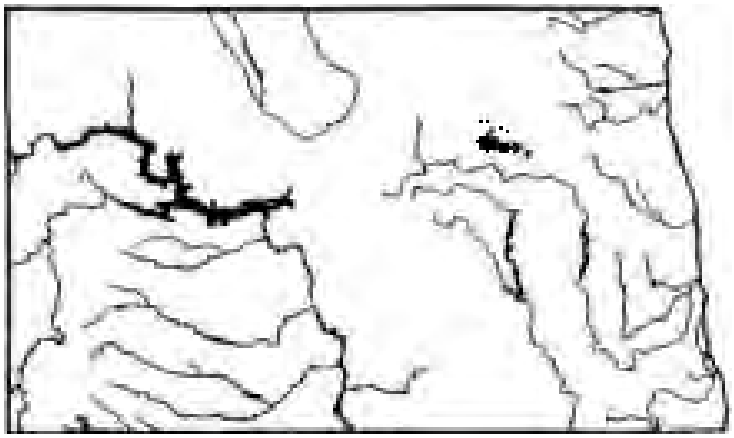

North Dakota
Water Resources Research Institute

North Dakota State University
University of North Dakota

ANNUAL REPORT

March 1, 2016 to February 28, 2017

Fiscal Year 2016 Report to the U.S. Geological Survey

June 1, 2017

Annual Report

Fiscal Year 2016 Report to the U.S. Geological Survey

Award No. G16AP00075
U.S. Geological Survey

Eakalak Khan, Director
North Dakota Water Resources Research Institute
North Dakota State University
Fargo, ND 58108-6050

June 1, 2017

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INTRODUCTION

This report describes the activities of the North Dakota Water Resources Research Institute (NDWRRI) during the period of March 1, 2016 to February 28, 2017.

The ND WRRI is one of the 54 institutes known collectively as the National Institutes for Water Resources. The NDWRRI was founded in 1965, by authority of Congress (Water Resources Research Acts of 1964, 1972, 1984, and 1990), and is administrated through the United States Geological Survey. Section 104 of the Water Resources Research Act requires the NDWRRI to apply its Federal allotment funds to:

1. Plan, conduct or otherwise arrange for competent research that fosters: (a) the entry of new research scientists into the water resources field, (b) training and education of future water resources scientists, engineers, and technicians; (c) the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena; and (d) the dissemination of research results to water managers and public.
2. Cooperate closely with other colleges and universities in the state that have demonstrated the capability for research, information dissemination and graduate training, in order to develop a statewide program designed to resolve State and regional water and related land problems.
3. Cooperate closely with other institutes and other organizations in the region to increase the effectiveness of the Institute and for the purpose of promoting regional cooperation.

This year (2016-2017), NDWRRI once again allocated its 104(B) resources to fund Graduate Fellowship research projects. The institute also continued its efforts to enhance communication between the State and Federal agency personnel and university faculty and students. NDWRRI also worked closely with the several departments/programs/schools at North Dakota State University (NDSU) such as Environmental and Conservation Sciences, Civil and Environmental Engineering, Agricultural and Biosystems Engineering, Industrial and Manufacturing Engineering, Chemistry and Biochemistry, Plant Sciences, and Natural Resource Sciences to facilitate water related research proposal collaborations.

The annual base grant amount received by NDWRRI was $92,335. The amount was used for administration and Fellowship awards. The Fellowship program was supported by the North Dakota State Water Commission with an additional amount of $18,850.

Program Management

The Institute continued the same administrative mechanism with a director managing the institute program with the help of a State Advisory Committee. Dr. Eakalak Khan, Professor of Civil and Environmental Engineering, has served as the director since March 1, 2015. Linda Charlton-Gunderson, a NDSU employee, has been working part-time for the Institute to assist the director with Institute finances, communications and information transfer. The State Advisory Committee consists of three members representing the three principal water agencies in North Dakota: State Water Commission, State Department of Health, and the U.S. Geological Survey North Dakota District. In addition, the Institute also seeks advices from the faculty of the two research universities of the State: NDSU and University of North Dakota (UND).

State Appropriation

The North Dakota State Water Commission (NDSWC) continued its support of 20.4% match ($18,850) to the 2016-2017 Graduate Research Fellowship program of NDWRRI under federal 104(B) funding. This is thirteenth year the NDSWC provided support to the Fellowship program.

University Support

North Dakota State University and the University of North Dakota administrations consider the NDWRRI activities important and are supportive of its efforts.

Institute Location

The Institute continues to operate from the Administrative Building of the College of Engineering of North Dakota State University in Fargo, North Dakota. The director may be reached at: ND Water Resources Research Institute, North Dakota State University, Civil and Environmental Engineering Dept. (# 2470), P.O. Box 6050, Fargo, ND 58108-6050, Phone: (701) 231-7717, Fax: (701) 231-6185, E-mail: eakalak.khan@ndsu.edu.

State Advisory Committee

The State Advisory Committee provided guidance on water resources research priorities in the State and region, and participated in the review and evaluation of research proposals and projects. The current committee members are:

1. Gregg Wiche, Former District Chief (Assigned by Current District Chief, Joel Galloway), U.S. Geological Survey, Water Resources Division, Bismarck, North Dakota
2. William Schuh, Water Appropriation Division, NDSWC, Bismarck North Dakota
3. Peter Wax, Water Quality Special Projects, North Dakota Department of Health, Bismarck, North Dakota

The committee members are senior officials in the three major agencies in North Dakota responsible for much of the water resources research done outside of NDSU and UND in North Dakota.

RESEARCH PROGRAM

Annual Base Grant (104-B)

For the last 16 years, NDWRRI has offered competitive fellowships to NDSU and UND graduate students for research on water resources topics under a Graduate Research Fellowship (GRF) program effectively using the modest amount of the 104(B) annual base grant. The program meets the requirements of Section 104 of the Water Resources Research Act of 1984. The fellowship program encourages entry of young university faculty and new research scientists and engineers into the water resources field; provides training and education to future water resource scientists and engineers; promotes exploration of new ideas that address water problems or expand understanding of water quantity, quality and related phenomena; and engages university faculty in collaborative research programs seeking supports from entities concerned with water problems.

This year also, the NDWRRI continued the GRF program and applied bulk of the federal allotment to it. The GRF program is administrated and monitored by the director. Applications are invited from the graduate students and their advisors of the two research universities of the State, NDSU and UND. A rigorous review by the State Advisory Committee and other water professionals in the state determines the awards. Active participation of the academic advisors of the students in meeting matching requirement and seeking co-funding from local, state and other sources is another positive aspect of the program. Periodical review of the progress of the students in meeting the fellowship expectations is ensured by seeking reports from the students and by encouraging them to make presentations in local, regional, and national technical seminars and conferences.

Guidelines for the 2016-2017 Graduate Research Fellowship were posted on the Institute website in the first week of October 2015, and the request for applications was announced in the faculty news publications of the two university campuses by the second week of October, 2015. The following is the request for application that was published on the UND and NDSU campus newsletters, and distributed by e-mail lists.

2016 ND WRRI graduate research fellowship applications invited

The North Dakota Water Resources Research Institute (ND WRRI) invites applications for its 2016 Graduate Research Fellowship program.

North Dakota State University and University of North Dakota graduate students who are conducting or planning research in water resources may apply for fellowships of varying duration, 3 months to one year. Typically in the past fellowship awards for master’s degree students have been in the range $800-$1,000 and for doctoral students it has been $1,000-$1,400 per month. The fellowship funds must be applied between March 1, 2016, and February 28, 2017. A technical completion report co-authored by the fellow and the adviser is expected of each fellowship research project.

Research proposed for fellowship support should relate to water resources issues in the state or region. Regional, state or local collaborations or co-funding will strengthen an application. Fellowships have a matching requirement of two non-federal dollars to one federal dollar. At the time of applying, applicants should have a plan of study filed and/or should have a thesis research topic selected. Applications need to be prepared in consultation with advisers. Advisers of the applicant should co-sign the applications. Applications from students and advisers who have not met the reporting requirements of their previous fellowship projects will not be considered for funding.

The general criteria used for proposal evaluation include scientific merit, originality, research related to state or region, and extent of regional, state or local collaboration and/or co-funding. The proposals will be reviewed by a panel of state water resources professionals. Announcement of awards will be made by early January subject to the appropriation of funds for the FY 2016 program by the federal government.

Consult the ND WRRI website, www.ndsu.edu/wrri, for background information on the program, and guidelines for preparation of applications. Applications are due by 5:00 PM, Wednesday, November 25, 2015. Submit original and four hard copies of applications to Linda Charlton, Family Life Center (FLC 320), NDSU Department 2030, P.O. Box 6050, Fargo, ND 58108-6050 and an electronic copy in Word format to eakalak.khan@ndsu.edu.

For additional information, contact Eakalak Khan at eakalak.khan@ndsu.edu or Linda Charlton at linda.charlton@ndsu.edu.

The above announcement appeared in NDSU News. An announcement similar in content was also published in the University of North Dakota campus publication University Letter.

NDWRRI Graduate Research Fellowships

In total, twenty applications were received. Thirteen were from NDSU and seven from UND. Out of twenty, eight (4 Ph.D. and 4 M.S.) are for renewal and twelve (2 Ph.D. and 10 M.S.) are new applications.

Approximately $69,000 was available for Fellowship projects from the annual base grant. An additional support of $18,850 came from NDSWC. Fellowships ranging from $1500 to $10,000 were awarded to fifteen graduate students, 5 Ph.D. and 10 M.S., conducting research on water resources topics at NDSU and UND. Selection of student Fellows and the award amounts were based on competitive proposals prepared by the students with the guidance of their advisers. A panel of state water resource professionals and the director reviewed the proposals and selected Fellows. The award amounts are based on the quality of proposals and the priority of the proposed projects for the state and region.

2016-17 ND WRRI Fellows, academic programs, university, faculty advisers, and Fellowship research projects are:

1. *Alexis Steinman, Natural Resources Management, NDSU, Dr. Christina Hargiss (School of Natural Resource Sciences), A Comparison of Wetlands across the Urban - Peri-Urban - Rural Gradient

2. Boonsiri Dandumrongsin, Environmental and Conservation Sciences, NDSU, Dr. Halis Simsek (Department of Agricultural and Biosystems Engineering), Contribution of Soluble Microbial Products on Dissolved Organic Nitrogen and its Biodegradability in Wastewater Effluent

3. Debjit Roy, Agricultural and Biosystems Engineering, NDSU, Dr. Xinhua Jia (Department of Agricultural and Biosystems Engineering), Snowmelt Water Infiltration into Frozen Soils in the Red River of the North Basin

4. *Luisa Torres, Environmental Engineering, NDSU, Dr. Eakalak Khan (Department of Civil and Environmental Engineering) and Dr. Om Yadav (Industrial and Manufacturing Engineering), Holistic Risk Assessment of Surface Water Contamination Due to Lead-210 Found in Produced Water from Unconventional Oil Production in North Dakota

5. Mohammad Hossain, Environmental and Conservation Sciences, NDSU, Dr. Achintya Bezbaruah (Department of Civil and Environmental Engineering), Biopolymers for Phosphate Removal from Eutrophic Lakes

6. *Marina Martin, Environmental and Conservation Sciences, NDSU, Dr. Eakalak Khan (Department of Civil and Environmental Engineering) and Dr. John McEvoy (Department of Microbiological Sciences), Tamoxifen and Endoxifen Detections in Wastewater and Receiving Waters in North Dakota

7. *Soklida Hong, Environmental and Conservation Sciences, NDSU, Dr. Eakalak Khan (Department of Civil and Environmental Engineering) and Dr. Jayaraman Sivaguru (Department of Chemistry and Biochemistry), Glutaraldehyde Removal from Flowback and Produced Water Using Photolysis

8. Swati Sharma, Agricultural and Biosystems Engineering, NDSU, Dr. Halis Simsek (Department of Agricultural and Biosystems Engineering), UV Light Effect on Bioavailability of Dissolved Organic Nitrogen in a Trickling Filter Process

9. Tong Lin, Agricultural and Biosystems Engineering, NDSU, Dr. Zhulu Lin (Department of Agricultural and Biosystems Engineering), Assessing the Impacts of Hydraulic Fracturing at Bakken on Regional Water Resources

10. Umma Salma Rashid, Civil Engineering, NDSU, Dr. Achintya Bezbaruah (Department of Civil and Environmental Engineering), Injectable Nanoparticle-based Permeable Reactive Barriers for Groundwater Contaminant Remediation

11. *Ursinio Puga, Environmental Engineering, NDSU, Dr. Wei Lin (Department of Civil and Environmental Engineering), Comparative Ultraviolet Disinfection Study for Wastewater Applications for the City of Fargo, North Dakota

12. Afshin Shabani, Earth System Science and Policy, UND, Dr. Xiaodong Zhang (Department of Earth Systems Science and Policy), Modeling Water Balance and Flows of Sediment and Nutrient in Devils Lake Watershed Using SWAT

13. Bahareh Shoghli, Civil Engineering, UND, Dr. Howe Lim (Department of Civil Engineering), Impacts of Climate Change on Embankment Dams in the Upper Midwest Region: Critical Design Parameters and Adaptation Measures

14. Benjamin York, Geology and Geological Engineering, UND, Dr. Philip Gerla (Harold Hamm School of Geology & Geological Engineering), Effect of Glacial Isostatic Adjustment on Rivers and Drainage Basins in the Red River Valley

15. Courtney Jackson, Geography and Geographic Information Science, UND, Dr. Paul Todhunter (Department of Geography and Geographic Information Science), Effects of Climate Change, Agricultural Land Use Change, and Dynamic Contributing Area on Streamflow Input to Devils Lake: A Case Study of the Mauvais Coulee Sub-Basins

* Fellowship co-funded by NDSWC

Modeling Water Balance and Flows of Sediment and Nutrient in Devils Lake Watershed Using SWAT

Project Number: 2016ND304B
Fellow: Afshin Shabani
Adviser: Xiaodong Zhang
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Shabani, A.; X. Zhang; M. Ell, 2017, Modeling Water Quantity and Sulfate Concentrations in the Devils Lake Watershed Using Coupled SWAT and CE-QUAL-W2, Accepted for Publication in Journal of American Water Resources Association.

Research Description

Devils Lake is an endorheic lake in the Red River of the North basin in northeastern North Dakota. Its proximity to the 100th meridian – a theoretical line that divides the North American continent into a generally wet region to the east and a dry region to the west – might be the reason for its significant precipitation fluctuation over time. Since the end of the last glaciation about 10,000 years ago, the alternating dry and wet cycles in the region dramatically changed the water level several times, varying from low to overflowing. The recent wet cycle that started in 1993 has raised the water level by nearly 10 m, reaching a record high of 443.3 meters above sea level on June 27, 2011. At a level of 444.7 meters above sea level, it would spill naturally and catastrophically into the Sheyenne River, which flows via the Red River into Lake Winnipeg, Manitoba, Canada. Because Devils Lake city and the adjacent communities are built within the historical confines of the lake, the rising lake level has inundated farm lands and caused significant damage to both infrastructure and the community. Over one billion USD have been spent in mitigation measures, including upper basin water management to reduce runoff, continuing infrastructure protection, and developing emergency outlets.

However, releasing water through the Devils Lake outlets is controversial because the water contains a significantly higher concentration of dissolved solids, particularly sulfates, than the surrounding water bodies. The impaired water quality is largely due to the fact that Devils Lake is a terminal lake, so it accumulates nutrients, sediment, and other dissolved solids entering from the watershed that has been primarily used for agricultural production. Because of its high salt concentration, the water is not suitable for irrigation. The concerns about artificially pumping water from Devils Lake to the Sheyenne River have led the Government of Manitoba to file a lawsuit in the United States court and the International Joint Commission to address a potentially detrimental impact on the water quality of Lake Winnipeg, which supports the largest freshwater commercial fishery in Western Canada and a thriving tourism industry for Manitoba.

Significance of Research

The rising water level in Devils Lake has raised concerns regarding both water quantity and quality; however, most of the previous studies on the Devils Lake flooding have been focused on its water balance. The goal of this study is to better understand how the water quality of the lake, particularly its sulfate concentration, changes with a rising water level by simulating both water quantity and quality. We further analyzed impact of artificial pumping on the water quality of the Sheyenne River. The SWAT and CE-QUAL-W2 models were selected for this simulation because of their proven capacity in simulating hydrology (SWAT) and water quality (CE-QUAL-W2) in tributaries and lakes. To the best of our knowledge, the spatial distribution and temporal changes of the sulfate concentration in Devils Lake have never been simulated before. The results of this study will aid in water management and decision making to mitigate Devils Lake flooding and the impact on downstream rivers.

Significant Findings

The coupled model performed well in simulating daily flow in tributaries with $E_{NS} > 0.5$ and $|PBIAS| < 25\%$, and reproduced the lake water level with a root mean square error of 0.35 m for the study period from 1995 to 2014. The water temperature and sulfate concentration simulated by coupled model for the lake are in general agreement with the field observations. The model results show that the operation of the two outlets since August 2005 has lowered the lake level by 0.70 m, while raised sulfate concentration in the Sheyenne River from ~100 to >500 mg l^{-1}. However, the coupled model simulation shows increasing sulfate concentration of Devils Lake from west to east, which makes operation of the east outlet more of a concern for degrading the water quality in the Sheyenne River. One possible solution proposed by this study to mitigate Devils Lake water level and Sheyenne River water quality degradation is to reduce the east outlet operation to < 8 m^3 s^{-1} and upgrade the west outlet capacity by at least 2 m^3 s^{-1}. This scenario would meet the ND state standard of 450 mg l^{-1} for stream Class IA.

Impacts of Climate Change on Embankment Dams in the Upper Midwest Region: Critical Design Parameters and Adaptation Measures

Project Number: 2016ND306B
Fellow: Bahareh Shoghli
Adviser: Yeo Howe Lim
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Shoghli, B.; Y.H. Lim; J. Alikhani, 2016, Evaluating the Effect of Climate Change on Design Parameters of Embankment Dams Using Remote Sensing:Data Case. in World Environmental & Water Resources Congress 2016, American Society of Civil Engineers, Reston, VA.

Research Description

Dams are the most important component of water resource systems found in many places. Water is stored and regulated by dams such that the development objectives of water supply, agriculture, manufacturing industry, energy generation, and other sectors are met. The impacts of climate change on the water resources distribution has been projected as one of the major problems in the next fifty years (U.S. Global Change Research Program, 2000). However, the adaptations to mitigate the changes still seriously lacking in many critical infrastructural systems. Embankment dams are very common in the U.S., hence a large number of these dams will be affected should there be a change in the climate regime.

Climate change can affect the dams and their performance through alterations of the hydrologic cycle. In an extreme scenario, warmer temperature accompanied by more precipitation could lead to larger snowpack and earlier spring melting of snowpack, which could increase the elevation of runoff in the basin. Conversely, lower temperatures accompanied by lesser precipitation could decrease the snowpack and delay the spring melting of the snowpack, which in turn, could lead to a reduction in the runoff within the basin. Both these extreme scenarios, along with other climate-change scenarios, could alter the basin water balance spatially and temporally. Sedimentation is an on-going natural process that will reduce the life-span of dams. Given the possibilities of an induced change in the hydrologic cycle, the rate of sedimentation will certainly be affected. In the assessment of climate change, three critical change factors are to be considered: (1) the magnitude and variability of rainfall and streamflow, (2) the magnitude and severity of extreme flood and storm events, and (3) the changes in vegetation and land use.

Many dams were designed and built at the beginning of the last century. Some specific questions to be answered would include: (1) how would the dams perform under a possible new climate regime. (2) to what extent is the safety of the dams being compromised under the new hydrologic regimes? (3) how the induced changes in the sedimentation rate in the basin may influence the operation of dams in return to the dam safety issue?

Significance of Research

Climate change can affect the dams and their performance through alterations of the hydrologic cycle. Warmer temperature accompanied by more precipitation could lead to larger snowpack and earlier spring melting of snowpack, which could increase the flood peaks in the basin. Conversely, lower temperatures accompanied by lesser precipitation could decrease the snowpack and delay the spring melting of the snowpack, which in turn, would lead to a decrease in peak discharges within the basin. Both scenarios, along with other climate-change scenarios, could alter the other basin-runoff associated processes. Reservoir sedimentation is a complicated process that depends on the watershed sediment production, flood frequencies, reservoir geometry and operation flocculation potential, sediment consolidation, density currents, and land use changes over the life expectancy of the reservoir. Accumulated sediment behind the dams can affect the flood attenuation function of the reservoir. As a result, the ecosystem of the river will change. Understanding the sediment dynamics and identifying the main effective parameters on erosion of soil are necessary to optimize the strategies for minimizing sediments entrance. Prediction of sediment deposition is always needed in the planning, design and operation stages of reservoir.

Significant Findings

Construction of a dam leads to the creation of an artificial reservoir, which normally decreases the flood peak discharge downstream of the dam. However, climate change will increase the magnitudes of extreme flood peak events generated by hydrologic processes at the upper watershed, which may result in an increased probability of overtopping the dam. In the first step of this study, ArcSWAT model was established for Sheyenne-Lake Ashtabula watershed area and the calibration- validation of hydrologic runoff from the watershed was performed using SWAT-CUP. Statistical results in terms of NSE and PBIAS have allowed us to infer our simulation as in the category of “good simulation.” Because of the special climatic conditions in North Dakota, there are discrepancies among observed and simulated data during a few extreme spring-melt events. Artificial neural networks were employed to improve the deficiencies of the software used in modeling the snowmelt process.

Effect of Glacial Isostatic Adjustment on Rivers and Drainage Basins in the Red River Valley

Project Number: 2016ND307B
Fellow: Benjamin York
Advisor: Phil Gerla
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

This research investigates the relationship between glacial isostatic adjustment and watershed asymmetry of tributaries in the Red River Valley, North Dakota, U.S.A. After the draining of glacial Lake Agassiz, channel networks began to develop and were affected by isostatic adjustment. This adjustment began after the recession of the Laurentide Ice Sheet and is still occurring today, but on a lesser degree. Adjustment in the Red River Valley, which has varied since the ice sheet retreated, is determined from differences in the elevation of the horizontally deposited beach ridges which are the ancestral beaches of glacial Lake Agassiz. The Red River Valley is currently experiencing 1 to 4 mm of uplift a year.

Untested in the Red River Valley is the concept that large-scale isostatic adjustment influenced the pattern and development of post-glacial rivers and watersheds. Because isostatic adjustment was greatest where ice was the thickest in the northern valley and least in the southern valley, watersheds should be more asymmetrical, with the main river channel offset from the center of the watershed, the farther north they are positioned in the valley. The purpose of this thesis is to determine if tributaries within the former glacial Lake Agassiz basin are asymmetric. The study further documented if asymmetry was the result of 1) changing watershed boundary; 2) a shifting river channel position; or 3) a combination of both a changing watershed boundary and a shifting river channel. Asymmetry of each watershed was determined by comparing the following landscape measurements: Transverse Topographic Symmetry Factor (TTSF), Asymmetry Factor (AF), and the total net change between pre-adjustment watersheds and current watersheds. Along with the measurements listed above, paleo-channels were identified in the Red River Valley to determine if there has been a uniform shift in drainage between Lake Agassiz stages and isostatic adjustment.

Significant of Research

The results of this study suggest that asymmetry in the watersheds is the result of a changing watershed boundary and a shift in river position, likely associated with glacial isostatic adjustment. The combination of TTSF and AF values, pre-adjustment watershed net change, and location of paleo-channels could help quantify the relationship between glacial isostatic adjustment and watershed development. I believe that these methods can be used to investigate isostatic adjustment on tributaries in other landscape settings.

Significant Findings

Twelve of the sixteen watersheds (Forest, Goose, Otter Tail, Park, Rush, Sand Hill, Snake, Tamarac, Turtle, Two Rivers, and western Wild Rice) analyzed in this thesis have TTSF values that are positive, while the remaining four watersheds (Buffalo, Maple, Red Lake, and Wild Rice) have negative values. A higher positive value indicates a river that lies farther north relative to the center of the watershed. Watersheds displaying the most asymmetry based on TTSF are farther north in the Red River Valley. Similarly, AF values reveal that the most asymmetric watersheds are also located near the northern part of the Red River Valley and suggest greater tilting has occurred, compatible with isostatic adjustment. Furthermore, analysis of the change in watershed boundaries revealed that all but one displays a northward shift in watershed boundary. Finally, paleo-channels were identified and associated with the current Turtle, Elm, Sand Hill, Buffalo, western Wild Rice, and Maple rivers, which flowed into the paleo-Red River. Six of the seven paleo-channels identified lie north of their current river channel, showing that rivers have shifted south. These results suggest that the asymmetry identified using the TTSF and AF values would result from a shifting river rather than a shifting watershed. This does not imply that a shift in watershed did not take place, but rather that the asymmetry observed is not solely the result of a change in watershed boundary.

Effects of Climate Change, Agricultural Land Use Change, and Dynamic Contributing Area on Streamflow Input to Devils Lake: A Case Study of the Mauvais Coulee Sub-Basin

Project Number: 2016ND308B
Fellow: Courtney Jackson
Adviser: Paul Todhunter
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Jackson, Courtney, 2017, Assessment of Climate Change and Agricultural Land Use Change on Streamflow Input to Devils Lake: A Case Study of the Mauvais Coulee Sub-basin, M.S. Thesis, Department of Geography, University of North Dakota, Grand Forks, ND.

Research Description

First, we investigated the basin land cover and land use. We used the National Wetlands Inventory dataset, and a Topographic Wetness Index developed from the 30 m, 10 m, and 3 m digital elevation models to identify the abundance and spatial distribution of wetlands within the Mauvais Coulee. This showed an abundant number of wetlands in the study area. Then we created a county-level time series of agricultural land use in Towner County for 1955-2012, and maps of agricultural land use for 1998 and 2015 from the USDA National Agricultural Statistics Service CropScape Crop Data Layer database. The results showed widespread agricultural development over the study area, and substantial intensification of agricultural land use since 1980, including a decrease in all hay and small grains coverage, and an increase in row crop.

Second, we created a hydroclimatic database for the Mauvais Coulee. Annual areal precipitation (1956-2015, mm) was estimated from monthly precipitation totals from the PRISM dataset, and weighted by sub-basin area. Annual potential evapotranspiratin (1956-2015, mm) was estimated from monthly Tmax and Tmin data from the PRISM dataset using the Hargreaves equation. Monthly streamflow (1956-2015, cfs) was downloaded from the USGS Water Data for the Nation web interface and converted to annual runoff depth (mm). Annual runoff ratio (1956-2015, %) was derived as a secondary variable from the areal precipitation and runoff depth time series.

Third, we selected the ecohydrological approach (conceptual model) developed by Tomer and Schilling (2009), and the Zhang et al. (2001) implementation of the Budyko framework to partition streamflow change (ΔQ) into climatic and human components. The ecohydrological approach provides a qualitative estimate of the partitioning based upon computed values of water excess (Pex) and energy excess (Eex). The Budyko approach provides quantitative estimates of the climatic (ΔQc) and human components (ΔQh) of ΔQ. Selection of the division of the study period into baseline and post-change periods followed standard procedures in the literature based upon streamflow change (1992 was the division year).

Fourth, results from the two methods were obtained and evaluated.

Significance of Research

Temporal trends in streamflow can be driven by natural climate forcing or by landscape forcing attributable to human modification of the landscape. Human drivers of hydrological variables in the Prairie Pothole Region include the original land cover change from native grasslands to crop covers, land use change from small grains and forage crops to more intensive row crop cultivation, agricultural drainage, wetland drainage, installation of tile drainage, development of more productive crop cultivars, and changes in land management.

Numerous methods are available to attempt to separate the individual effects of natural climate variation from human landscape change upon the streamflow record. These methods include statistical regression approaches, physically-based modeling, application of the SWAT model, the ecohydrological approach, and various implementations of the Budyko Hypothesis. These later two approaches, in particular, have been frequently implemented, with dozens of papers in the hydrological literature over the 15+ years. Both approaches are based upon a formulation of the annual water balance equation in which storage change (ΔS) is assumed equal to zero. Further, they identify a baseline period within which streamflow variation is assumed to be driven only by climate variations ($Q = f(climate)$), and a post-change period, in which both climate and human drivers operate ($Q = f(climate, human)$). Both approaches utilize relationships established during the baseline period to partition changes in streamflow during the baseline and post-change periods (ΔQ) into climate and human components (ΔQc, ΔQh). Thus, stationarity of climate during the baseline and post-change periods is assumed. Demonstration of the suitability of these approaches to the Prairie Pothole Region would provide a helpful tool to water resource managers.

Significant Findings

Both the ecohydrological and Budyko framework approaches produced physically unrealistic findings for the Mauvais Coulee streamflow record. In particular, the Budyko approach estimated that 90 percent of the change in streamflow was due to human factors. This is, by far, the largest percentage reported in the literature using this methodology. Several factors made these approaches unsuited to the Devils Lake Basin, in particular, and the glaciated plains, more generally. First, the period-of-record for streamflow at Mauvais Coulee (1956-2015) samples a period of non-stationary climate. The data show that the region experience a shift between two hydroclimate modes, as suggested by the paleoclimatological and historical records. The baseline and post-change periods traverse two separate climate modes, making the baseline period an unsuitable period from which to estimate streamflow changes during the post-change period. All such approaches must demonstrate climatic stationarity, and not assume it. Second, the streamflow record at Mauvais Coulee experiences a non-linear precipitation-streamflow relationship. This results from two major factors. First, the assumption that ΔS is zero over the study period is clearly not satisfied. The study covers a drought to deluge period in which groundwater and vadose zone storage is emptying during the earlier portion of the study period, and filling during the latter portion of the study period. Thus, the sensitivity coefficients of

streamflow to precipitation and potential evapotranspiration are incorrect estimates in both periods. Second, the study area experiences principles of fill-spill hydrology, such that wetland complexes are not filled nor connected to one another in the earlier portion of the study, but progressively experience greater filling and connectivity during the latter portion of the study. The effective basin area contributing to measured streamflow is dynamic over time, and often substantially less than the gross basin contributing area.

A Comparison of Wetlands across the Urban - Peri-Urban - Rural Gradient

Project Number: 2016ND309B (co-funded by NDSWC)
Fellow: Alexis Steinman
Adviser: Christina Hargiss
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

This study assessed wetlands across the rural, peri-urban, and urban gradient for the first time in the region to determine the impacts of urbanization on water quality and vegetation composition. A combination of thirty wetlands were randomly selected and classified based on current land use and ground cover. Rural wetlands were classified as areas with limited human development such as roads. Urban wetlands within this study were constructed storm water retention basins utilized for artificial management of storm flows in the cities of Fargo and West Fargo. These sites were highly altered, and usually did not have established vegetation within the wet meadow and shallow marsh vegetative zones due to the presence of riprap. Peri-urban wetlands typically occurred along the semi-developed urban fringe or the transitional zone between the undeveloped rural environment and the densely developed urban environment.

Research for this study included a vegetation survey and water quality assessment. A vegetation survey was completed in July and August 2015 to create a comprehensive species list across the gradient. A 1.0 m^2 quadrat was distributed clockwise throughout the low prairie, wet meadow, and shallow marsh vegetative zones of each wetland. Individual plant species found within the quadrat were identified and given a percent aerial cover. Water quality samples were gathered in compliance with North Dakota Department of Health protocol. Samples were obtained once per month, July through September 2015 and April through September 2016, from each of the study's 30 sites. Water quality parameters measured during the lab analysis include total suspended solids (TSS), nutrients complete (TKN, $NO_{2\text{-}3}$, $NH_{3\text{-}4}$, and P), nutrients complete dissolved, major cations and anions, trace metals, and E. coli. Additional measurements were recorded in the field using a Yellow Spring Instrument Co. YSI model 650 MDS data logger combined with a model 600 QS Sonde to measure temperature, electrical conductivity, pH, and dissolved oxygen.

Significance of Research

Information from this study is useful to wetland professionals across the globe as urban development and sprawl continue to influence land use. Limited research has been conducted on urban wetlands nationally and internationally. Research efforts have never focused on urban or peri-urban wetlands in North Dakota. This project provided the first opportunity to establish: 1) the first understanding of urban wetlands in North Dakota; 2) baseline data on urban and peri-urban wetland water quality; 3) a complete survey of vegetation composition across the gradient (annual/ biennial/ perennial, introduced/native); and 4) an initial comparison of wetlands across the rural, peri-urban, and urban gradient in North Dakota.

Significant Findings

Wetland water quality parameters differed spatially across the rural, peri-urban, and urban gradient and between sampling time periods. These findings indicate a relationship between urban development and water quality, and stresses the importance of taking samples on a regular basis to assess water quality changes over time. Water quality parameters results at peri-urban and urban sites were significantly different than at rural sites. Unexpectedly, water quality parameters gathered at the peri-urban wetlands were consistent and similar between sampling periods, whereas the parameters from rural and urban wetlands were highly variable. Further research is necessary to determine if peri-urban wetland sites have the potential to become useful tools to buffer disturbances from urban development. Wetland vegetation differed by zone and as a whole across the rural to urban gradient. Anthropogenic disturbances and alterations influenced the plant species distribution and composition of the study's thirty wetlands. Species richness increased within the peri-urban wetlands due to intermediate levels of disturbance and the introduction of ornamental species, whereas species richness declined in the urban wetlands in comparison to rural wetlands.

Contribution of Soluble Microbial Products on Dissolved Organic Nitrogen and its Biodegradability in Wastewater Effluent

Project Number: 2016ND310B
Fellow: Boonsiri Dandumrongsin
Adviser: Halis Simsek
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

According to intensive growing in water demand, lowering wastewater pollution level is very important and challenging in order to achieve water security toward a sustainable way. Overloading of nutrient in receiving waters can cause problems in downstream since excess amount of nitrogen (N) in aquatic systems causes eutrophication and rapid depletion of oxygen. Therefore, N compounds often become a limiting nutrient for aquatic plants. In order to be able to lower effluent total dissolved nitrogen (TDN) level, all forms of organic nitrogen including particulate, colloidal and dissolve organic nitrogen (DON) in treated effluent need to be removed. DON in treated effluent mainly consists of non-biodegraded transformed nitrogen from cell degradation and activities in biological wastewater treatment process.

Treated effluent from biological wastewater treatment system contains a number of organic compounds delivered from different sources including slowly degradable organics in wastewaters and microbial products released during biological processes (substrate utilization and cell lysis). Soluble microbial product (SMP) is categorized into two sub-categories based on the types of bacterial metabolism by which it is originated from utilization-associated products (UAP) and biomass-associated products (BAP). UAP is produced directly from substrate utilization while BAP is originated from biomass hydrolysis. BAP is speculated to contribute for at least a part of effluent dissolved organic matters (EfOM) as DON and dissolved organic carbon (DOC). In biological treatment process, the factor which affects biofilm characteristics should be influenced on DON, biodegradable DON (BDON), and SMP. Therefore, the condition that impact on contribution of SMP on DON and BDON is important to study for a better understanding of the relationship between microbial activity and DON to minimize effluent TDN.

In this research, the contribution of SMPs on EfOM, including DON, DOC and their biodegradability under different organic loading rates (OLRs) were investigated. Synthetic domestic wastewater and actual primary domestic wastewater from the Fargo wastewater treatment plant were used to feed lab-scale moving bed biofilm reactors (MBBRs).

Significance of Research

Over past decade, wastewater treatment plants have used advanced nutrient removal technologies to meet the more demanding discharge standards. The major portion of inorganic nitrogen has been removed using these technologies, hence the major portion of effluent TDN is DON. Understanding the characterization of DON is critical since DON consists of complex and

uncharacterized molecules. The proposed research elucidates the relationship between SMP and DON. Although the occurrence and characteristics of SMPs in biological treatment systems has already been investigated, there is lack of information regarding their relationship with DON. Formation and characterization of SMPs by using four laboratory-scale biofilm reactors have been explored. Presently, there is limited knowledge on how DON biodegradation can be increased by controlling SMPs, which can be controlled either during the substrate metabolisms or from cell lysis during biomass decay. The results from this study will benefit to water quality managers and scientists in improving water quality in wastewater industry.

Significant Findings

The lab-scale MBBR removed more than 80% of soluble chemical oxygen demand (SCOD). The synthetic wastewater fed reactors can remove SCOD up to 90% due to glucose was used as a C-source. Proteins are found as a major component (50 - 80%) of SMP. The result of this study by measuring protein and carbohydrate concentrations showed that the amount of SMPs is increasing proportionally with organic loading rate (OLR). Excitation–emission matrix (3DEEM) fluorescence results showed that the small protein structure like amino acids are found in the influent but not found in the effluent while humic acids are found in the effluent. This result suggests that EfOM was mainly produced during the biological treatment system. Organic matter concentration in the effluent decreased since it was used as nutrients. Similarly, the amount of organic matter produced was less than uptaken by bacteria during biological treatment process. However, the residue organic matter in the effluent shows more complexity than the influent organic matter as evidenced by increasing of aromaticity. Humic acid can be found in the effluents of both the synthetic and raw primary wastewater. However, humic acid concentration in the effluent of the raw primary wastewater was higher. OLR and temperature were found having an important effect on organic removal efficiency of the system and protein was released more when having higher concentrations of toxic substances present in the system.

Snowmelt Water Infiltration into Frozen Soils in the Red River of the North Basin

Project Number: 2016ND311B
Fellow: Debjit Roy
Adviser: Xinhua Jia
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

Frozen soil is a key component which has direct effects on infiltration and indirect effects on heat transfer from and to snowpack lying on the soil surface in cold region hydrology. Frozen soil infiltration is different than that of unfrozen soil because of infiltrating water re-freezing and melting of ice content within soil profile. When soil temperature decreases below 0°C, soil starts to freeze from surface. So, the soil water contents along the soil profile gradually reduce and change to ice contents. Permeability and infiltration capacity greatly decrease with increase in ice contents formation within soil profile. The amount and distribution of ice contents within the 0-30 cm of uncracked frozen Prairie soil profile, i.e. “zone of infiltration”, is the dominant factor that affects water infiltration during melting time. The pore size distribution of “zone of infiltration” also affects the melt water infiltration in frozen soil.

Snowmelt water infiltration during spring greatly governs by air-filled porosity of top 10 cm soil and soil moisture content of top 30 cm soil that stored in fall. Infiltration rates are inversely related to soil moisture contents at freezing time. The flow path tortuosity increases due to formation of ice in soil, because soil water in large pores freezes first and restricts water movement in those pores. As a result, infiltration capacity of that frozen soil reduces. Many ice lenses form within the soil profile, make the agricultural soil very hard as like concrete and turn the frozen soil almost impermeable so that water can barely infiltrate into it. In cold winter, large amount of rain water that stored in soil surface froze due to air temperature fall and resulted a frozen ice layer on soil surface which impeded snowmelt infiltration. But water can still infiltrate into frozen soil even after freezing if the soil is not wet to saturation during the time of freezing.

Snowmelt water infiltration involves complex processes of heat and mass transfer through the frozen soils and very important for measuring snowmelt surface runoff and flood water level prediction. Many factors, such as soil moisture, soil temperature, snow cover water release rate, porosity, soil cracks, snowmelt water infiltrating energy content, and presence or absence of macropores, affect the total infiltration process. Water infiltration in frozen soils after snow melting mainly occurs in macropores and along cracks, especially for clayey soils. A severely cracked heavy-textured clay soil can absorb large amounts of water. For a unit area, infiltration amount can be higher than the snow equivalent water amount due to interflow to and through cracks from outside the area. Due to presence of cracks, snowmelt water mostly enters into the cracks and cannot produce significant runoff flow at the field edge. If the fields are heavily cracked during fall, it is expected that most of snowmelt water will be infiltrated through the cracks.

In northern cold region, more than half of the land surface is seasonally frozen (minimum annual temperature below 0°C) and snow melting is a major hydrological event in this area. In the Red River of the North Basin (RRB), frozen dry soil absorb as much as half of snowmelt water through infiltration and lack of understanding of the snowmelt water infiltration process is the major limiting factor affecting spring flood forecasting. In the last few years, spring flooding occurred almost every year, and created a huge financial burden for the RRB. The objectives of this research study were to measure infiltration rates into a frozen silty clay loam soil with three initial moisture contents, and to evaluate soil volumetric water content changes with temperature at three depths.

Significance of Research

Frozen soil infiltration is a complicated hydrological process that contributes to crop water intake, surface runoff generation and ground water recharge in northern latitudes. The infiltration process into frozen soils could have a broad impact to the hydrological field for the entire and especially in permafrost regions. It would help to better understand the runoff processes and flooding events in winter and spring. The relationship between infiltration and soil water contents of frozen soil could be used to predict actual runoff peaks to prevent damage from floods or to prevent overestimation of runoff. This knowledge of frozen soil infiltration also will help to modify and adjust the existing flood prediction models. The benefit from this proposed study will be several million dollars each year in flood preparation.

Significant Findings

The infiltration rates in a frozen silty clay loam soil of RRB for initial moisture condition θ_{pwp}, initial moisture condition $\theta_{pwp} \leq \theta \leq \theta_{fc}$ and initial moisture condition θ_{fc}, respectively were measured in this study. Because of low soil moisture content in the soil with θ_{pwp}, the soil was comparatively dry with high pore space. Water infiltrated in that soil quickly and infiltration rate decreased sharply. The ice content did not contribute much to soil moisture, resulted higher infiltration rate in that soil. Water infiltration was comparatively slower in the soil with $\theta_{pwp} \leq \theta \leq \theta_{fc}$ as melted ice water increased soil moisture content in that soil and reduced the infiltration rate by filling the pore spaces in the soil. Soil with θ_{fc} had highest soil water content among all soils with low pore space. The ice content in the soil blocked the pore space after freezing and restricted the water movement. So, the infiltration rate was found very low in that soil. As the soil reached saturation very rapidly, infiltration amount was very low in that soil compare to other soils with θ_{pwp} and $\theta_{pwp} \leq \theta \leq \theta_{fc}$, respectively.

The observed infiltration data were fitted with nonlinear regression equation with three parameters: $i_t = 0.060 + 0.68 * e^{-0.16*t}$ with $R^2 = 0.87$ for θ_{pwp}; $i_t = 0.010 + 0.42 * e^{-0.12*t}$, with $R^2 = 0.84$ for $\theta_{pwp} \leq \theta \leq \theta_{fc;}$ and $i_t = 0.027 + 0.53 * e^{-0.54*t}$, with $R^2 = 0.75$ for θ_{fc}. The average final infiltration rate was close to predicted rate for θ_{pwp}, was higher than predicated rate for $\theta_{pwp} \leq \theta \leq \theta_{fc}$ and was lower than predicted rate for θ_{fc}. The infiltration curves over time shifted downwards with the shifting of soil from dry to wet. The θ_v changing over time and with temperature resulted due to the combined effects of infiltrating water addition and melted ice water contribution during phase change of water to the soil profile. The θ_v changing varied along the soil profile with time. In the soil with θ_{pwp}, θ_v changed with temperature gradually due to less

water addition from melted ice. But in the soil with $\theta_{pwp} \leq \theta \leq \theta_{fc}$, θ_v changed rapidly after temperature reached at 0°C as ice changed to liquid water and added to existing soil water content. The soil with θ_{fc} already had soil water content at field capacity and less pore space, so the addition of infiltration water and melted ice water did not change much θ_v with temperature increase in that soil. Comparison between Soil Water Release Curves of before experiments and after experiments indicated that soil aggregates were destroyed and macropore number was reduced greatly which changed the water holding capacity of that soil from saturation to field capacity.

Holistic Risk Assessment of Surface Water Contamination Due to Lead-210 Found in Produced Water from Unconventional Oil Production in North Dakota

Project Number: 2016ND312B (co-funded by NDSWC)
Fellow: Luisa Torres
Advisers: Eakalak Khan and Om Yadav
Start Date: 03/01/2016
End Date: 02/28/2017

Publications

Torres, L.; O.P. Yadav; E. Khan, 2017, Perceived Risks of Produced Water Management and Naturally Occurring Radioactive Material Content in North Dakota, Journal of Environmental Management, 196, 56-62.

Torres, L.; O.P. Yadav; E. Khan, 2017, Holistic Risk Assessment of Surface Water Contamination due to Pb-210 in Oil Produced Water from the Bakken Shale, Chemosphere, 169, 627-635.

Torres, L.; O.P. Yadav; E. Khan, 2016, A Review on Risk Assessment Techniques for Hydraulic Fracturing Water and Produced Water Management Implemented in Onshore Unconventional Oil and Gas Production, Science of the Total Environment, 539, 478-493.

Torres, L.F.G., 2016, Holistic Risk Assessment of Surface Water Contamination by Naturally Occurring Radioactive Material in Oil Produced Water from the Bakken Shale, M.S. Thesis, Department of Civil and Environmental Engineering, College of Engineering, North Dakota State University, Fargo, ND.

Research Description

The risks to the environment and human health due to hydraulic fracturing (HF) in onshore unconventional oil and gas (O&G) development have been studied in the past but results are inconclusive. A common shortcoming in previous studies is the absence of social risk perception and awareness analysis. This research proposes the combination of statistical methods to analyze risks to human health due to improper management of produced water, the major by-product of HF. The research focuses on the Bakken Shale located in North Dakota but data from other States is used as needed. The objectives of the research are:

1. To review different risk assessment techniques and select the most applicable ones to onshore unconventional O&G development.
2. To conduct a risk assessment from an engineering perspective on human exposure to Ra-226 in produced water from the Bakken Shale.
3. To develop a holistic risk assessment method by incorporating social awareness and perception with risk characterization of surface water contamination due to Pb-210 in produced water from the Bakken Shale.

4. To understand the factors that shape social risk perception and awareness of produced water from different stakeholders in ND.

Significance of Research

The expansion of unconventional O&G development using HF has resulted in multiple studies. Although these studies have become more available, the information on risks related to the water and produced water management in unconventional O&G development and the impacts in the U.S. is still insufficient. There are evident gaps in data on naturally occurring radioactive material (NORM) in produced water and the impacts on the environment and human health. Data on NORM, especially radium 226 (Ra-226) the most common radionuclide present in unconventional O&G produced water, has been collected in different States such as Pennsylvania and used to create standards and regulations. However, in North Dakota (ND) which is second in the country in oil production, research on Ra-226 in produced water from the Bakken Shale is extremely scarce. The lack of data is even more evident for other radionuclides including Ra-226's decay product, lead 210 (Pb-210). Studies on Pb-210 in produced water have not been conducted in ND despite its known harmful health effects, especially on children, mobility and relatively long life in the environment.

Moreover, the studies available to the public are typically focused on other locations and references to ND are limited. These studies were conducted mostly from an engineering approach, the preferred method to assess risks. Applying only this approach results in an incomplete analysis of the risks. Thus, scarce data and narrow view of the risks to the environment and human health merit the improvement of current techniques used to study and measure the real risks involved in unconventional O&G development. This improvement includes conducting risk assessment from a social perspective. To date, no research has been conducted to understand public risk perception of hazards associated with produced water from HF in ND.

Significant Findings

A risk assessment of radium-226 was performed from a technical perspective only. The simulated total annual effective dose rate of Ra-226 for an adult in ND is above the global average effective dose rate via food and drinking water. A second assessment, focused on lead-210, combined technical analysis with risk perception and awareness of ND residents. Although findings from this study include a low probability of a produced water spill reaching surface water, the consequence of this event could have a great impact since the simulated concentration of Pb-210 in drinking water was found to be higher than the recommended value established by the World Health Organization. Finally, results from the survey conducted for this research indicate that the most important variables that seem to positively or negatively influence the risk perception and awareness of produced water are the images and thoughts associated with produced water, level of knowledge about produced water handling and content, and knowing how to proceed in case of a spill of produced water.

Tamoxifen and Endoxifen Detections in Wastewater and Receiving Waters in North Dakota

Project Number: 2016ND313B (co-funded by NDSWC)
Fellow: Marina Martin
Adviser: Eakalak Khan and John McEvoy
Start Date: 3/1/2016
End Date: 2/28/2017

Research Description

Endoxifen is an active metabolite responsible for the effectiveness of tamoxifen, a chemotherapeutic drug widely used for endocrine responsive breast cancer and chemo-preventive long-term treatment. Endoxifen is not completely metabolized in human body and is actively excreted. As a result, endoxifen is released to the water environment via wastewater treatment plants (WWTPs). The antiestrogenic activity of endoxifen potentially produces negative effects on aquatic lives. Data on actual concentrations of endoxifen in the environment is limited due to recent discovery of endoxifen pharmaceutical activity. However, endoxifen has been detected in hospital and municipal wastewater effluents. The detection of endoxifen in wastewater effluents questions the treatment efficiency of WWTPs. However, studies reporting information about endoxifen removal in WWTPs are scarce.

There was a study on the use of chlorination as a treatment method to eliminate endoxifen in wastewater. Inefficient degradation of endoxifen by chlorination and the production of hazardous disinfection by-products were observed. Therefore, there is an urgent need to remove endoxifen through an alternative treatment method. Several techniques can be applied in wastewater treatment plants to eliminate endoxifen. Among these techniques, a biological treatment scheme called bioaugmentation is a promising method to enhance the elimination of selected chemicals present in wastewater. Therefore, in an attempt to eliminate endoxifen from wastewater treatment plants, the identification and isolation of bacterial strains responsible for endoxifen biodegradation through bioaugmentation techniques is the first key step in order to avoid the potential detrimental effects that endoxifen could cause in the environment. The aim of this research is to determine for the first time the presence and levels of endoxifen in North Dakota water bodies and to test biodegradation as a method to remove endoxifen. For this purpose, an extraction and detection method was developed and bacteria strain(s) from WWTPs capable of degrading endoxifen into less hazardous compound(s) will be isolated and identified.

Significance of Research

The research results will show endoxifen levels in wastewater, treated wastewater, and surface waters receiving treated wastewater in North Dakota. The occurrence of endoxifen in these water bodies is likely due the administration of tamoxifen for cancer treatment by oncological hospitals such as Sanford Medical Center in Fargo. The current lack of knowledge about the presence and level of endoxifen in the water environment could lead to unknown toxicological effects on aquatic lives or even humans. The actual concentrations of endoxifen in surface waters that aquatic and benthic lives are exposed to could guide future remediation and toxicological studies.

Identification of endoxifen bacteria degraders will lead to a better understanding of the biological techniques needed in order to remove endoxifen in wastewater. Moreover, the identification of endoxifen in North Dakota will reveal the presence of an emerging micropollutant that is a growing concern worldwide.

Significant Findings

Thirty-seven bacterial strains were isolated from a mixed bacterial culture from a WWTP. The culture was incubated in synthetic wastewater enriched with endoxifen at a concentration of 1 mg/L for 40 days. Isolated bacteria were incubated in a selective minimal salt media (MSM) enriched with Luria-Bertani broth (LB) (0.001%) and endoxifen at 10 mg/L. Bacteria growth was observed and an aliquot of the selective MSM was plated in MSM Agar enriched with endoxifen at 10 mg/L. Resultant colonies were incubated together as a mixed bacterial culture in MSM containing endoxifen (15 mg/L) as the sole carbon source. Bacterial growth was monitored by plate counting and endoxifen concentration is determined by liquid-liquid extraction and posterior injection to Liquid Chromatography-Fluorescence Detector (LC-FLD). Bacteria showed growth but more analyses are needed in order to reach a final conclusion.

The extraction and detection methods were optimized and validated. Analytical parameters in order to identify and quantify endoxifen through LC-FLD were optimized to achieve acceptable peak shape, separation, and resolution of endoxifen within an appropriated elution time. The actual achieved limit of quantification and limit of detection were 8.97 ng/ml and 2.96 ng/ml, respectively. Endoxifen recovery through liquid-liquid extraction was greater than 80%, and standard calibration curve for MSM spiked with endoxifen at five different concentrations (1-1000 ng/ml) showed R^2 values greater than 0.99. Therefore, liquid-liquid extraction and LC-FLD detection have provided reliable results for endoxifen quantification.

Endoxifen extraction by the solid-phase micro-extraction method still needs to be optimized. Endoxifen has been extracted and detected in water samples spiked with endoxifen at concentrations ranging from 500 to 1,000 pg/mL. However, the reconditioning process of the extraction fiber after the first extraction of endoxifen, needs more research. A stable reconditioning process is needed to ensure the fiber endurance with a consistent endoxifen extraction recovery between 80 and 110%.

Glutaraldehyde Removal from Flowback and Produced Waters Using Photolysis

Project Number: 2016ND315B (co-funded by NDSWC)
Fellow: Soklida Hong
Advisers: Eakalak Khan and Jayaraman Sivaguru
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Hong, S.; T. Ratpukdi; J. Sivaguru; E. Khan, 2016, Glutaraldehyde Removal from Flowback and Produced Waters Using Photolysis, in Proceeding 89th Annual Water Environment Federation Technical Exposition and Conference, Water Environment Federation, Alexandria, VA, 2448-2457.

Research Description

In unconventional oil and gas extraction, hydraulic fracturing has been applied to ensure high and prolonged production of oil and gas from shale deposits. This technology induces cracking network in low-permeability shale to allow trapped oil and/or gas flow to the production wells by injection of hydraulic fracturing fluid at extremely high pressure and flow rate. Primarily, due to this recently improved technique, North Dakota right now is the second largest crude oil producing state in the United States, with 314 million barrels of oil produced in 2013. After hydraulic fracturing, there are two types of waters discharged from the well along with oil and gas. These waters are flowback water, mostly hydraulic fracturing water, and produced water, naturally occurred shale water. Hydraulic fracturing fluid is mainly water (98-99%) and proppant (mostly sand, 1-1.9%); however, several chemicals are added to the water to increase hydraulic fracturing performance. Among the chemical additives, biocides are one of the most common additives in hydraulic fracturing fluid.

After hydraulic fracturing, biocides are also periodically injected to the wellbores. They are used to prevent corrosion to the wells associated with microbial growth. Glutaraldehyde (GA) is the most common biocide used in shale fracturing accounting for 80% of all shale fracturing. It is a harmful chemical to environment, human and aquatic organisms, however, a portion of glutaraldehyde returns with flowback and produced waters making the waters more harmful to the environment. This study will investigate the capability of photolysis by UV light in removing glutaraldehyde in flowback and produced waters, since this technology has small footprints, easy to operate, and effective against organic compounds.

Significance of Research

This study helps in addressing an obstacle associated with flowback and produced waters treatment and disposal. After removing GA from flowback and produced waters, biological treatment, which is economical, will become viable for treatment of the waters for potential

fracturing reuse, or will make the waters less harmful for disposal. The work provides an effective treatment scheme for a common biocide in flowback and produced waters.

Significant Findings

GA can be photolyzed by UV at all studied conditions with the removal ranging from 52 to 85% within one hour irradiation. Photolysis of GA followed pseudo-first order kinetics. The degradation rate of GA was substantially affected by light intensity (112-224 W), initial GA concentration (0.1-1 mM) and salt concentration (0-300 g/L) but minimally influenced by pH (5-9). Photolysis rate constant of GA at 0.1 mM in 200 g/L of salt at pH 7 was 0.0269 min^{-1} with a quantum yield of 0.0549 under 224 W illumination. The degradation rate of GA increased with increasing incident light intensity and decreasing pH. Increasing in initial GA concentration resulted in decreasing rate of GA. Interestingly, salt concentration affected the GA degradation rate. At lower salt concentrations, a notable retardation of GA degradation rate was observed; however, as salt concentration increased the degradation rate of GA also increased. In quenching experiments, it is found that photolysis of GA was governed by the following mechanisms: direct photolysis and indirect photolysis via $^{\bullet}OH$ and $^{1}O_2$ photooxidation. Oligomers were identified as the main photolytic byproducts and GA photolytic pathways were proposed.

Biopolymers for Phosphate Removal from Eutrophic Lakes

Project Number: 2016ND316B
Fellow: Mohammad Enayet Hossain
Adviser: Achintya Bezbaruah
Start Date: 03/01/2016
End Date: 02/28/2017

Presentation

Enayet Hossain, M., 2016, Iron Nanoparticles and Biopolymers for Plant Nutrient Fortification, Ph.D. Dissertation, Environmental and Conservation Sciences Program, College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND.

Research Description

Typical methods for controlling and removing phosphorus from eutrophic lakes include sediment dredging, oxygenation, the use of chemical flocculants (Al, Fe or Ca-based chemical products) and in-situ sediment capping. Many of these methods are not practically feasible considering the high cost of sediment dredging, the inefficient control of P by means of oxygenation, and the ecological risks associated with the use of chemical products. Capping contaminated sediment with thin-layer solid reactive material is potentially the most effective method for controlling eutrophication in lakes. Capping material must be economically feasible, environmentally friendly and geographically available. Phosphorus (P) sorbents based on natural Al, Ca or lanthanum-modified clay minerals are used for this purpose. However, most of these methods are meant for in-situ controlling of phosphorus in eutrophic lakes. There are no accepted methods which can mine phosphate from eutrophic lakes for subsequent use. Adsorption is one of the most attractive options for phosphate removal from aqueous media because of its effectiveness at low phosphate concentrations.

In this research, novel iron (Fe) cross-linked alginate (FCA) beads were used for aqueous phosphate removal. Batch experiments were conducted with the beads using three different concentrations of phosphate (5, 50 and 100 mg PO_4^{3-}-P/L) as well as environmentally relevant (eutrophic lakes) concentration of 100 µg PO_4^{3-}-P/L. FCA beads were also used with actual lake waters (11-69 µg PO_4^{3-}-P/L). Phosphate-laden spent or used iron cross-linked alginate (FCA) beads were used in hydroponics to evaluate the bioavailability of P and Fe using lettuce (*Lactuca sativa*) as a test plant. The spent FCA beads were found to support the plants throughout the growth period. The bioavailability of P and Fe in the spent beads is promising considering the importance of phosphorus and iron in global food and nutrient security.

Significance of Research

Eutrophication of lakes is a major problem in North Dakota and in the US. The eutrophication problem is even more severe in North Dakota state because agriculture is the major industry. It ranks first in the nation in the production of many crops, including spring wheat, durum, barley, sunflowers, dry edible beans, pinto beans, flaxseed, canola and honey. North Dakota is also an

important producer of sugar beets, potatoes and oats. There are 1.7 million heads of cattle, 160,000 pigs and 88,000 sheep in North Dakota. Farms and ranches cover more than 39 million acres, almost 90% of North Dakota's land area (http://www.agclassroom.org). Agriculture constitutes the major non-point source for phosphorus responsible for eutrophication. Phosphorus- and nitrogen-containing fertilizers are extensively used in agriculture; therefore, runoff from animal feedlots and firms make North Dakota as one of the most eutrophication-prone states.

The other facet of phosphorous is that it is used for agriculture and global food security will be in jeopardy if phosphorous fertilizer production rate declines. Phosphorus is a nonrenewable resource. Phosphorus assumes an added importance when geopolitics is taken into consideration. Phosphorus reserves for fertilizer production is held by Morocco, Peru and China, which make the other countries in the world completely dependent on those three countries.

Considering all those aspects of phosphorus, the amount of P compounds in waters should be curtailed to prevent eutrophication in lakes and other surface waters. It is imperative to devise effective methods to remove and reclaim excessive phosphate from water and wastewater. The present research entailed developing a novel sorbent for phosphate removal and reclamation from eutrophic lakes and subsequently using reclaimed phosphate in agriculture.

Significant Findings

In this research, novel FCA beads were synthesized and used for aqueous phosphate removal. The beads were found to remove lower concentrations of phosphate very fast from the solution. About 80-97% phosphate was removed within 3 h. for lower concentrations of phosphate. Phosphate removal was not affected by the presence of competing ions and compounds. The FCA beads was also used in real-life situation (e.g., in eutrophic lakes), and the beads were found to remove 81-100% of phosphate from lake waters. The maximum sorption capacity (78.7 mg PO_4^{3-}-P/g of beads) and the point of zero charge (PZC) (9.2) of the beads make the beads an ideal candidate for eutrophic lakes. The cost analysis showed that the beads are also very affordable compared to other sorbents. Assuming a factor of safety of 4 (i.e., adsorption capacity is only 25% of the experimental value) the cost comes to $0.36 per g P removed.

Used or spent FCA beads were used for plant studies to see the bioavailability of P and Fe and to evaluate the potential use of spent FCA beads as slow-release phosphorus and iron fertilizers. Spent FCA beads were found to support biomass production to a certain extent indicating that the phosphorus and iron were available for plant uptake. This research indicates that these FCA beads are promising as a phosphate remover and as a slow-release non-conventional phosphate fertilizer. While these spent FCA beads were not meant for the primary source of phosphate and iron fertilizer, they can certainly be used as supplementary sources of phosphorus and iron. Because of the biodegradable nature, the phosphate-laden FCA beads could be applied directly to soil as a fertilizer. The concept and findings from this research can be used to develop new technologies to combat eutrophication of waterbodies, to form a supplementary source of phosphorus.

UV Light Effect on Bioavailability of Dissolved Organic Nitrogen in a Trickling Filter Process

Project Number: 2016ND317B
Fellow: Swati Sharma
Adviser: Halis Simsek
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Sharma, S.; D.L. Tucker; H. Simsek, 2016, Wastewater Derived Dissolved Organic Nitrogen Removal Using Integrated System of Biological Reactors and UV Light Irradiation, in Proceeding 89th Annual Water Environment Federation Technical Exposition and Conference, Water Environment Federation, Alexandria, VA.

Research Description

Dissolved organic nitrogen (DON), a complex structure, in wastewater has been a major environmental concern especially for receiving waters. Understanding the biodegradability (BDON) and bioavailability (ABDON) characteristics of wastewater derived DON is important to achieve successful removal of DON from anthropogenic sources using bacterial and algal inocula. The purpose of this study is to evaluate the impact of hydraulic retention time on biodegradability and bioavailability of wastewater derived DON using integrated two moving bed biofilm reactors (MBBRs). The MBBR media (plastic white media, about 1 inch in diameter) are used in the reactors to support the growth of bacteria and algae. Various hydraulic retention times (HRTs) at 1, 3, and 6 days have been investigated on primary effluent samples collected from the city of Fargo wastewater treatment plant (WWTP). The samples are further incubated in batch reactors with bacteria and alga + bacteria for 21 days to investigate the utilization of bio-available/degradable DON. A significant reduction in DON has been observed when the reactors are run at an HRT of 3 days.

In the second phase of the experiments, the samples were collected from the second MBBR reactor exposed to UV light to determine photodegradable DON (PDON) and further incubated to determine photo biodegradable DON (PBDON) and photo bioavailable DON (PABDON). For the experiments, 500 ml of samples from reactor-2 effluent was transferred into a quartz flask and two 40 watt and 254 nm wavelength of UV lamps were used to irradiate the samples continuously for 6 days. PDON values were determined after UV light exposure and the samples were further incubated for 21 days to determine PBDON and PABDON.

Significance of Research

This research provided a comprehensive data to address nutrient contamination introduced to surface waters in North Dakota. Using algae and bacteria in a chemostat reactor to determine BDON and ABDON is a new approach. Additionally, the effect of UV light on bioavailable

DON (PABDON) to algae + bacteria has not been studied in wastewater treatment processes including trickling filter process. The findings of this research were presented at national and/or regional conferences and will be submitted for publication in a peer review journal. A final report containing all the information on the project including raw data will be delivered at the end of the project.

Significant Findings

The optimum removal of organic nitrogen can be achieved at an average HRT of 3 days. About 40% of DON was bioavailable to bacteria and algae. Lower HRTs may result in inefficient removal whereas HRTs higher than 6 days could result in low nutrient uptake and cell lysis. From the algae + bacteria seeded samples, it can be understood that wastewater derived DON in receiving waters can be taken up by algae in the presence of bacteria. This facilitates our conclusion that algae can uptake higher level of wastewater derived DON in receiving waters in the presence of bacteria. The photodegradability of DON using UV light has been conducted in batch study to understand the fate of DON when exposed to UV light continuously for 6 days. Results showed that, using UV light to the reactor effluents can further degrade DON to a significant level. Thus, working towards reduction in the level of DON should be considered a primary concern in the treatment plants before its discharge to the receiving water bodies.

Assessing the Impacts of Hydraulic Fracturing at Bakken on Regional Water Resources

Project Number: 2016ND318B
Fellow: Tong Lin
Adviser: Zhulu Lin
Start Date: 03/01/2016
End Date: 02/28/2017

Publication

Lim, S.H.; Z. Lin; M. Border; T. Lin, 2016, Shale Oil Production Expansion and Water-Energy Nexus in North Dakota: A Decentralized Agent-Based Modeling Approach, in Proceedings of 2016 Agricultural & Applied Economics Association Annual Meeting, Agricultural & Applied Economics Association, Milwaukee, WI.)

Research Description

Unconventional oil production at the Bakken Shale of western North Dakota increased nearly 13 times from 2008 to 2014. The industrial water use in western North Dakota has increased dramatically since 2008, mainly due to hydraulic fracturing for oil and gas well development in the Bakken Shale. Although unconventional oil production uses less water than conventional oil production per unit of energy, the cumulative water needs for unconventional oil production due to multiple drilling and fracturing operations may be locally or temporally significant.

In this project, we analyzed the Bakken oil well completion data, North Dakota water use data, groundwater level and streamflow observations data to estimate the water uses for hydraulic fracturing at Bakken and their impacts on region water resources. We are in the process of developing an agent-based model to better understand the water depot based water allocation system in western North Dakota.

Significance of Research

Our research helps to quantify how much fresh water is used for hydraulic fracturing at Bakken, how significant HF water use at Bakken when compared with other types of water use, and how HF water use at Bakken has affected the surface water and groundwater resources in the region. Our research will also develop an agent-based model for the unique water depot based water allocation system. A clear understanding of the dynamics of the water depot based water allocation system and its interactions with individual streams and aquifers in the region will help policy and decision makers devise appropriate policy tools to manage the regional water resources for long-term and sustainable use.

Significant Findings

From 2008 to 2014, the annual industrial water use for shale oil development in the Bakken ranged from 520 MG (2.0 Mm^3) to 10,200 MG (38.5 Mm^3), approximately 85% of which were

consumed in well geo-stimulation (or hydraulic fracturing) process and the remaining were used for drilling, cement mixing and maintenance water of brine dilution.

From 2008 to 2014, the annual total industrial water uses for Bakken shale oil development accounted for 0.5% to 10% of state-wide total consumptive water use. The percentage increased from 3.0% to 40% within Bakken oil production region (Dunn, McKenzie, Mountrail, and Williams). The increased population of temporary oilfield service workers contributed additional domestic water use, which was about 15% of annual industrial water use for the shale oil development in the Bakken.

On average the freshwater sources for Bakken development were equally split between groundwater sources and surface water sources. Despite in a semi-arid region, the impact of Bakken development on regional water supply was limited because the water in the Bakken was actively managed and the region received on average over 20% more precipitation than normal during 2008-2014. The average annual 7-day low flows in nine small to medium sized streams in the region actually increased since the development. Out of the fifteen glaciofluvial aquifers under study, twelve have seen average water level increasing or unchanged and the average water level for the remaining three aquifers has decreased compared to 2000-2007.

We are in the process of modifying the agent-based model which was developed to simulate water depot based water allocation system in western North Dakota.

Injectable Nanoparticle-based Permeable Reactive Barriers for Groundwater Contaminant

Project Number: 2016ND319B
Fellow: Umma Rashid
Adviser: Achintya Bezbaruah
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

A novel polymer was used to coat nanoscale zero-valent iron (NZVI) particles to increase their sticking coefficient in the aquifer materials. Two dimensional (2-D) transport study was done to study the dispersion and transport of bare and polymer-coated NZVI (CNZVI) in porous media under steady state conditions. The results from the 2-D transport study were used to determine if coated NZVI particles could be the potential candidates for creating injectable permeable reactive barriers (PRBs) in the subsurface; experiments were done at different flow velocities and different aquifer porosities. Nitrate (NO_3^--N) was selected as test contaminants to evaluate bare and coated NZVI particles' removal efficiencies. Shelf-life study was also conducted for the coated NZVI. Many batches of CNZVI were prepared and stored in a cabinet at room temperature. NO_3^--N degradation studies were conducted at predetermined time interval over a 4-month period.

A set of wood-based activated carbon (AC) was made by chemical activation with metal salt and metal hydroxides (KCl, NaCl, KOH and NaOH) to remove fluoride. Chemical activation was done at different impregnation ratio of KCl, KOH, NaCl and NaOH (1:1, 1:2, 1:3 and 1:4 (w/w)). The aim of this study was to get an organized pore structure, high surface area, and high pore volume for effective removal of fluoride. To check and compare the quality of different ACs, methylene blue (textile dye) removal batch studies were conducted at three different initial dye concentrations. However, activated carbon exhibited very poor fluoride removal efficiency. To remove fluoride more efficiently activated carbon surface was then modified with nitric acid and citric acid. This experiment is on-going.

Significance of Research

Nitrate is one of the most common groundwater contaminants in rural areas. An incredible number of sources contribute to groundwater NO_3^--N contamination, including fertilizers, septic systems, and industrial atmospheric pollution. Exposure to this containment has been implicated in cancers, such as non-Hodgkins lymphoma, and neonatal disease, including blue baby syndrome. To protect human health, the U.S. Environmental Protection Agency (USEPA) set the maximum contaminant level (MCL) for nitrate at 10 mg L^{-1} (as N). We have used surface modified nanoscale zerovalent iron (NZVI) for nitrate removal. To prepare physically more stable and chemically more reactive NZVI, different polymers have been used as coatings. Polysaccharides are promising biopolymers for coating NZVI particles. Starch is one of the cheaper and greener polysaccharides compared to other dispersants. Starch is a branched, hydrophilic polymer which can improve NZVI's colloidal stability. To improve functionality,

native starches is modified by chemical, physical or enzymatic process. Modified starch containing carboxyls is ideal for coating NZVI because carboxyls have an affinity to bind with the surface of iron oxides. Others have reported successful transport of surface modified NZVI. This transport behavior has limited the use of surface modified NZVI in permeable reactive barriers (PRBs). PRBs can be installed by injecting NZVI which are not mobile. To achieve this, NZVI particles were coated with octenyl succinic anhydride (OSA) modified tapioca starch. The prepared coated NZVI has exhibited better colloidal stability, higher sticking coefficient and same NO_3-N removal effciency compared to the bare NZVI.

Fluoride (F^-) is an anionic constituent found naturally in surface and groundwater The world health organization (WHO) recommends a threshold of 1.5 mg F/L in drinking water, beyond which fluoride can cause detrimental effect (WHO, 2004). The USEPA has established a maximum contaminant level (MCL) of 4 mg/L to prevent against skeletal fluorosis and a secondary maximum contaminant level (SMCL) of 2 mg/L to protect against dental fluorosis. Prolonged exposure to high F^- levels can lead to dental and skeletal fluorosis. Chronic intake of fluoride may also lead to muscle fiber degeneration, low hemoglobin level, excessive thirst, skin rashes, depression, growth retardation, DNA structural changes. Activated carbons in both granular and powdered forms are the most widely used adsorbents for removing organic pollutants, heavy metals and industrial dyes. The adsorption property of activated carbon depends on the method of preparation (physical or chemical activation) and nature of raw material. The chemical activation process has been proven to develop more organized pore structure and higher surface area comparatively at lower temperature compared to the physical activation process. We have demonstrated that chemical activation using metal hydroxides and metal salts is very effective as more pores are formed due to the intercalation of metals into the carbon lattice at specific temperature. A set of ACs was made by chemical activation with metal salt and metal hydroxides at different ratio to get an organized pore structure, high surface area and high pore volume. The surface of prepared activated carbon was modified with nitric acid and citric acid to remove fluoride more efficiently.

Significant Findings

- Octenyl succinic anhydride (OSA) modified tapioca starch was used to coat NZVI particles to increase their sticking coefficient in the aquifer materials.
- The polymer has successfully increased the colloidal stability of NZVI in water. After 2 hours 70% of polymer coated NZVI particles remained suspended whereas only 10% of bare NZVI particles remained suspended.
- The 2-D transport study showed that, even at highest velocity (150 ft/d), the coated NZVI particles did not move in porous media (made of sand) as surface modification has increased the sticking coefficient of NZVI particles in the aquifer material.
- The nitrate treatability studies showed that, at low concentration (20 mg/L NO_3^- - N) CNZVI exhibited less removal efficiency (71%) compared to the bare NZVI (99%). However, at high concentration (40 mg/L and 60 mg/L of NO_3^- - N) both bare NZVI and CNZVI showed similar removal efficiency (69% for 40 mg/L and 54% for 60 mg/L).
- The CNZVI particles need to have long shelf-life to be commercially viable (storage and transportability requirements). The shelf-life study showed that the NO_3^- - N degradation rate remained more or less unchanged for 4 months.

- PRB study showed that bare NZVI removed nitrate till 11 days and after that the removal was zero. After doing mass balance for NZVI and nitrate it was found that only 20.6% of the NZVI was utilized to remove nitrate.
- At lower concentration (200 mg/L of methylene blue) all the AC samples showed same amount of removal but at high concentration (500 mg/L of methylene blue) KOH and KCl showed better removal (99%) than NaOH and NaCl (66%).
- The optimum impregnation ratio found for KCl is 1:1 and and for NaCl is 1:2. Nitric acid modified activated carbon removed 72% fluoride and citric acid modified activated carbon showed 52% fluoride removal in 90 min whereas unmodified activated carbon removed only 14% fluoride in 90 min.

Comparative Ultraviolet Disinfection Study for Wastewater Applications for the City of Fargo, North Dakota

Project Number: 2016ND320B (co-funded by NDSWC)
Fellow: Ursinio Puga
Adviser: Wei Lin
Start Date: 03/01/2016
End Date: 02/28/2017

Research Description

The City of Fargo owns and operates the only wastewater treatment plant (WWTP) in Fargo, North Dakota, United States. The WWTP was built in 1934 and it has been expanded several times since its construction. Currently, the WWTP treats an average daily flow of 15 million gallons per day (MGD) and has the ability to handle a peak pumping capacity of 29 MGD. The Fargo WWTP will yet undergo another expansion, increasing its peak pumping capacity from 29 to 50 MGD.

The current method used to disinfect the wastewater at the Fargo WWTP is chlorination followed by de-chlorination. The expansion requires the construction of an additional chlorine contact basin to properly treat the future flow. Due to the close proximity to the Red River, there is extremely limited space for a new contact basin on the existing WWTP's campus. After studying several alternatives, the engineers designing the plant's expansion recommended switching to a UV disinfection system. According to the consulting firm, retrofitting the existing disinfection contact basin into a UV system will allow the plant to provide adequate disinfection to its wastewater without having to increase the footprint of the existing disinfection contact basin to handle the future flow.

Although UV disinfection is a proven technology, its application in wastewater treatment is relatively new in North Dakota and throughout the Midwest. Additionally, past research indicates that there is a need to develop on-site studies to effectively design a full-scale UV disinfection system for a particular plant depending on its flow and water quality characteristics. The management of the Fargo WWTP decided to perform on-site studies to determine the UV disinfection efficiency under different flow conditions, potential seasonal water quality changes, and quartz sleeve fouling prior to start implementing this technology in a full-scale basis.

It was decided that the best way to perform on-site studies was through a pilot study. Fargo's WWTP management proposed a 7-month pilot study (April 1st through October 31st 2016) to match the current Fargo's WWTP disinfection season. The pilot was carried out by North Dakota State University researchers with collaboration with the scientists and wastewater experts from the City of Fargo, engineers from Apex Engineering Group, and representatives from UV system manufacturers. The specific objectives of the study are as follows:

1. To evaluate the impact of effluent water quality change on UV Transmittance (UVT);
2. To evaluate the impact of UVT changes on UV disinfection of E. coli;
3. To evaluate the fouling tendency of quartz sleeves; and

4. To evaluate the impacts of fouling and flow rate variations on UV disinfection of E. coli.

A pilot unit was used to determine the UV disinfection efficiency under different flow conditions, potential seasonal water quality changes, and UV lamp fouling material deposition. Additionally, a collimated beam (CB) apparatus was used to find the relationship between UV dose and *E. coli* inactivation efficiency in wastewater for different UVTs.

Significance of Research

Previous studies show that absorption of UV light by dissolved substances is a major contributor to the reduction UV light transmission in wastewaters. Dissolved substances interfering with the operation of the UV disinfection system was a major concern for the Fargo WWTP management since the city applies ferrous salts in its sewer system for odor control. Both the WWTP management and the engineering consulting firm anticipated that some of the iron added throughout the collection system may make their way through the plant and end up in the effluent in dissolved or particulate form hindering UV disinfection performance through absorption of UV light. The motivation that lead the WWTP management to proposing this pilot study was to investigate the behavior of the fouling material accumulation on the surface of the quartz sleeves and whether it was impacted by the iron added to the system. On the other hand, engineers from Apex Engineering Group supported the idea of performing a pilot study to obtain parameters needed to improve the design of the future full-scale UV disinfection system that will be installed on-site. All the data collected during this research effort will be made available to the City of Fargo as well as to the Apex Engineering Group as a basis to develop operation strategies and to improve the design of the future full-scale UV disinfection system.

Significant Findings

Instead of using the commonly accepted first-order kinetic model, a second-order kinetic model was successfully applied to explain the experimental results obtained with the CB apparatus. By using the second-order model we were able to quantify the impact of UVT on E. coli inactivation and to properly explain the impact of initial E. coli concentration on its inactivation rates. Reduction of UV intensity due to fouling of the quartz sleeves was a major concern during the UV system operation. Results of the pilot system showed that fouling was caused mostly by precipitation of metal salts and the impact of fouling on UV intensity reduction was successfully explained by the application of the Beer-Lambert law. *E. coli* inactivation in the pilot reactor was found to be dependent on influent UVT, flow rate, and UV intensity. The first-order plug flow model was used to interpret the pilot study results. No significant seasonal water quality changes that may affect the UV system operation were identified. However, water quality changes due to storm events could cause short term adverse impact on the UV system performance.

INFORMATION DISSEMINATION

Information Transfer Program Introduction

Information dissemination is done through an annual newsletter, and presentations and publications by grant and fellowship recipients. A website also helps disseminating institute research information. The institute's website address is http://www.ndsu.edu/wrri. Past newsletters can be accessed through the institute website. Technical reports of Fellowship projects authored by the Fellows and advisers are also placed on the institute website.

Information Dissemination and Communication

Project Number: 2016ND321B
Start Date: 3/1/2016
End Date: 2/28/2017
Principal Investigator: Eakalak Khan

Activities to disseminate information related to the Institute and research under this project included:

1. Maintaining website as an effective way communicating to the public
2. Publishing the annual institute newsletter
3. Publishing Fellowship and other research done through the Institute
4. Hosting the annual "Distinguished Water Seminar"
5. Presenting research results by affiliated faculty and Fellows
6. Sponsoring or co-sponsoring local or regional conferences

The website of the Institute was updated at least quarterly, and more often when a research project wished to provide updates or when a Fellow graduates. The website provides additional details on the research. The list of Institute Affiliate Faculty with their expertise was updated. Research reports published by the institute were placed on this website as and when they became available. The institute website is: http://www.ndsu.edu/wrri.

The Institute continued its annual newsletter, which highlighted the graduate research fellowship program, the research grants associated with it, and general summaries of ongoing research. The newsletter profiled institute research and researchers and published other newsworthy water issues in the State.

The Institute also encouraged its Fellows and affiliated faculty to present their work at seminars and conferences. Here is a list of seminar and conference presentations made by Fellows and affiliated faculty.

1. Chitikela, R., Rashid, U.S., Bezbaruah, A.N. (2016). Trends in Drinking Water Treatment and Regulatory Requirements: Preparing for the Future. World Environmental and Water Resources Congress, May 22-26, 2016, West Palm Beach, FL.

2. Hong, S., Ratpukdi, T., Sivaguru, J., Khan, E. (2016). Glutaraldehyde Removal from Flowback and Produced Waters Using Photolysis. The 89th Annual Water Environment Federation Technical Exposition and Conference, Sept. 24-28, 2016, New Orleans, LA.
3. Lim, S.H., Lin, Z., Borders, M., Lin, T. (2016). Shale Oil Production Expansion and Water-Energy Nexus in North Dakota: A Decentralized Agent-Based Modeling Approach. 2016 Agricultural & Applied Economics Association Annual Meeting, August 2, 2016, Boston, MA.
4. Lin, T., Lin, Z., Borders, M., Lim, S.H. (2016). The Impacts of Hydraulic Fracturing at Bakken on Regional Water Resources. ND EPSCoR State Conference, April 19, 2016, Grand Forks, ND. (Poster Presentation)
5. Martin, M., McEvoy, J., Khan, E. (2016). Isolation and Identification of Microbes Responsible for Biodegradation of Endoxifen in Wastewater under Aerobic Batch Condition. ND Water Quality Monitoring Conference, Mar. 2-4, 2016, Bismarck, ND. (Poster Presentation)
6. Rashid, U.S., Bezbaruah, A.N. (2016). Injectable Nanoparticle-based Permeable Reactive Barriers for Groundwater Contaminant Remediation, World Environmental and Water Resources Congress, May 22-26, 2016, West Palm Beach, FL.
7. Rashid, U.S., Simsek, S., Bezbaruah, A.N. (2016). Tapioca Starch Based Polymer for Surface Modification of Iron Nanoparticles, AEESP Distinguished Lecture Poster Session, March 31, 2017, University of Minnesota, MN. (Poster Presentation)
8. Shabani, A., Zhang, X., Ell, M. (2016). Modeling Water Quantity and Sulfate Concentration in Devils Lake Watershed Using Coupled SWAT and CE-QUAL-W2. American Geophysical Union (AGU) Conference, Dec. 12-16, 2016, San Francisco, CA.
9. Shabani, A., Zhang, X., Ell, M. (2016). Modeling Water Quantity and Quality in Devils Lake Watershed Using Coupled SWAT and CE-QUAL-W2. South Dakota Water Quality Conference, October 27, 2016, South Dakota State University, Brooking, SD.
10. Shabani, A., Zhang, X. and Ell, M. (2016). Modeling Water Quantity and Quality in the Devils Lake Watershed Using SWAT Model. North Dakota Water Quality Conference, Mar. 2-4, 2016, Bismarck, ND.
11. Shabani, A., Zhang, X. and Ell, M. (2016). Modeling Water Quantity and Quality in the Devils Lake Watershed Using SWAT Model. North Dakota EPSCoR State Conference, April 19, 2016, Grand Forks, ND. (Poster Presentation)
12. Sharma, S., Tucker, D., Simsek, H. (2016). Wastewater Derived Dissolved Organic Nitrogen Removal using Integrated System of Biological Reactors and UV light Irradiation. The 89th Annual Water Environment Federation Technical Exposition and Conference, Sept. 24-28, 2016, New Orleans, LA.
13. Shoghli, B, Lim, Y.H, Alikhani, J. (2016). Evaluating the Effect of Climate Change on Design Parameters of Embankment Dams Using Remote Sensing: Data Case. World Environmental and Water Resources Congress, May 22-26, 2016, West Palm Beach, FL.
14. Shoghli, B, Mirghasemi, A.A., Lim, Y.H. (2016). Assessing and Evaluating the Operation of Pressure Cells in Embankment Dams: A Case Study of Five Iranian Embankment dams", USSD 2016 Annual meeting and conference,
15. Shoghli, B. and Lim, Y.H. (2016). Impacts of Climate Change on the Sustainability of Embankment Dam Reservoir: A Case Study. North Dakota EPSCoR State Conference, April 19, 2016, Grand Forks, ND.

16. Steinman, A. and Hargiss, C. (2016). Understanding the Impacts of Urbanization on Wetlands. ND Water Quality Monitoring Conference, Mar. 2-4, 2016, Bismarck, ND. (Poster Presentation)
17. Torres, L., Yadav, O.P., Khan, E. (2016). Holistic Risk Assessment of Surface Water Contamination due to Pb-210 in Oil Produced Water from the Bakken in ND. The 68th Annual Conference, May 12, 2016, Bethlehem, PA.
18. Torres, L., Yadav, O.P., Khan, E. (2016). Holistic Risk Assessment of Surface Water Contamination due to Pb-210 in Oil Produced Water from the Bakken. ND Water Quality Monitoring Conference, Mar. 2-4, 2016, Bismarck, ND. (Poster Presentation)

Sixth Annual Distinguished Water Seminar

The 6th Annual Distinguished Water Seminar sponsored by the Institute was held on January 23, 2017. The featured speaker was Dr. Ximing Cai, Colonel Harry F. and Frankie M. Lovell Endowed Professor, Civil and Environmental Engineering Department, University of Illinois at Urbana-Champaign. Dr. Cai, is also the Ven Te Chow Faculty Scholar in Water Resources and Donald Biggar Willett Faculty Scholar. He is a renowned research leader in integrated hydrologic-economic modeling for river basin management and water systems operations. His current research areas include coupled human-natural system analysis with an emphasis of human interferences in hydrological processes, water-energy-food system modeling especially in dry areas, and sustainable water resources management particularly in developing countries.

The title of Dr. Cai's presentation was "Observations and Thoughts on Water Resources Research." His presentation focused on a historical review of water resources research and discuss the pressing research issues and directions for future studies, which call for a paradigm shift to deal with the challenges of sustainable water resources management. It was well attended by affiliated faculty and Fellows, and NDSU faculty and students in general.

PUBLICATIONS FROM PRIOR YEARS

Dose, H.L., A.M. Fortuna, L.J. Cihacek, J. Norland, T.M. DeSutter, D.E. Clay, J. Bell, 2015, Biological Indicators Provide Short Term Soil Health Assessment during Sodic Soil Reclamation, Ecological Indicators, 58, 244-253.

Habtezion, N., M.T. Nasab, X. Chu, 2016, How Does DEM Resolution Affect Microtopographic Characteristics, Hydrologic Connectivity, and Modelling of Hydrologic Processes? Hydrological Processes, 30, 4870-4892.

Simsek, H., M. Kasi, J.-B. Ohm, S. Murthy, E. Khan, 2016, Impact of Solids Retention Time on Dissolved Organic Nitrogen and its Biodegradability in Treated Wastewater, Water Research, 92, 44-51.

Swanson, M., M. Kasi, E. Khan, 2016, Bioavailability of Phosphorus Species in Secondary Effluents, in Proceeding 89th Annual Water Environment Federation Technical Exposition and Conference, Water Environment Federation, Alexandria, VA.

Jingyi, S., H., Simsek, 2016, Bioavailablity of Dissolved Organic Nitrogen to Algal Species, North Dakota Water Resources Research Institute, North Dakota State University, Fargo, ND.

Dose, H.L., 2016, Advancing Soil Health: Linking below Ground Microbial Processes to above Ground Land Management, Ph.D. Dissertation, Department of Soil Science, College of Agriculture, Food Systems, and Natural Resources, North Dakota State University, Fargo, ND.

Leelaruban, N., 2016, Spatial Scale Dependence of Drought Characteristics and Impact of Drought on Agriculture and Groundwater, Ph.D. Dissertation, Department of Civil and Environmental Engineering, College of Engineering, North Dakota State University, Fargo, ND.

Valkov, V.A., 2016, Impact of Artificial Aeration on Phytoplankton Growth and Seasonal Succession in a Eutrophic Lake, Ph.D. Dissertation, Environmental and Conservation Sciences Program, College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND.

Swanson, M., 2016, The Role of Algal Species on Phosphorus Bioavailability in Secondary Wastewater Effluents, M.S. Thesis, Department of Civil and Environmental Engineering, College of Engineering, North Dakota State University, Fargo, ND.