A summary of the supplemental SSC data is provided in Table 5. The Hermann station on the Missouri River (06934500) had 137 days of missing daily SSC data during the collection period. Seven out of the total 137 days were able to be supplemented from Landsat. An additional 170 days were supplemented with Landsat predicted SSC for the period before collection started at Hermann (1984-2008). The St. Charles station on the Missouri River (06935965) did not have any daily mean SSC data gaps during the station collection period (2005-2008); however, SSC data were provided to supplement the record prior to 2005 and after 2008. The Thebes station on the Mississippi River (07022000) had 311 days of missing daily mean SSC data during the collection period and 5 days were able to be supplemented using Landsat data. The Chester station on the Mississippi River (07020500) had 5,413 days of missing daily mean SSC data and 102 days were able to be supplemented using Landsat data. The Chester and Thebes stations on the Mississippi River are no longer collecting daily mean SSC data, so the Landsat surface reflectance-SSC relationship can be used to continue monitoring SSC at these locations.

Table 5. Summary of Supplemental SSC Data from USGS Gauge Stations in the MMR.

USGS Gauge Station ID	Station Location	Period of SSC Collection at Gauge Station	Total Supplemented SSC Data from Landsat
06934500	Hermann, MO	10/01/2008 - Present	176
06935965	St. Charles, MO	10/01/2005 - 09/29/2008	217
07022000	Thebes, IL	10/01/1982 - 09/29/2017	5
07020500	Chester, IL	10/01/1982 - 09/30/2017	102

Products and Dissemination Activities

Journal Article Published (included as an attachment)

Pereira, L.S.F., Andes, L.C., Cox, A.L., and Ghulam, A. (2017). "Measuring Suspended-Sediment Concentration and Turbidity in the Middle Mississippi and Lower Missouri Rivers using Landsat Data." *Journal of the American Water Resources Association*, DOI: 10.1111/1752-1688.12616.

Masters of Science Thesis

Pereira, L.S.F. (2016). Landsat Imagery Based Method for Characterization of Suspended-sediment Concentration along the Middle-Mississippi River and Lower Missouri River. M.S. Thesis, Saint Louis University, Department of Civil Engineering, St. Louis, MO.

Abstracts Presented at Conferences and Symposiums

Pereira, L.S.F., Andes, L.C., Cox, A.L., and Ghulam, A. (2016). "Remote Sensing of Suspended Sediment Concentration along the Middle-Mississippi River" Geological Society of America GSA North-Central Section 50th Annual Meeting, presented April 18-19, Champaign, MO.

Pereira, L.S.F., Andes, L.C., Cox, A.L., and Ghulam, A. (2016). "Remote Sensing of Suspended Sediment Concentration along the Middle-Mississippi River" 22nd Annual Graduate Student Association Research Symposium, presented April 22, St. Louis, MO.

Other Presentations

Cox, A.L. (2016). "Use of Remote Sensing to Monitor Suspended Sediment Concentrations in the Middle Mississippi River." presented as a webinar for the St. Louis Chapter of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE), December 15, St. Louis, MO.

Cox, A.L. (2016). "Using Remote Sensing as a Surrogate Method for Suspended Sediment Concentration Measurements along the Middle-Mississippi River." Invited Speaker for the Joint Seminar Series of the University of Mississippi National Center for Computational Hydroscience and Engineering and the U.S. Department of Agriculture – Agricultural Research Service National Sedimentation Laboratory, October 25, Oxford, MS.

Cox, A.L. (2017). "Measuring Suspended-Sediment Concentrations and Turbidity in the Middle-Mississippi and Lower-Missouri Rivers using Remote Sensing Technology." Invited Speaker for the Hydrosystems Lab Seminar Series at the University of Illinois, March 3, Urbana, IL.

Student Involvement

Four students contributed to the project - two masters students, two Ph.D. students, and an undergraduate research assistant (who later became a masters student). Under the direction of the PI and Co-PI, the first masters student completed the initial regression model development for predicting SSC from surface reflectance, with technical assistance from a Ph.D. student. Following the initial masters student work, research activities continued with an undergraduate research assistant with technical assistance provided by a second Ph.D. student. The undergraduate research assistant became a masters student in August of 2017 and completed the majority of the work for the second set of regression models and the sediment budget analysis under the direction of the PI and Co-PI.

Appendix A: Supplemental SSC Data from Reflectance-SSC Models and Landsat Data for USGS Stations at Hermann, St. Charles, Thebes and Chester.

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06934500	Hermann, MO	8/25/1984	127.27
06934500	Hermann, MO	12/15/1984	189.49
06934500	Hermann, MO	11/16/1985	500.24
06934500	Hermann, MO	4/25/1986	297.23
06934500	Hermann, MO	2/7/1987	91.91
06934500	Hermann, MO	3/11/1987	116.67
06934500	Hermann, MO	5/14/1987	287.23
06934500	Hermann, MO	11/22/1987	96.54
06934500	Hermann, MO	12/8/1987	108.83
06934500	Hermann, MO	1/25/1988	98.89
06934500	Hermann, MO	2/26/1988	193.48
06934500	Hermann, MO	3/29/1988	445.53
06934500	Hermann, MO	4/14/1988	126.73
06934500	Hermann, MO	5/16/1988	131.13
06934500	Hermann, MO	6/1/1988	421.50
06934500	Hermann, MO	7/3/1988	125.85
06934500	Hermann, MO	9/5/1988	134.54
06934500	Hermann, MO	9/21/1988	169.87
06934500	Hermann, MO	12/10/1988	92.36
06934500	Hermann, MO	7/22/1989	231.01
06934500	Hermann, MO	9/24/1989	301.95
06934500	Hermann, MO	10/10/1989	108.79
06934500	Hermann, MO	11/11/1989	106.06
06934500	Hermann, MO	10/29/1990	109.75
06934500	Hermann, MO	11/14/1990	114.00
06934500	Hermann, MO	4/7/1991	263.65
06934500	Hermann, MO	8/13/1991	156.14
06934500	Hermann, MO	8/29/1991	133.06
06934500	Hermann, MO	9/30/1991	137.09
06934500	Hermann, MO	10/16/1991	125.89
06934500	Hermann, MO	11/17/1991	256.36
06934500	Hermann, MO	6/12/1992	211.80
06934500	Hermann, MO	10/2/1992	165.35
06934500	Hermann, MO	8/18/1993	397.18

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06934500	Hermann, MO	10/5/1993	268.76
06934500	Hermann, MO	10/21/1993	206.11
06934500	Hermann, MO	11/6/1993	132.68
06934500	Hermann, MO	3/30/1994	160.39
06934500	Hermann, MO	4/15/1994	372.50
06934500	Hermann, MO	5/17/1994	180.20
06934500	Hermann, MO	8/21/1994	136.58
06934500	Hermann, MO	9/6/1994	189.17
06934500	Hermann, MO	10/8/1994	301.05
06934500	Hermann, MO	10/24/1994	136.62
06934500	Hermann, MO	12/27/1994	85.32
06934500	Hermann, MO	5/4/1995	305.84
06934500	Hermann, MO	8/8/1995	359.29
06934500	Hermann, MO	9/9/1995	150.86
06934500	Hermann, MO	9/25/1995	194.42
06934500	Hermann, MO	10/11/1995	123.35
06934500	Hermann, MO	7/9/1996	726.73
06934500	Hermann, MO	9/11/1996	375.65
06934500	Hermann, MO	9/27/1996	195.61
06934500	Hermann, MO	10/29/1996	327.99
06934500	Hermann, MO	3/22/1997	288.25
06934500	Hermann, MO	5/9/1997	306.69
06934500	Hermann, MO	7/12/1997	388.80
06934500	Hermann, MO	7/28/1997	250.54
06934500	Hermann, MO	9/30/1997	132.62
06934500	Hermann, MO	10/16/1997	266.67
06934500	Hermann, MO	5/12/1998	204.72
06934500	Hermann, MO	2/8/1999	449.84
06934500	Hermann, MO	2/24/1999	129.82
06934500	Hermann, MO	3/28/1999	132.45
06934500	Hermann, MO	7/18/1999	430.52
06934500	Hermann, MO	8/11/1999	602.27
06934500	Hermann, MO	8/19/1999	264.32
06934500	Hermann, MO	9/12/1999	150.84
06934500	Hermann, MO	9/20/1999	121.58
06934500	Hermann, MO	9/28/1999	100.01
06934500	Hermann, MO	10/6/1999	119.00

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06934500	Hermann, MO	10/14/1999	105.72
06934500	Hermann, MO	10/22/1999	109.67
06934500	Hermann, MO	11/15/1999	79.73
06934500	Hermann, MO	11/23/1999	92.93
06934500	Hermann, MO	12/9/1999	90.53
06934500	Hermann, MO	12/25/1999	92.94
06934500	Hermann, MO	2/19/2000	246.34
06934500	Hermann, MO	2/27/2000	164.65
06934500	Hermann, MO	3/7/2000	114.07
06934500	Hermann, MO	3/23/2000	103.15
06934500	Hermann, MO	4/8/2000	139.22
06934500	Hermann, MO	5/10/2000	96.21
06934500	Hermann, MO	7/21/2000	211.41
06934500	Hermann, MO	8/30/2000	125.57
06934500	Hermann, MO	9/7/2000	137.50
06934500	Hermann, MO	9/15/2000	104.79
06934500	Hermann, MO	10/9/2000	112.19
06934500	Hermann, MO	10/17/2000	149.33
06934500	Hermann, MO	11/2/2000	99.11
06934500	Hermann, MO	11/18/2000	91.21
06934500	Hermann, MO	2/6/2001	177.95
06934500	Hermann, MO	3/26/2001	643.72
06934500	Hermann, MO	6/30/2001	436.73
06934500	Hermann, MO	8/17/2001	115.24
06934500	Hermann, MO	9/2/2001	211.44
06934500	Hermann, MO	9/10/2001	138.59
06934500	Hermann, MO	9/26/2001	393.78
06934500	Hermann, MO	10/20/2001	146.29
06934500	Hermann, MO	10/28/2001	131.24
06934500	Hermann, MO	11/5/2001	94.50
06934500	Hermann, MO	11/21/2001	88.56
06934500	Hermann, MO	12/7/2001	110.97
06934500	Hermann, MO	2/9/2002	77.94
06934500	Hermann, MO	2/17/2002	90.88
06934500	Hermann, MO	3/13/2002	149.03
06934500	Hermann, MO	6/25/2002	243.26
06934500	Hermann, MO	7/27/2002	136.86

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06934500	Hermann, MO	9/5/2002	133.74
06934500	Hermann, MO	9/21/2002	98.42
06934500	Hermann, MO	10/7/2002	92.41
06934500	Hermann, MO	10/15/2002	145.79
06934500	Hermann, MO	11/8/2002	77.81
06934500	Hermann, MO	12/10/2002	73.06
06934500	Hermann, MO	1/11/2003	72.93
06934500	Hermann, MO	2/4/2003	83.97
06934500	Hermann, MO	2/12/2003	69.73
06934500	Hermann, MO	3/24/2003	121.49
06934500	Hermann, MO	4/1/2003	106.19
06934500	Hermann, MO	7/14/2003	226.00
06934500	Hermann, MO	8/7/2003	130.09
06934500	Hermann, MO	8/15/2003	157.02
06934500	Hermann, MO	8/23/2003	123.70
06934500	Hermann, MO	9/16/2003	219.97
06934500	Hermann, MO	10/2/2003	140.29
06934500	Hermann, MO	10/18/2003	108.48
06934500	Hermann, MO	11/19/2003	126.37
06934500	Hermann, MO	12/21/2003	102.98
06934500	Hermann, MO	4/3/2004	470.40
06934500	Hermann, MO	5/5/2004	181.58
06934500	Hermann, MO	8/1/2004	341.37
06934500	Hermann, MO	8/17/2004	160.25
06934500	Hermann, MO	9/26/2004	261.81
06934500	Hermann, MO	10/4/2004	199.55
06934500	Hermann, MO	11/5/2004	410.33
06934500	Hermann, MO	11/13/2004	136.55
06934500	Hermann, MO	12/15/2004	86.88
06934500	Hermann, MO	1/24/2005	107.86
06934500	Hermann, MO	2/25/2005	234.20
06934500	Hermann, MO	8/12/2005	148.65
06934500	Hermann, MO	8/20/2005	454.64
06934500	Hermann, MO	9/5/2005	180.94
06934500	Hermann, MO	9/13/2005	104.12
06934500	Hermann, MO	9/21/2005	395.10
06934500	Hermann, MO	9/29/2005	642.28

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06934500	Hermann, MO	10/15/2005	161.35
06934500	Hermann, MO	4/1/2006	128.55
06934500	Hermann, MO	5/27/2006	117.38
06934500	Hermann, MO	6/28/2006	154.30
06934500	Hermann, MO	8/15/2006	133.51
06934500	Hermann, MO	8/23/2006	169.62
06934500	Hermann, MO	9/8/2006	162.51
06934500	Hermann, MO	9/16/2006	101.48
06934500	Hermann, MO	11/19/2006	85.94
06934500	Hermann, MO	12/13/2006	105.25
06934500	Hermann, MO	4/20/2007	209.88
06934500	Hermann, MO	7/25/2007	122.76
06934500	Hermann, MO	8/10/2007	153.53
06934500	Hermann, MO	8/26/2007	196.43
06934500	Hermann, MO	9/3/2007	445.16
06934500	Hermann, MO	9/11/2007	163.14
06934500	Hermann, MO	9/19/2007	158.27
06934500	Hermann, MO	9/27/2007	117.99
06934500	Hermann, MO	10/5/2007	121.10
06934500	Hermann, MO	11/6/2007	239.90
06934500	Hermann, MO	2/10/2008	575.55
06934500	Hermann, MO	4/6/2008	208.13
06934500	Hermann, MO	7/11/2008	498.82
06934500	Hermann, MO	8/4/2008	570.97
06934500	Hermann, MO	11/16/2008	129.00
06934500	Hermann, MO	11/24/2008	139.69
06934500	Hermann, MO	12/10/2008	94.84
06934500	Hermann, MO	1/11/2009	112.58
06934500	Hermann, MO	2/4/2009	94.19
06934500	Hermann, MO	2/12/2009	323.91
06934500	Hermann, MO	4/23/2017	268.19
06935965	St. Charles, MO	8/25/1984	138.43
06935965	St. Charles, MO	12/15/1984	143.08
06935965	St. Charles, MO	1/19/1986	95.50
06935965	St. Charles, MO	6/12/1986	631.75
06935965	St. Charles, MO	2/7/1987	94.15
06935965	St. Charles, MO	8/2/1987	217.71

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06935965	St. Charles, MO	11/22/1987	99.42
06935965	St. Charles, MO	12/8/1987	134.25
06935965	St. Charles, MO	1/25/1988	100.20
06935965	St. Charles, MO	4/14/1988	133.41
06935965	St. Charles, MO	4/30/1988	113.81
06935965	St. Charles, MO	5/16/1988	149.04
06935965	St. Charles, MO	6/17/1988	430.23
06935965	St. Charles, MO	7/3/1988	128.23
06935965	St. Charles, MO	9/5/1988	154.06
06935965	St. Charles, MO	9/21/1988	266.53
06935965	St. Charles, MO	10/7/1988	147.07
06935965	St. Charles, MO	12/10/1988	95.27
06935965	St. Charles, MO	9/24/1989	342.03
06935965	St. Charles, MO	10/10/1989	126.49
06935965	St. Charles, MO	11/11/1989	111.48
06935965	St. Charles, MO	10/29/1990	115.03
06935965	St. Charles, MO	11/14/1990	119.17
06935965	St. Charles, MO	8/13/1991	153.96
06935965	St. Charles, MO	9/14/1991	173.62
06935965	St. Charles, MO	10/16/1991	149.31
06935965	St. Charles, MO	1/20/1992	133.69
06935965	St. Charles, MO	10/2/1992	180.55
06935965	St. Charles, MO	6/15/1993	501.57
06935965	St. Charles, MO	10/5/1993	326.12
06935965	St. Charles, MO	10/21/1993	205.94
06935965	St. Charles, MO	11/6/1993	136.15
06935965	St. Charles, MO	2/10/1994	98.18
06935965	St. Charles, MO	3/30/1994	177.00
06935965	St. Charles, MO	5/17/1994	211.06
06935965	St. Charles, MO	9/6/1994	211.56
06935965	St. Charles, MO	9/22/1994	125.70
06935965	St. Charles, MO	10/8/1994	143.86
06935965	St. Charles, MO	10/24/1994	127.97
06935965	St. Charles, MO	1/28/1995	118.17
06935965	St. Charles, MO	8/8/1995	496.95
06935965	St. Charles, MO	9/9/1995	187.30
06935965	St. Charles, MO	9/25/1995	247.93

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06935965	St. Charles, MO	10/11/1995	123.15
06935965	St. Charles, MO	7/9/1996	598.83
06935965	St. Charles, MO	9/11/1996	157.55
06935965	St. Charles, MO	9/27/1996	198.53
06935965	St. Charles, MO	10/13/1996	127.92
06935965	St. Charles, MO	10/29/1996	499.43
06935965	St. Charles, MO	3/22/1997	356.54
06935965	St. Charles, MO	7/12/1997	356.93
06935965	St. Charles, MO	7/28/1997	299.43
06935965	St. Charles, MO	9/30/1997	139.85
06935965	St. Charles, MO	10/16/1997	216.32
06935965	St. Charles, MO	11/17/1997	109.92
06935965	St. Charles, MO	4/10/1998	497.67
06935965	St. Charles, MO	5/12/1998	304.97
06935965	St. Charles, MO	8/16/1998	256.29
06935965	St. Charles, MO	11/20/1998	255.19
06935965	St. Charles, MO	2/8/1999	379.08
06935965	St. Charles, MO	2/24/1999	111.24
06935965	St. Charles, MO	3/28/1999	124.26
06935965	St. Charles, MO	7/18/1999	404.17
06935965	St. Charles, MO	8/3/1999	258.33
06935965	St. Charles, MO	8/19/1999	228.40
06935965	St. Charles, MO	9/12/1999	106.30
06935965	St. Charles, MO	9/28/1999	124.67
06935965	St. Charles, MO	10/6/1999	129.53
06935965	St. Charles, MO	10/14/1999	112.30
06935965	St. Charles, MO	10/22/1999	121.86
06935965	St. Charles, MO	11/15/1999	87.71
06935965	St. Charles, MO	2/19/2000	422.60
06935965	St. Charles, MO	2/27/2000	200.94
06935965	St. Charles, MO	3/7/2000	120.17
06935965	St. Charles, MO	3/15/2000	125.25
06935965	St. Charles, MO	3/23/2000	129.06
06935965	St. Charles, MO	4/8/2000	154.23
06935965	St. Charles, MO	5/10/2000	146.84
06935965	St. Charles, MO	6/3/2000	261.84
06935965	St. Charles, MO	8/30/2000	169.52

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06935965	St. Charles, MO	9/7/2000	163.58
06935965	St. Charles, MO	10/1/2000	114.17
06935965	St. Charles, MO	10/9/2000	119.05
06935965	St. Charles, MO	2/6/2001	246.34
06935965	St. Charles, MO	3/26/2001	633.40
06935965	St. Charles, MO	8/17/2001	114.27
06935965	St. Charles, MO	9/2/2001	233.18
06935965	St. Charles, MO	9/10/2001	164.95
06935965	St. Charles, MO	9/26/2001	601.99
06935965	St. Charles, MO	10/20/2001	163.59
06935965	St. Charles, MO	10/28/2001	143.55
06935965	St. Charles, MO	11/13/2001	107.72
06935965	St. Charles, MO	12/7/2001	106.83
06935965	St. Charles, MO	1/8/2002	78.37
06935965	St. Charles, MO	2/9/2002	87.43
06935965	St. Charles, MO	2/17/2002	96.04
06935965	St. Charles, MO	3/13/2002	92.94
06935965	St. Charles, MO	6/1/2002	307.32
06935965	St. Charles, MO	7/27/2002	138.86
06935965	St. Charles, MO	9/5/2002	180.08
06935965	St. Charles, MO	9/21/2002	95.49
06935965	St. Charles, MO	9/29/2002	113.34
06935965	St. Charles, MO	10/7/2002	92.19
06935965	St. Charles, MO	10/15/2002	157.38
06935965	St. Charles, MO	11/8/2002	82.58
06935965	St. Charles, MO	1/11/2003	75.22
06935965	St. Charles, MO	2/12/2003	73.95
06935965	St. Charles, MO	3/24/2003	126.45
06935965	St. Charles, MO	4/1/2003	124.48
06935965	St. Charles, MO	7/14/2003	193.30
06935965	St. Charles, MO	8/7/2003	125.92
06935965	St. Charles, MO	8/15/2003	172.24
06935965	St. Charles, MO	8/23/2003	122.77
06935965	St. Charles, MO	9/16/2003	260.15
06935965	St. Charles, MO	10/2/2003	150.73
06935965	St. Charles, MO	10/18/2003	115.81
06935965	St. Charles, MO	10/26/2003	131.72

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06935965	St. Charles, MO	11/19/2003	167.96
06935965	St. Charles, MO	12/21/2003	126.11
06935965	St. Charles, MO	1/14/2004	87.61
06935965	St. Charles, MO	2/15/2004	72.69
06935965	St. Charles, MO	4/11/2004	164.18
06935965	St. Charles, MO	5/5/2004	193.30
06935965	St. Charles, MO	6/14/2004	560.60
06935965	St. Charles, MO	8/1/2004	365.09
06935965	St. Charles, MO	9/26/2004	239.04
06935965	St. Charles, MO	10/4/2004	192.93
06935965	St. Charles, MO	11/5/2004	599.23
06935965	St. Charles, MO	11/13/2004	158.10
06935965	St. Charles, MO	1/24/2005	111.46
06935965	St. Charles, MO	2/1/2005	109.48
06935965	St. Charles, MO	2/25/2005	286.72
06935965	St. Charles, MO	4/14/2005	262.71
06935965	St. Charles, MO	8/12/2005	168.23
06935965	St. Charles, MO	8/20/2005	345.64
06935965	St. Charles, MO	9/5/2005	210.45
06935965	St. Charles, MO	9/13/2005	112.98
06935965	St. Charles, MO	9/21/2005	407.43
06935965	St. Charles, MO	9/29/2005	377.67
06935965	St. Charles, MO	10/31/2008	412.50
06935965	St. Charles, MO	12/10/2008	102.39
06935965	St. Charles, MO	1/11/2009	130.05
06935965	St. Charles, MO	1/19/2009	99.77
06935965	St. Charles, MO	2/4/2009	96.68
06935965	St. Charles, MO	3/8/2009	162.03
06935965	St. Charles, MO	4/17/2009	330.67
06935965	St. Charles, MO	10/10/2009	616.91
06935965	St. Charles, MO	10/18/2009	224.84
06935965	St. Charles, MO	11/3/2009	780.48
06935965	St. Charles, MO	11/11/2009	172.43
06935965	St. Charles, MO	11/27/2009	182.95
06935965	St. Charles, MO	12/5/2009	200.09
06935965	St. Charles, MO	2/23/2010	587.01
06935965	St. Charles, MO	4/12/2010	339.77

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
06935965	St. Charles, MO	5/6/2010	463.14
06935965	St. Charles, MO	5/22/2010	551.51
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06935965	St. Charles, MO	8/26/2010	512.02
06935965	St. Charles, MO	9/3/2010	534.34
06935965	St. Charles, MO	10/5/2010	449.33
06935965	St. Charles, MO	10/21/2010	190.45
06935965	St. Charles, MO	10/29/2010	126.82
06935965	St. Charles, MO	11/6/2010	161.15
06935965	St. Charles, MO	12/8/2010	133.95
06935965	St. Charles, MO	5/17/2011	434.45
06935965	St. Charles, MO	7/12/2011	330.18
06935965	St. Charles, MO	7/20/2011	415.92
06935965	St. Charles, MO	7/28/2011	323.85
06935965	St. Charles, MO	8/13/2011	284.38
06935965	St. Charles, MO	8/21/2011	369.95
06935965	St. Charles, MO	8/29/2011	283.01
06935965	St. Charles, MO	9/6/2011	387.01
06935965	St. Charles, MO	10/8/2011	208.32
06935965	St. Charles, MO	10/16/2011	139.51
06935965	St. Charles, MO	10/24/2011	175.52
06935965	St. Charles, MO	11/1/2011	116.93
06935965	St. Charles, MO	11/17/2011	110.67
06935965	St. Charles, MO	1/4/2012	100.52
06935965	St. Charles, MO	3/24/2012	509.76
06935965	St. Charles, MO	4/9/2012	366.08
06935965	St. Charles, MO	5/27/2012	158.00
06935965	St. Charles, MO	6/28/2012	168.09
06935965	St. Charles, MO	8/15/2012	106.96
06935965	St. Charles, MO	10/18/2012	122.51
06935965	St. Charles, MO	12/5/2012	83.16
06935965	St. Charles, MO	12/21/2012	87.16
06935965	St. Charles, MO	5/14/2013	243.84
06935965	St. Charles, MO	7/17/2013	97.21
06935965	St. Charles, MO	8/26/2013	135.18
06935965	St. Charles, MO	9/3/2013	113.87
06935965	St. Charles, MO	10/13/2013	129.68

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
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06935965	St. Charles, MO	12/24/2013	73.24
06935965	St. Charles, MO	4/15/2014	126.16
06935965	St. Charles, MO	8/13/2014	297.67
06935965	St. Charles, MO	9/22/2014	503.48
06935965	St. Charles, MO	10/16/2014	750.54
06935965	St. Charles, MO	11/1/2014	121.37
06935965	St. Charles, MO	8/24/2015	614.33
06935965	St. Charles, MO	9/1/2015	232.33
06935965	St. Charles, MO	9/25/2015	128.06
06935965	St. Charles, MO	10/11/2015	193.24
06935965	St. Charles, MO	10/19/2015	123.26
06935965	St. Charles, MO	11/12/2015	97.04
06935965	St. Charles, MO	4/4/2016	171.01
06935965	St. Charles, MO	4/12/2016	139.85
06935965	St. Charles, MO	8/18/2016	134.00
06935965	St. Charles, MO	10/5/2016	358.79
06935965	St. Charles, MO	10/13/2016	324.96
06935965	St. Charles, MO	10/21/2016	161.19
06935965	St. Charles, MO	10/29/2016	147.32
06935965	St. Charles, MO	11/6/2016	115.03
06935965	St. Charles, MO	12/8/2016	87.68
06935965	St. Charles, MO	3/22/2017	125.20
06935965	St. Charles, MO	4/23/2017	306.92
06935965	St. Charles, MO	5/9/2017	428.88
06935965	St. Charles, MO	6/26/2017	688.50
07022000	Thebes, IL	11/12/1986	172.76
07022000	Thebes, IL	8/22/1991	162.14
07022000	Thebes, IL	8/3/1996	229.77
07022000	Thebes, IL	1/29/1998	103.42
07022000	Thebes, IL	12/24/2001	150.14
07020500	Chester, IL	7/10/1987	329.93
07020500	Chester, IL	10/14/1987	105.82
07020500	Chester, IL	4/7/1988	337.82
07020500	Chester, IL	5/9/1988	137.32
07020500	Chester, IL	5/25/1988	139.63
07020500	Chester, IL	8/29/1988	140.63

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
07020500	Chester, IL	1/20/1989	119.36
07020500	Chester, IL	3/9/1989	91.84
07020500	Chester, IL	4/10/1989	197.99
07020500	Chester, IL	5/28/1989	235.89
07020500	Chester, IL	10/3/1989	171.85
07020500	Chester, IL	11/20/1989	99.45
07020500	Chester, IL	1/7/1990	96.30
07020500	Chester, IL	7/2/1990	499.49
07020500	Chester, IL	9/4/1990	228.32
07020500	Chester, IL	10/22/1990	122.22
07020500	Chester, IL	3/31/1991	503.18
07020500	Chester, IL	4/16/1991	529.81
07020500	Chester, IL	7/5/1991	302.09
07020500	Chester, IL	8/22/1991	195.09
07020500	Chester, IL	8/24/1992	314.90
07020500	Chester, IL	10/11/1992	168.26
07020500	Chester, IL	4/21/1993	281.55
07020500	Chester, IL	7/26/1993	293.20
07020500	Chester, IL	9/28/1993	394.85
07020500	Chester, IL	10/1/1994	142.72
07020500	Chester, IL	1/21/1995	200.43
07020500	Chester, IL	3/10/1995	354.46
07020500	Chester, IL	3/26/1995	279.43
07020500	Chester, IL	4/27/1995	373.96
07020500	Chester, IL	6/30/1995	450.72
07020500	Chester, IL	7/16/1995	370.99
07020500	Chester, IL	8/1/1995	244.64
07020500	Chester, IL	2/9/1996	96.37
07020500	Chester, IL	7/18/1996	213.54
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07020500	Chester, IL	8/19/1996	215.82
07020500	Chester, IL	10/6/1996	161.99
07020500	Chester, IL	3/15/1997	333.93
07020500	Chester, IL	3/31/1997	201.90
07020500	Chester, IL	7/5/1997	420.22
07020500	Chester, IL	7/21/1997	225.77
07020500	Chester, IL	8/6/1997	137.58

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
07020500	Chester, IL	8/22/1997	164.78
07020500	Chester, IL	12/12/1997	108.72
07020500	Chester, IL	8/9/1998	288.82
07020500	Chester, IL	8/25/1998	163.58
07020500	Chester, IL	9/10/1998	185.87
07020500	Chester, IL	9/26/1998	152.11
07020500	Chester, IL	10/12/1998	495.74
07020500	Chester, IL	11/13/1998	362.32
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07020500	Chester, IL	8/4/1999	314.44
07020500	Chester, IL	8/12/1999	297.45
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07020500	Chester, IL	9/29/1999	127.97
07020500	Chester, IL	10/23/1999	90.61
07020500	Chester, IL	11/8/1999	85.37
07020500	Chester, IL	12/10/1999	77.49
07020500	Chester, IL	1/11/2000	74.67
07020500	Chester, IL	1/19/2000	92.28
07020500	Chester, IL	4/1/2000	138.66
07020500	Chester, IL	4/25/2000	156.37
07020500	Chester, IL	6/4/2000	245.18
07020500	Chester, IL	7/14/2000	381.09
07020500	Chester, IL	8/15/2000	144.33
07020500	Chester, IL	8/23/2000	134.18
07020500	Chester, IL	9/16/2000	131.86
07020500	Chester, IL	10/2/2000	116.59
07020500	Chester, IL	10/10/2000	134.14
07020500	Chester, IL	10/18/2000	115.21
07020500	Chester, IL	11/19/2000	105.01
07020500	Chester, IL	3/27/2001	377.27
07020500	Chester, IL	4/12/2001	423.07
07020500	Chester, IL	4/28/2001	319.45
07020500	Chester, IL	7/1/2001	380.91
07020500	Chester, IL	8/18/2001	149.39

USGS Gauge Station ID	Station Location	Date	Landsat Predicted SSC (mgL^{-1})
07020500	Chester, IL	9/11/2001	134.51
07020500	Chester, IL	9/27/2001	461.07
07020500	Chester, IL	10/29/2001	158.65
07020500	Chester, IL	11/6/2001	124.43
07020500	Chester, IL	11/14/2001	93.53
07020500	Chester, IL	12/24/2001	116.82
07020500	Chester, IL	1/25/2002	87.19
07020500	Chester, IL	3/6/2002	126.44
07020500	Chester, IL	3/22/2002	142.28
07020500	Chester, IL	4/23/2002	340.52
07020500	Chester, IL	5/9/2002	672.49
07020500	Chester, IL	7/20/2002	177.51
07020500	Chester, IL	7/28/2002	118.49
07020500	Chester, IL	8/21/2002	144.06
07020500	Chester, IL	9/6/2002	147.41
07020500	Chester, IL	10/16/2002	123.88
07020500	Chester, IL	10/24/2002	136.49
07020500	Chester, IL	11/1/2002	120.98
07020500	Chester, IL	11/17/2002	95.69
07020500	Chester, IL	1/20/2003	72.70
07020500	Chester, IL	4/2/2003	117.97
07020500	Chester, IL	4/10/2003	108.49

A Novel Artificial Hormone Receptor for the Sensing of Total Endocrine Disruptor Chemicals (EDCs) Concentration in Natural Waters

Basic Information

Title:	A Novel Artificial Hormone Receptor for the Sensing of Total Endocrine Disruptor Chemicals (EDCs) Concentration in Natural Waters
Project Number:	2017MO154B
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End Date:	2/28/2018
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Congressional District:	4
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Focus Categories:	Toxic Substances, Water Quality, Groundwater
Descriptors:	None
Principal Investigators:	Maria M Fidalgo, Chung-Ho Lin

Publication

1. Kadhem, A. J., S. Xiang, S. Nagel, C-H Lin, and M. Fidalgo de Cortalezzi*, Photonic Molecularly Imprinted Polymer Film for the Detection of Testosterone in Aqueous Samples, Polymers, (2018), 10(4), 349.

1. Title: A Novel Artificial Hormone Receptor for the Sensing of Total Endocrine Disruptor Chemicals (EDCs) Concentration in Natural Waters

2. Project Type: Research

3. Focus Categories: Toxic Substances (TS); Water Quality (WQL); Groundwater (GW)

4. Research Category: Water Quality

5. Keywords: endocrine disruptor chemical; molecularly imprinted polymers; water quality monitoring

6. Project Dates: 5/1/2016 - 4/30/2018

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Co-PI(s): Chung-Ho Lin, Research Assistant Professor, University of Missouri; Email: LinChu@missouri.edu

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Year 1 results:

1. ***Colloidal Crystals and Porous Films: Fabrication and Characterization***

We fabricated colloidal crystals by vertical deposition and self-assembly of silica particles obtained in the laboratory by the Stöber method. The particle sizes were characterized by Dynamic Light Scattering (DLS) and Scanning Electron Microscopy (SEM) with the ImageJ software (National Institutes of Health, NIH), resulting in diameters of 375± 7nm, 330±8nm, respectively. The relative standard deviation was less than 5%, therefore accepted for the intended application (Figure 1 (a)).

(a) (b)

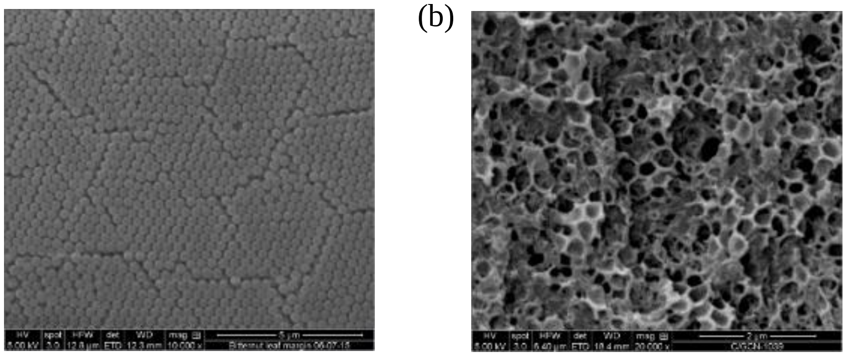

Figure 1. SEM images: (a) colloidal crystal; (b) porous polymeric film (molar ratio 1:0.1 of AA: EGDMA)

Obtaining a colloidal crystal of the needed dimensions (1.5 cm – 2 cm length) is a slow process when the deposition is conducted at room temperature, as we need to wait for the level of the ethanol suspension of silica particles drops by that same amount due to evaporation. However, fast deposition, as for example induced by reduced pressure or higher temperature, may lead to colloidal crystal growth limited by particle availability at the glass slide/suspension interphase , resulting in incomplete coverage and uneven layers. In this case, the film would lose its optical properties and detection by light reflection will not be feasible. Experiments at different temperatures / times showed that colloidal crystals with good order were achieved by self-assembly in the furnace at 50 ˚C for 24 hr. This method was used for the remainder of the experiments.

For the formulation of MIPs, mixtures were prepared from a functional monomer, EGDMA as crosslinker agent, AIBN as initiator, testosterone as the target molecule, and a solvent.

The monomers were polymerized under UV light at 365 nm for 3 hours at T = 25 °C . Then, the silica particles were removed by immersing the system for 12 hs in 5% hydrofluoric acid solution (Figure 1 (b)). after that the silica particles were removed by immersed the film inside (HF) 0.5 % for 12 hr and then wash by water and immersed in Acetic acid 0.1 M for 2 hr to remove the testosterone (Figure 1 (b)).

The properties of films from two different functional monomers were investigated: acrylic acid (AA) and methaacrylic acid (MAA). MAA was used as a comonomer in the mixture, at a 1:1 AA:MAA ratio. The addition of MA is expected to yield a more less hydrophobic polymer film which may result in slow response due to a decreased water absorption of the film and non-specific interaction with compounds; however, MA would improve mechanical strength and from more rigid, stable absorption cavities, which may have a beneficial effect in the recognition capacity. Poly-AA films are hydrogels and more hydrophilic than Poly-MAAA (comonomer); as such, they showed higher swelling ratios at neutral and basic environments. Contact angle measurements performed on nonporous thin films of 64 ± 2 ° for PAA and of 96 ± 2 ° for Poly-MAAA. The presence of MA made the films more manageable, as expected, due to the increased mechanical strength. The FTIR spectra were obtained for both polymers (Figure 2). The peaks at around 2955 cm^{-1} for both PAA and copolymer are associated with the methylene (– CH_2–). The bands due to the carbonyl group –C=O of PAA and copolymer overlap at 1737 cm^{-1}. The absence of the peaks at ~1600 cm^{-1} of unsaturated C=C stretch for both samples proves the absence of monomer impurities. The spectrum also displays bands at ~1450 cm^{-1} (scissors of CH_2), ~1230 cm^{-1} (OH bending of carboxyl group) and ~1170 cm^{-1} (C-O stretch).

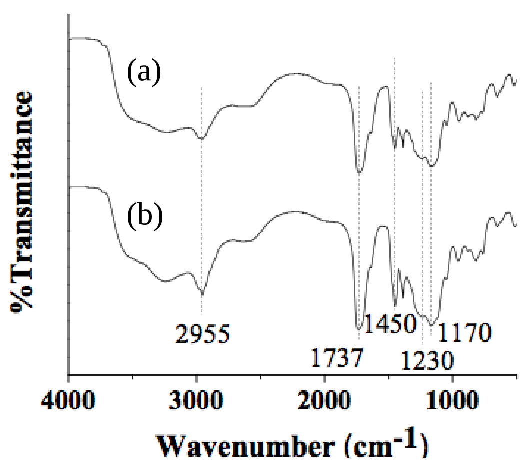

Figure 2. FTIR spectra of NIP-PMAAA (a) and NIP-PAA (b).

2. *Film incubation – Effect of template removal method and functional monomer*

One of the common pitfalls in MIP fabrication is related to the incomplete removal of the template molecule before use, which may give rise to leaching of hormone into the sample being tested and leads to bias in the sensor. We investigated different washing strategies by comparing the recognition capacities (RC) in mg of hormone bound after incubation for 24 hours per gram of imprinted film. The weight of MIP's used in this experiment was 60 mg.

The different washing schemes were as follows: (A) washing with 1:1 (V:V) acetic acid / ethanol (20 ml) for 30 min once; (B) washing with 1M acetic acid solution in ethanol 6 times, each one 20-30 min.; (C) washing with 1M acetic acid solution in ethanol 6 times (30 minutes), followed by 2 hour washing by methanol once.

The results are presented in Figure 3, for the three procedures and different initial concentrations of testosterone. Appraoch A gave the best results regarding RC. The films appeared to showed signs of damage by prolonged exposure to acetic acid, which may be partially responsible for the poor performance of the films subjected to extensive cleaning. In order to avoid this damage, the films were thoroughly rinsed with water after the treatment.

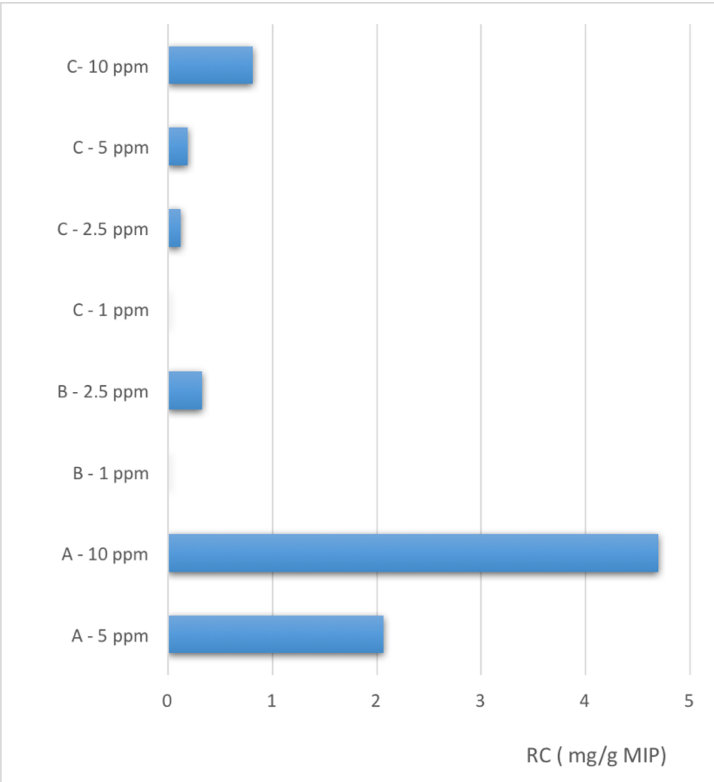

Figure 3. Recognition capacity of MIP films after target removal processes A, B, and C (see text for details)

The different monomers considered were used in the fabrication of MIPs and non-imprinted polymers (NIPs) with same morphology but lacking the specific binding pockets created by the target molecule. The films were subjected to the same incubation experiments. The RC value for the NIPs in an indication of the degree of non-specific binding and it is expected to be much lower than the MIPs RC. However, the Poly-AA films gave RC_{MIP}:RC_{NIP} ratios much higher than the other two materials (data not shown for brevity), so all experiments were continued with AA as the functional monomer.

3. Testosterone Attachment Kinetics

The kinetics of the capture of testosterone by a PAA MIP and NIP was investigated, and results presented in Figure 4.

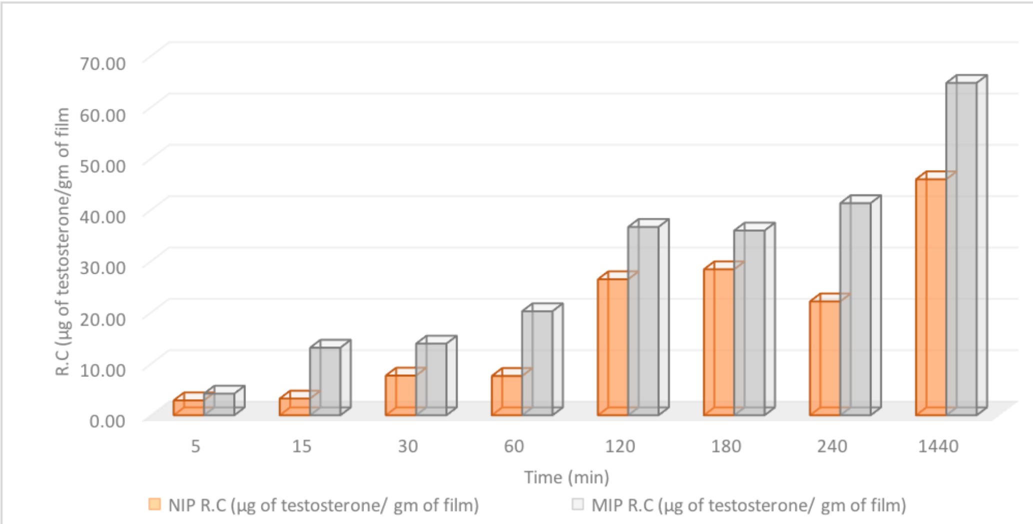

Figure 4. Observed RC for PAA MIPs and NIPs as a function of incubation time; Co= 5 mg/L testosterone.

Adsorption was consistently higher for the MIP, and also faster in the first minutes of the incubation. After 200 minutes, the increase in adsorption is proportional for both materials. Figure 3 shows the evolution of recognition capacity for both films. Although adsorption increases with time, the maximum RC_{MIP}:RC_{NIP} occurred at 15 minutes. At his time, the sensor exhibits the best specificity and it is also a reasonable time for practical purposes. We therefore propose that all sensor tests be performed at an incubation time of 15 minutes. We are currently performing further experiments to confirm this value.

4. *Testosterone Concentration Sensing by Reflectance Measurements*

We started work in order to determine our ability to quantify testosterone re binding to the film by measuring the spectra of the light reflected by the 3-D porous films, before and after incubation in the presence of the target molecule.

In this task, the binding of the target molecules was quantified through the change in diffraction properties of the ordered structure of the MIP. The diffraction peak λ_{max} for the porous hydrogel is determined by the Bragg equation :

$$\lambda_{max} = 1.633(d/m)(D/D_0)(n_a^2 - \sin\,\theta^2)^{0.5}$$

where *d* is the sphere diameter of the silica colloidal particle, *m* is the order of Bragg diffraction, (D/D_0) is the degree of swelling of the gel (D and D_0 denote the diameters of the gel in the equilibrium state at a certain condition and in the reference state, respectively), n_a is the average refractive index of the porous gel at a certain condition, and θ is the angle of incidence. Analyte adsorption into the binding sites results in a change in Bragg diffraction of the polymer.

UV-vis spectra of the films were recorded and their respective shifts in λ_{max} , before and after incubation, related to testosterone initial concentration in the sample. Reflectance of the photonic hydrogel films was measured over a wavelength range of 200–800 nm, using a double-beam UV–Vis–NIR spectrophotometer (Cary 60, Varian) with a Harrick Scientific's Specular Reflection Accessory (ERA-30G) for measurement reflectance at 30 degrees.

The spectra obtained before (clean) and after incubation in testosterone solutions of concentrations ranging from 5 ppm to 100 ppb are shown in Figure 5. Both the intensity of the reflectance and the wavelength of the peak changes with increasing concentration, and therefore is responsive to the amount or rebinding of the target molecule (Figure 5a). On the other hand, the peak of maximum reflectance remained constant under the same conditions for the NIPs films. The shift in the maximum wavelength is therefore associated with specific binding of the target molecule into the imprinted sites and it is not affected by the non-specific adsorption.

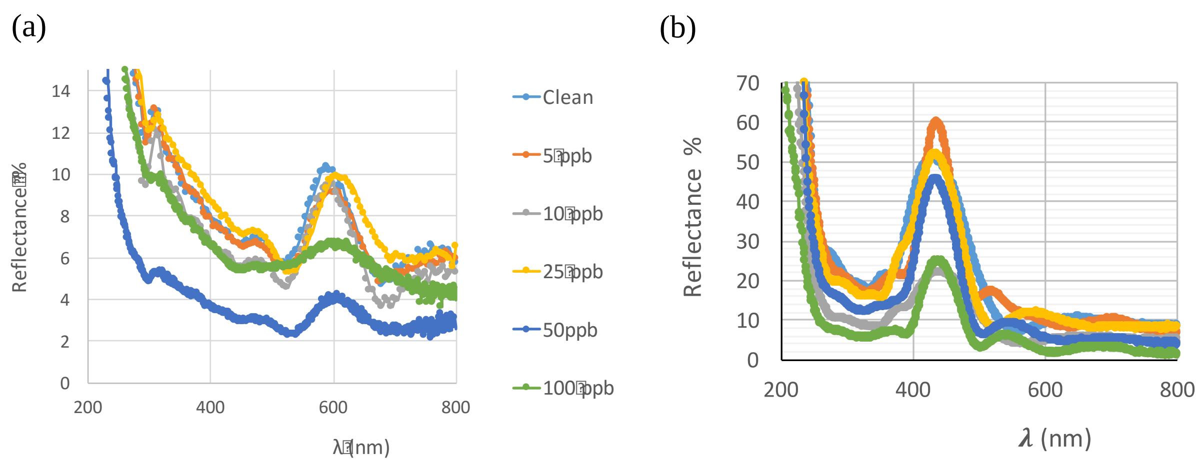

Figure 5. Reflectance spectra of PAA MIPs(a) and NIPs(b) after incubation in testosterone solution of variable concentration; incubation time= 30 minutes; initial concentration= 0 to 100 ppb testosterone.

The wavelength shift was calculated for each spectrum and compared to the one recorded before (clean) exposure to testosterone to calculate the shift induced at each concentration of target molecule. The response (shift) as a function of sample concentration is shown in Figure 6. The NIP films show negligible variation in maximum wavelength, but the MIP films' shift shows a linear correlation with initial concentration in the sample. The thickness of the sensor films used were very thin (micron range) and actual surface area per sensor was low enough so that the change in concentration due to binding on the polymer can be neglected; therefore, we can expect the measurement procedure to not affect the sample, i.e. initial and final concentration of testosterone in the liquid after the incubation period was assumed to be equal.
The linear relationship between the shift and sample concentration allows for the technique to be used for quantification of the testosterone level in solution.
We are currently working in follow up experiments to determine the detection limit and the quantification limit of the sensors in pure water conditions, as well as the influence of water matrix on the sensitivity of the technique.

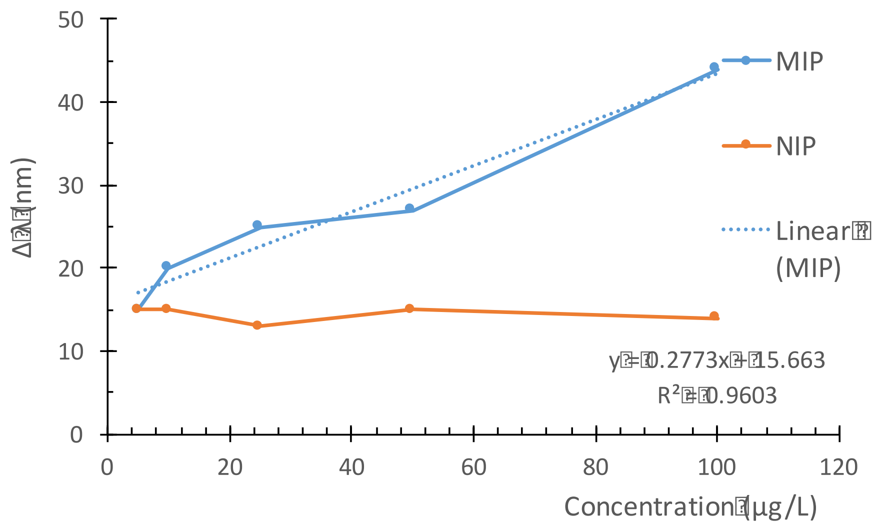

Figure 6. Maximum wavelength shift recorded after incubation at variable concentrations of testosterone, MIP and NIP films; linear fit for the MIP films response.

The cost effectiveness of the sensor is directly related to its shelf life and the possibility of reuse. Regarding the former, MIPs showed no evidence of degradation when store in the lab at regular ambient conditions even after more than 1 year of fabricated. The reuse was investigated, subjecting a film to several cycles of use and regeneration by solvent washing. The results of 12 consecutive uses of a single film are reported in Figure 7. Even after the 12^{th} rinse, the sensor is able to return to its original state and produces a similar response (maximum wavelength) than in the first use. These results indicate a high reusability for the material is expected.

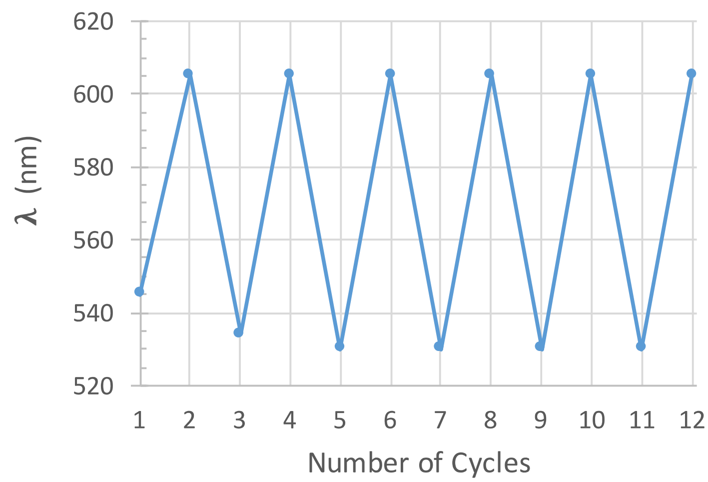

Figure 7. Sensor response after consecutive cycles of incubation and washing; sample testosterone concentration = 100 ppb; incubation time = 30 minutes; washing solvent: 9:1 ethanol:acetic acid.

Principal Findings and Significance:

We were able to successfully synthesize a molecular imprinted polymer using testosterone as the target molecule, through selection of the active monomer and the elution solvent.

In order to provide high surface area as required for fast re binding, the polymer was fabricated inside the void volume of a colloidal crystals. Silica particles of narrow size distributions were synthesized to grow the colloidal crystals and obtain a porous film supported on a plastic (PMMA) slide to be used as a sensor.

The MIPs showed significantly improved recognition capacity than the non-imprinted polymers with similar surface area, which indicates a predominance of specific over non-specific adsorption (binding in cavities rather than general surface adsorption).

We investigated the optical properties of the films for the assessment of re binding into the imprinted cavities. We found that the wavelength of the reflected light from the sensor is highly sensitive to re binding, and in particular the shift in wavelength displayed a linear relationship with sample concentration. Moreover, non-specific adsorption, as that occurring in non-imprinted polymer films, did not cause measurable variation in wavelength of reflected light, increasing specificity. These results indicate the possibility of using the films to quantify testosterone concentration in unknown samples.
Finally, we demonstrated the reusability of the fabricated sensor, which showed excellent reproducibility after up to 12 stages of use and regeneration.

Information Transfer Program Introduction

The Center maintained an active information transfer program that included: 1) coordination of the University of Missouri seminar program, 2) publication of Water Center newsletter, 3) interaction with state and federal water agencies, 4) Director served on various national and local water related boards, organizations and committees, 5) continued cooperation with district USGS office (representative on advisory committee), 6) maintenance and expansion of comprehensive web site, 7) making available of Center's publications, 8) responding to public requests and questions, 9) meeting with advisory committee to improve information transfer activities.

A

Technology Transfer

Basic Information

Title:	Technology Transfer
Project Number:	2017MO152B
Start Date:	3/1/2017
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Funding Source:	104B
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Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	Baolin Deng

Publications

There are no publications.

The Center maintained an active information transfer program that included: 1) coordination of the University of Missouri seminar program, 2) publication of Water Center newsletter, 3) interaction with state and federal water agencies, 4) Director served on various national and local water related boards, organizations and committees, 5) continued cooperation with district USGS office (representative on advisory committee), 6) maintenance and expansion of comprehensive web site, 7) making available of Center's publications, 8) responding to public requests and questions, 9) meeting with advisory committee to improve information transfer activities.

Coordination of Seminar Program

The Water Resources Research Center hosted a joint University of Missouri-Columbia seminar series throughout the year. In addition, other special seminars included speakers from out of state to speak on a variety of topics:

Friday, January 26, 2018 - 10:00 a.m., Monsanto Auditorium, Christopher S. Bond Life Sciences Center Convergence of Science: Linking Nanotechnology, Photonics, Biology, and Nuclear Technology to Impact Energy and Health Care, Dr. Para N. Prasad, Distinguished Professor of Chemistry, Physics, Medicine & Electrical Engineering Institute for Lasers, Photonics, & Biophotonics, University at Buffalo, The State of New York.

April 24, 2017 - E2511 Lafferre Hall at 1:00 p.m. Seminar on "Permeable Reactive Concrete," Megan Hart, is a nationally recognized expert on environmental geotechnical processes and in-situ remediation techniques and Missouri Registered Geologist.

February 10, 2017 – E2511 Lafferre Hall at 1:00 p.m., Managing Contaminated Sediments: Innovation in Biological Assessment to Support Remediation, Jeffery A. Steevens, Ph.D., Research Toxicologist, U.S. Geological Survey, Columbia Environmental Research Center.

Publication of the Water Center Newsletter

The Water Center newsletter is a yearly publication. The purpose of the Centers newsletter is to inform the scientific community as well as the public, of the activities of the Center, i.e., new research projects funded, and upcoming conferences. The Centers primary focus is on its own information transfer activities and the general scope of the projects that were funded. Highlights of the 2014 Newsletter can be seen on the Missouri Water Resources Research Center website at https://engineering.missouri.edu/research/user-facilities/water-research/ .

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	0	0	0	5
Masters	2	0	0	0	2
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	10	0	0	0	10

Notable Awards and Achievements

Publications from Prior Years

1. 2017MO154B ("A Novel Artifical Hormone Receptor for the Sensing of Total Endocrine Disruptor Chemicals (EDCs) Concentration in Natural Waters") - Articles in Refereed Scientific Journals - Kadhem, A. J., S. Xiang, S. Nagel, C-H Lin, and M. Fidalgo de Cortalezzi*, Photonic Molecularly Imprinted Polymer Film for the Detection of Testosterone in Aqueous Samples, Polymers, (2018), 10(4), 349.
2. 2009MO99B ("Visible Light-activated Titanium Dioxide-based Photocatalysts: Synthesis and Potential Environmental Applications ") - Articles in Refereed Scientific Journals - Oliver, Samantha, Sarah Collins, Patricia Soranno, Tyler Wagner, Emily Stanley, John Jones, Craig Stow, Noah Lottig, 2017, Global Change Biology,23-5455-5467.
3. 2009MO99B ("Visible Light-activated Titanium Dioxide-based Photocatalysts: Synthesis and Potential Environmental Applications ") - Articles in Refereed Scientific Journals - Collins, Sarah, Samantha Oliver, Jean-Francois Lapierre, Emily Stanley, John Jones, Tyler Wagner, Patricia Soranno, 2017, Ecological Applications (27(5), pp. 1529-1540.
4. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Articles in Refereed Scientific Journals - Hu, W.; Yin, J.; Deng, B.; Hu, Z. (2015) Application of nano TiO2 modified hollow fiber membranes in algal membrane bioreactors for high-density algae cultivation and wastewater polishing , Bioresource Technology, 193: 135- 141.
5. 2014MO145B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Articles in Refereed Scientific Journals - Ding, C.; J. Yin; and B. Deng, 2014, Effects of Polysulfone (PSF) Support Layer on the Performance of Thin-Film Composite (TFC), Journal of Chemical and Process Engineering, Vol 1102, Pages 1-8.
6. 2014MO145B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Dissertations - Wang, X. 2014, Ultrafiltration of surface water by poly(vinylidene fluoride) (PVDF)/TIO2 mixed matrix hollow fiber membranes (HFMs) with advanced antifouling properties under visible light irradiation, M.S. Thesis, Department of Chemical Engineering, University of Missouri, Columbia, MO, 58. Engineering, University of Missouri, Columbia, MO.
7. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Articles in Refereed Scientific Journals - Yin, J.; B. Deng, 2015, "Polymer-matrix nanocomposite membranes for water treatment", Journal of Membrane Science, 479, pp 256-275.
8. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Articles in Refereed Scientific Journals - Yang, Z.; Yin, J.; and Deng, B. (2016) Enhancing water flux of thin-film nanocomposite (TFN) membrane by incorporation of bimodal silica nanoparticles , AIMS Environmental Science, 3(2): 185-198.
9. 2013MO140B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinection Byproducts") - Articles in Refereed Scientific Journals - Wan, P.; Yin, J.; and Deng, B. (2017) "Seven-bore hollow fiber membrane (HFM) for ultrafiltration (UF)", Chemical Engineering Research and Design, 128, 240-247.
10. 2013MO140B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinection Byproducts") - Articles in Refereed Scientific Journals - Wan, P.; Bernards, M.; and Deng, B. (2017) "Modification of polysulfone (PSF) hollow fiber membrane (HFM) with zwitterionic or charged polymers", Industrial & Engineering Chemistry Research, 56(26), 7576-7584.
11. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Conference Proceedings - Nano Composite Membranes for Water Treatment , International Workshop of Computational Geodynamic Frontiers, Chinese Academy of Sciences Key Laboratory of Computational Geodynamics, Beijing, China, July 8 9, 2015.

12. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Conference Proceedings - Designing polymer-matrix nanocomposite membranes for water treatment and reuse , IPACES Annual Meeting, June 27 28, 2015, Nanjing, China.
13. 2015MO147B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Conference Proceedings - Designing polymer-matrix nanocomposite membranes for water treatment and reuse , IPACES Annual Meeting, June 27 28, 2015, Nanjing, China.
14. 2014MO145B ("Removal of NOMs by Advanced Thin Film Composite Membranes for the Control of Disinfection Byproducts") - Other Publications - Invited poster presentation to SciMix for the paper Fabrication and application of mixed matrix TiO2-PVDF membranes in algal MBR systems (Hu, W.; Yin, Y.; Hu, Z.; Deng, B.), 248th ACS National Meeting, San Francisco, CA, August 10-14, 2014.