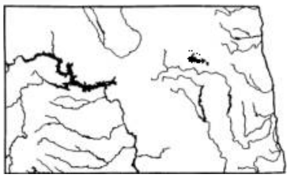
September 2023

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



Newsletter

The National Institutes for Water Resources

http://www.ndsu.edu/wrri

From the Director

I extend my sincere gratitude to Dr. Xuefeng Chu, Professor of Civil, Construction and Environmental Engineering at North Dakota State University (NDSU), for his outstanding leadership over the past three years at the North Dakota Water Resources Research Institute (NDWRRI). Dr. Chu's dedication and professionalism have been invaluable. In August 2022, I assumed the role of Director with strong support from the NDSU Office of Research and Creativity Activity.

This newsletter for the 2021-2022 period introduces the nine NDWRRI Fellows for 2022-2023, and highlights the thirteen graduate fellowship research projects from 2021-2022, along with the related findings and achievements of the Fellows and their advisors.

Over the past few years, we have welcomed several new junior faculty members with expertise in water-related issues, who have joined the two research universities in the State. They are recognized as Institute affiliated faculty, and three of them are introduced in the "Meet Our Faculty" section. This edition also introduces three esteemed Institute affiliate faculty members: Dr. Jiale Xu, Assistant Professor in the Department of Civil, Construction and Environmental Engineering and Dr. Iris Feng, Assistant Professor in the Department of Agricultural and Biosystems Engineering at NDSU, as well as Dr. Mark Kaemingk, Assistant Professor in the Department of Biology at University of North Dakota (UND).

Additional sections provide information about the NDWRRI State Advisory Board Committee. The Institute has consistently benefited from the guidance and assistant of the State Advisory Committee, comprised of Joel Galloway from United States Geological Survey (USGS) ND Water Science Center, Andrew Nygren from ND Department of Water Resources (DWR), and Peter Wax from ND Department of Environmental Quality. Their insightful direction, especially in determining research priorities, allocating Fellowship funding, and aiding in securing support from ND DWR, has been instrumental in the Institute's success.

Inside this issue:

Furthermore, you will find lists of recent water-related publications from the USGS, DWR, and the Institute.

In the 2021-22 fiscal year, the Institute received full base grant funding from USGS, along with supplementary support from the North Dakota DWR. The latter demonstrates a strong commitment from the ND DWR toward supporting research on water resources in the State. The entire supplementary grant has been allocated to support Graduate Fellowships. The Institute extends its appreciation to ND DWR for this invaluable support.

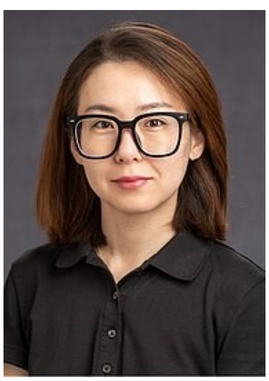
Water stands as a vital resource for the growth and prosperity of North Dakota. It is indispensable for the thriving agriculture and industry sector of the State, as well as for municipal and domestic consumption. The Institute remains steadfast in its commitment of supporting research, education, training, and outreach that contribute to the benefit of water resources in the State.

The Institute has met mandates required by Section 104 of the *Water Resources Research Act of 1984* through a range of research, education, training, and outreach activities addressing water issues in the State. This newsletter, though a small part, is a testament to these efforts.

Thank you for your interest in the Institute, and to those of you who have been a part of it. I hope you find this newsletter informative and enjoyable.

Best regards,
Xinhua Jia, Ph.D., P.E.
Professor, Agricultural and Biosystems Engineering
North Dakota State University

Meet Our New Faculty



Dr. Iris (Xiaoyu) Feng is an Assistant Professor in the Department of Agricultural and Biosystems Engineering. Dr. Feng earned her Ph.D. in Agricultural Engineering from Purdue University, MS in Environmental Engineering from Clemson University, and BS in Environmental Science from Hunan University. Before moving to NDSU in July 2022, Dr. Feng worked as a research associate in the Biological Systems Engineering Department at the University of Wisconsin, Madison and Animal Science Department at the University of California, Davis.

Dr. Feng specializes in a range of research areas, including smart livestock, water and nutrient management, biogas production, process-based modeling, greenhouse gas (GHG) emissions, and life cycle assessments (LCA). Her Research Group at North Dakota State University currently delves into projects of biogas/biofertilizer production from agricultural waste, GHG emissions from ruminants, remote-sensing in controlled environmental agriculture and water contamination related to fertilizer applications. The primary aim of Dr. Feng's group is to discern the short-term and long-term environmental impacts of agricultural activities, and to develop mitigation strategies through precision technology and modeling techniques.

In addition to her research, Dr. Feng teaches undergraduate and graduate courses on Introduction to Controlled Environmental Agriculture (ABEN 286), Bioenvironmental Systems Design (ABEN 452/652), Seminar (ABEN 391), Structures and Environmental Systems (ASM 368), and Management of Agricultural Systems (ASM 475/675). Integrating research findings from Feng’s group into teaching and outreach initiatives, Dr. Feng is dedicated to advancing sustainable and precision agriculture.

Meet Our New Faculty

Dr. Mark Kaemingk is an Assistant Professor of Aquatic Ecology in the Department of Biology at the University of North Dakota (UND). Mark has started the UNDerwater Lab, which focuses on undergraduate and graduate research in aquatic ecology that will contribute to improving natural resource conservation and management. His integrated education and research program requires cross-disciplinary collaborations and novel approaches to address challenges in the Anthropocene. Specifically, Mark enjoys understanding and sharing how cross-scale spatial and temporal processes interact to shape fish communities, anglers, and their environments. We are a question-driven lab and not tied to any particular ecosystem. Thus, students in our lab are working in wetlands, lakes, reservoirs, and rivers. The UNDerwater Lab is excited to form partnerships that will address current and future challenges within aquatic ecosystems.

Mark received his Ph.D. in Fisheries Sciences from South Dakota State University, M.S. in Conservation Biology from Central Michigan University, and B.S. in Wildlife and Fisheries Sciences from South Dakota State University. He then held a National Science Foundation Postdoctoral Fellowship in Biology, working in New Zealand at the Victoria University Coastal Ecology Laboratory. Prior to his current position at UND, Mark was a Research Assistant Professor within the School of Natural Resources and Nebraska Cooperative Fish and Wildlife Research Unit at the University of Nebraska-Lincoln.

Please contact him (mark.kaemingk@und.edu) if you have questions about UND's Fisheries and Wildlife Biology program or research opportunities.

Dr. Jiale Xu is an Assistant Professor in the Department of Civil, Construction and Environmental Engineering at North Dakota State University. Before joining NDSU in August 2022, he worked as a postdoctoral fellow in the Department of Chemical and Environmental Engineering at University of Arizona and subsequently in the School of Civil and Environmental Engineering at Georgia Tech. Dr. Xu's research lies in controlling contaminants of emerging concerns in engineered and natural water systems using physical-chemical processes. His broad research interests span from controlling PFAS in the environment to developing novel technologies for pesticide residual and produced water treatment. He has worked on novel photocatalytic processes based on krypton chloride excimer lamps for pesticide removal, electrochemical technologies to degrade PFAS in wastewater, electrochemical-assisted high-efficiency reverse osmosis for produced water treatment, recovery of rare earth elements from coal fly ash by ionic liquids, and investigation of disinfection byproducts in wastewater recycling. Dr. Xu received a Ph.D. degree in Civil Engineering from SUNY at Buffalo, an M.S. degree in Environmental Engineering from the University of Illinois at Urbana-Champaign, and a B.E degree in Environmental Engineering from Beijing Normal University, Beijing, China.

Xu Research Group at NDSU works on understanding, mitigating, and predicting water pollution by toxic and emerging contaminants, such as PFAS, pesticides, and carcinogenic disinfection byproducts. The major focus is on complex systems with mixtures of contaminants. Current environmental problems commonly exist in the combination of different sources of pollution, making conventional technologies fail to effectively remove each individual contaminant. For example, when PFAS is present at high background salt concentration from agricultural runoff or spilled produced water, strong competition occurs and traditional methods (e.g., adsorption and ion exchange) are ineffective. To tackle these challenges, the Xu Group employs three tiers of research steps. First, the fate and transport of mixtures of contaminants in drinking water, wastewater, and plant-water systems will be investigated to provide insights into hotspots of pollution. Second, novel water treatment technologies, such as photocatalytic processes with far-UVC lamps and advanced electrochemical technologies based on nanomaterials, are developed to remove multiple contaminants simultaneously. Third, mechanistic and statistical models will be established to predict the occurrence and removal of contaminants in these systems. The ultimate goal is to systematically solve environmental issues with interdisciplinary tools.

The Institute Awarded Nine Graduate Fellowships for the Year 2022-2023

The North Dakota Water Resources Research Institute announced its Graduate Research Fellowship recipients for the year 2022-2023. The fellowships were awarded to nine graduate students, including five Ph.D. and four M.S. students, who will conduct water resources research at NDSU and UND. These nine graduate rearch projects are supported with the annual base (104b) federal grant and an additional fund form North Dakota State Water Commission. The 2022-2023 NDWRRI Fellows and their faculty advisors, academic programs, and research projects are listed as follows:

Fellow: Biraj Saha (Ph.D. student) **Advisor:** Syeed Md Iskander
Program: Civil, Construction and Environmental Engineering, North Dakota State University
Title: Per and polyfluoroalkyl substances removal from landfill leachate by coagulation

Fellow: Christine Cornish (Ph.D. student) **Advisors:** Marinus Otte & Jon Sweetman
Program: Environmental and Conservation Sciences/Biological Sciences, North Dakota State University
Title: Reconstructing glyphosate use in the Prairie Pothole Region: A paleolimnological approach

Fellow: Fafa Tackie-Otoo (M.S. student) **Advisor:** Hallie Boyer Chelmo
Program: Mechanical Engineering, University of North Dakota
Title: Treatment and reuse of produced water through the measurement and elimination of coagulated petrochemicals/hydrocarbons in inorganic and organic aqueous solutions

Fellow: Himani Yadav (Ph.D. student) **Advisor:** Syeed Md Iskander
Program: Civil, Construction and Environmental Engineering, North Dakota State University
Title: Landfill leachate plastics: occurrence, transformation, fate, and environmental implications

Fellow: Malachi Graupma (M.S. student) **Advisor:** Achintya Bezbaruah
Program: Civil, Construction and Environmental Engineering, North Dakota State University
Title: Environment friendly phosphate removal and recovery from surface and agricultural waters

Fellow: Mosammat Mustari Khanaum (Ph.D. student) **Advisors:** Xuefeng Chu & Marinus Otte
Program: Civil, Construction and Environmental Engineering, North Dakota State University
Title: Assessing the role of wetlands in reducing sediment and nutrient loads from an impaired watershed in North Dakota

Fellow: Nadhem Ismail (Ph.D. student) **Advisor:** Ali Alshami
Program: Chemical Engineering, University of North Dakota
Title: Synthesis and Performance Evaluation of Novel Carboxyl-Based Grafted Polyacrylamide fibers for Ions Removal from Produced Water (PW)

Fellow: Rehnuma Mobin Maisha (M.S. student) **Advisor:** Dean Steele
Program: Agricultural and Biosystems Engineering, North Dakota State University
Title: Building NRCS technical capacity in irrigation water management for variable rate irrigation

Fellow: Whitney Sauskojus (M.S. student) **Advisors:** Marinus Otte & Jon Sweetman
Program: Environmental and Conservation Sciences/Biological Sciences, North Dakota State University
Title: Aquatic macroinvertebrates as indicators of restoration success in Prairie Pothole Region wetlands

2021-2022 NDWRRI Fellowship Research Highlights

Drought Identification, Categorization, and Prediction in Cold Climate Regions

Mohammad Hadi Bazrkar (Fellow) & Dr. Xuefeng Chu (Advisor), North Dakota State University

Identification, categorization, and prediction of droughts are crucial for mitigating and preventing the drought-induced losses. However, non-stationarity in climate change makes drought prediction more challenging, especially in cold climate regions. Change point detection techniques have been used for drought analysis to fill the gap in drought prediction as a result of nonstationary time series in a changing climate. This study aims to improve drought prediction by removing the nonstationary problem in climatic datasets. In the early stage of this drought study, two new drought indices, including hydroclimatic aggregate drought index (HADI) and snow-based hydroclimatic aggregate drought index (SHADI), were developed. The new method was applied to the Red River of the North Basin (RRB) for drought prediction. Specifically, the nonstationary time series of the selected climatic predictors were divided into stationary time series by using a change point detection technique. Then, canonical correlation analysis was utilized to increase the correlation between predictors and predictands. Support vector regression was applied on each stationary time series to predict the HADI and SHADI. A category-based scoring support vector regression model was developed based on an improved drought categorization method to overcome misclassification in drought prediction. This study provides stakeholders and decision-makers with early warnings of drought development in the RRB, a typical cold climate region and help prevent socio-economic damages and losses from droughts in North Dakota.

Simulation of Soil Water Dynamics for Drip-mulch Fields Using Hydrus-2D

Uday Bhanu Prakash Vaddevolu (Fellow) & Dr. Xinhua Jia (Advisor), North Dakota State University

Hydrus-2D model was used to replicate soil and water behavior under various mulching conditions. In 2020, a field experiment was conducted by incorporating TDR sensors, hydra probe, TEROS 21, and watermark sensors at depths of 5, 15, 30, and 45 cm. These instruments, along with other sensors, were employed to monitor soil water variations under four different mulches, as well as the energy balance above it. Based on this data, a model was established by setting appropriate initial conditions, including soil properties, initial soil moisture, transpiration, drainage parameters, and evaporation rates, in accordance with the domain geometry. Additionally, Van Genuchten parameters were determined using field data obtained from the experiment and incorporated into the model. This model was then applied to simulate soil moisture levels on uncovered soil. Likewise, we defined initial conditions (such as soil moisture and drainage properties) and surface domain conditions (no flux for plastic mulch, variable flux boundary condition for landscape fabric mulch) to replicate soil water dynamics for clear plastic, black plastic, and landscape fabric mulches as well as no mulch. Through this investigation, the efficacy of employing Hydrus-2D was demonstrated for simulating soil water dynamics under various mulching scenarios. Furthermore, by introducing different crops into the model for precision irrigation, more consistent field conditions and optimizing water usage can be achieved, thus positively impacting agricultural practices.

2021-2022 NDWRRI Fellowship Research Highlights

Dynamics of Flows under Ice-coverage in the Red River

Berkay Koyuncu (Fellow) & Dr. Trung Bao Le (Advisor), North Dakota State University

Our project focuses on examining changes in flow dynamics in the presence of ice cover. Within the scope of this project, we conducted field surveys during the summer, winter, and fall seasons of 2021 on the Red River near Lindenwood Park in Fargo, ND. These surveys utilized an Acoustic Doppler Current Profiler (ADCP) in stationary mode. We drilled ice holes and deployed the sensor to collect bathymetry and velocity components along the depth. The collected data sets were processed to identify boundary layers under the ice using the logarithmic law of the wall method and were published in the peer-reviewed journal, Water Resources Research. Our results demonstrate the logarithmic method's applicability in identifying the boundary layer near the river bed under the ice cover. Furthermore, the shear velocity profiles, which were derived from the logarithmic law and a relatively recent quartic solution method, revealed changes in the spatial distribution of bed shear stress caused by the presence of the ice cover. Additionally, the existence of the ice cover altered secondary flow patterns and circulations, which have significant implications for sediment transport and erosion. Finally, we proposed a simple formula for computing the cross-stream distribution of bed shear stress under the ice cover. This method was validated using our field measurements and published in the peer-reviewed journal, The Meandering Streamflows: Patterns and Processes across Landscapes and Scales.

A Novel Numerical Model for Transient Mixed Flow Analysis in Sewer Pipes

David Khani (Fellow) & Dr. Yeo Howe Lim (Advisor), University of North Dakota

Existing models for simulating hydraulic transient flow in conduit systems during wet weather events have limitations, particularly in accounting for column separation in systems with combined open channel and pressurized flows. To address this, we've modified the Two-Component Pressure Method (TPA) to incorporate column separation, resulting in the MTPA model. MTPA accurately calculates both cavitating and pressurized flows using a single set of equations governing unsteady flow in open channels. Comparative analyses with experimental data, the Discreet Gas Cavity Model (DGCM), and analytical solutions from hypothetical systems reveal several key findings: (1) MTPA's results align closely with experimental data; (2) In systems with smaller pipes, MTPA performs on par with DGCM; (3) MTPA, with its realistic pressure distribution on pipe cross-sections, offers more precise calculation of water hammer pressure spike frequencies, especially in systems with larger pipe diameters; (4) MTPA effectively captures the shape of extensive vapor cavities spanning multiple computational cells; (5) In cases of a large vapor cavity in a steep-sloped pipe, DGCM produces inaccurate results, while MTPA accurately calculates the cavitating flow hydraulics; and (6) MTPA successfully captures large vapor cavities forming in the middle of a pipe, characterized by significant energy dissipation. This study underscores MTPA's superiority in automatically capturing vapor cavities and interfaces, making it an accurate and easy-to-implement tool for computing column separation in systems with diverse conduit shapes and flow conditions.

2021-2022 NDWRRI Fellowship Research Highlights

Use of LiDAR and Synthetic Bathymetry to Develop Stream Cross Sections for Alternative Modeling of Streamflow in North Dakota Using HEC-RAS: A Case Study on the Tongue River in North Dakota

James B. Sullivan (Fellow) & Dr. Yeo Howe Lim (Advisor), University of North Dakota

Analyzing streamflow levels is vital for effective flood protection and management. Specialized software like the U.S. Army Corps of Engineers' HEC-RAS is used to compute water surface elevations based on historical or statistical flows. Creating accurate models for river hydraulics relies on precise elevation data, often collected using Airborne LiDAR technology. However, LiDAR data alone may lack vital bathymetric information, especially in areas with flowing water. It's worth noting that near-infrared LiDAR data can present challenges, as water can interfere with LiDAR pulses, leading to inaccuracies in representing the channel bottom. This discrepancy in bathymetry becomes more pronounced with higher flow conditions. To address this, we focused on a segment of the Tongue River near the City of Cavalier in North Dakota. Our goal was to create a synthetic cross-section to complement the missing bathymetry beneath the LiDAR water surface. We estimated the flow area of the absent bathymetry using a model of the flow area above the LiDAR surface. Before conducting flow calculations, we manually corrected triangular surface distortions through a process of hydro-flattening the cross sections. Synthetic bathymetry was approximated using a trapezoidal shape. Comparative analyses of HEC-RAS model results were conducted for different scenarios: a USGS gage, an established calibrated Tongue River model with existing bathymetry, a LiDAR-only model, and a model with synthetic bathymetry. The synthetic bathymetry closely matched water surface elevations for the USGS gauge and the calibrated model. Further research is needed to simplify or automate the process of generating synthetic bathymetry.

Hydraulic and Hydrologic Routing Parameters in Natural Channels in North Dakota Under Snowmelt-induced Flooding Conditions

Vida Atashi (Fellow) & Dr. Yeo Howe Lim (Advisor), University of North Dakota

This research paper presents the development of a nonlinear Muskingum model that achieves precise flood routing through river reaches while considering lateral inflow conditions. Incorporating lateral inflow conditions in the Muskingum model allows for the consideration of additional water inputs from surrounding areas, such as tributaries, which play a crucial role in the accurate prediction of flood routing dynamics within river reaches. Fourteen pairs of flood hydrographs found at two specific United States Geological Survey (USGS) stations located along the Red River of the North, namely Grand Forks and Drayton, are used for the calibrations and validations of the Muskingum model. To enhance the accuracy of the procedure, a reach is divided into multiple sub-reaches, and the Muskingum model calculations are performed individually for each interval using the distributed Muskingum method. Notably, the model development process incorporates the use of the Salp Swarm algorithm. The obtained results demonstrate the effectiveness of the developed nonlinear Muskingum model in accurately routing floods through the very gentle river channel between the USGS stations with a bed slope of (0.0002 to 0.0003). The number of sub-reaches in a model has a significant influence on parameter estimates and model performance, as demonstrated by the analysis of hydrologic parameters and performance evaluation criteria. Optimal performance varied across case studies, emphasizing the importance of selecting the appropriate number of sub-reaches for accurate peak discharge predictions. The field application of the developed model in calibration and validation steps shows its ability for flood modeling in real conditions.

2021-2022 NDWRRI Fellowship Research Highlights

Impact of Groundwater Tables on the Water Use, Yield, Root Growth Distribution and Quality of Spring Wheat (Triticum aestivum L.)

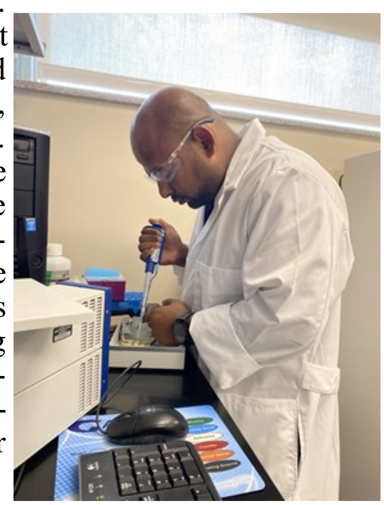
Franklin Odili (Fellow) & Dr. Halis Simsek (Advisor), North Dakota State University

Groundwater is a significant source of plant water use since groundwater consumption of plants reduces the volume of surface irrigation water. In this study, groundwater table effect on hard red spring wheat (Triticum aestivum L.) growth and yield parameters were investigated using a lysimeter technique in a controlled environment. Three different groundwater table depths including 30, 60, and 90 cm and a control treatment with surface irrigation were tested. The results showed that water consumption in the 90 cm water table depth was 11% and 31% lower than the water consumption in the 60 and 30 cm water table depths, respectively. Consequently, the groundwater table depth increased, and crop water consumption decreased. Similarly, with the increasing water table depth from 30 to 90 cm in the lysimeter, the crop water use efficiency and crop yield increased by 79% and 71%, respectively. The 90 cm water table produced the highest crop yield, aboveground biomass, and kernel quality compared to 30 and 60 cm water table depths. Quality analysis of the wheat kernels indicated that the kernels from the 90 cm depth had relatively higher starch content, pasting properties, and gluten proteins compared to the kernels from other water table depths.

Microalgae Based Biofilm-mediated Nutrient Removal from Municipal Wastewater and Bioenergy Generation

Shashi Bhushan (Fellow) & Dr. Halis Simsek (Advisor), North Dakota State University

Microalgae, minute eukaryotic organisms proficient in photosynthesis, offer substantial promise for wastewater treatment, energy generation, and nutraceutical applications. However, their cultivation and harvest present significant challenges. The high cost of growth media necessitates meticulous testing to optimize their growth. Employing wastewater in attached media systems emerges as a cost-effective alternative. In this study, we utilized simulated wastewater to evaluate the growth of four algal strains. Among them, *C. sorokiniana* demonstrated the highest biomass productivity at 111.97 ± 0.9 mg L-1d-1. The integration of image analysis and the Modified Gompertz model proved instrumental in tracking growth dynamics. Moreover, distinct CH_4 yield patterns were observed across strains, with *C. minutum* and *C. vulgaris* emerging as noteworthy contenders. Subsequently, *Chlorella sp.* were selected for further pretreatment investigations. UV-C pretreatment facilitated the release of 73.61 mgL-1 of sugar after 10 hours of exposure. Enzymatic pretreatment yielded a maximum sugar yield of 190 mgg-1 biomass and a peak soluble chemical oxygen demand (sCOD) of 1350 mgg-1 biomass. This study establishes critical parameters for the enzymatic pretreatment of algal biomass, providing valuable insights into tailoring operational conditions for specific biofuel production requirements. The findings not only contribute to advancing algal-based technologies but also underscore the potential of microalgae in sustainable wastewater treatment and renewable energy production.



2021-2022 NDWRRI Fellowship Research Highlights

Assessment of Agricultural Impact on Biotic Components of North Dakota Wetland Resources Using Habitat Suitability Landscape Genomics of Amphibians

Justin Waraniak (Fellow) & Dr. Craig Stockwell (Advisor), North Dakota State University

We conducted genetic surveys of northern leopard frog (*Rana pipiens*) populations across North Dakota, with intensive sampling within the Lake Oahe and James River basins to analyze genetic patterns at multiple spatial scales. Within the Lake Oahe and James River basins, we tested landscape effects on connectivity and found land use and topographic roughness were the most important factors influencing gene flow among leopard frog breeding populations. Grasslands and flat areas were the most important habitat for maintaining connectivity, while cropland acted as a permeable barrier and urban, open water, and steep terrain were impassable barriers. We also found evidence for local adaptation due to climate and agriculture, identifying 57 genes that appeared to be responding to climate differences and pesticide usage. Statewide, we found similar patterns in adaptive genetic variation being influenced by climate, though few genes were identified as under selection with high confidence. Northern leopard frog populations were morphologically similar across the state, contrasting with the higher degree of genetic differentiation. These studies provide information on the amount and arrangement of genetic diversity within populations of one of North Dakota's most abundant and widespread amphibian species. This research forms the basis with which to predict how leopard frog populations may respond to future changes in climate and land use and may help identify populations at risk or identify populations that may be suitable donors for genetic rescue programs supporting other leopard frog populations in the northern Great Plains.

Does Wetland Restoration Affect the Accumulation of Glyphosate?

Christine Cornish (Fellow) & Drs. Jon Sweetman & Marinus Otte (Advisors), North Dakota State Univ.

In the Prairie Pothole Region, wetland restoration is an important remediation tool. However, more information is needed on how its efforts impact agrochemicals and microbial succession, which play crucial roles in ecosystem functioning. This project is investigating relationships between wetland restoration, common use herbicides, and microbial communities. I collected surface sediment (~5 cm depth) from 20 wetlands in North Dakota, where 15 wetlands were restored and 5 were natural. Sediments were analyzed for the top five most commonly used herbicides in the region, glyphosate, atrazine, 2,4-D, metolachlor, and acetochlor. Results showed non-detectable residues or residues below the limit of quantification in all samples for all herbicides tested. This could indicate that herbicide residues are not persistent in benthic sediments of these wetlands, potentially due to microbial degradation. Additionally, sediments were used to extract environmental [prokaryotic] DNA and sequence the 16S rRNA gene. Preliminary data show no differences in richness or diversity between restored and natural wetlands. These results suggest that rapid succession of microbial communities occurs after restoration, which would be beneficial for biogeochemical-related wetland functions. Using herbicide residue analysis and microbial communities, my findings give a brief picture on how wetlands chemically and biologically respond to restoration.

2021-2022 NDWRRI Fellowship Research Highlights

Understanding the Impacts of Hydrology on Seasonal and Spatial Water Chemistry Changes in Two Adjacent Prairie Potholes in North Dakota Using Stable Isotopes

Kui Hu (Fellow) & Drs Jon Sweetman & Craig Stockwell (Advisors), North Dakota State University

Prairie-pothole wetlands are an important freshwater resource in the Northern Great Plains and play a crucial role in providing vital ecosystem services. The high variability of regional meteorological conditions and complicated hydrology can make it challenging to effectively predict changes in water chemistry. As wetland water chemistry changes are the function of processes like evaporative concentration, dilution of snowmelt and rainfall, export through surface outlets or seepage to groundwater, which could be reflected by water isotope. In this study, combing meteorological data, we examined water stable isotopes and chemical changes from two adjacent, but hydrologically different, prairie-pothole wetlands over a two-year period at the Cottonwood Lake Study Area, North Dakota. Our results show the lower deuterium excesses indicated higher evaporation in both wetlands in the year 2018 with higher temperature and precipitation. Higher nutrient concentrations in both wetlands responded mostly to increased rainfall, while major ion concentrations were more closely related to the presence or absence of an overland outlet. Overall, the closed-basin wetland had higher concentrations of major ions compared to the open-basin wetland, which was likely due to the input of surface-subsurface exchanges of salts with wetland sediments, and a lack of surface outflows. This study highlight the importance of considering basin topographic features such as natural or artificial outlets when managing prairie-pothole wetlands.

An Investigation of Thermal Air Degradation and Pyrolysis of Per– and Polyfluoroalkyl Substances (FPASs) and Aqueous Film-Forming Foams in Soil

Ali Alinezhad (Fellow) & Dr. Feng Xiao (Advisor), University of North Dakota

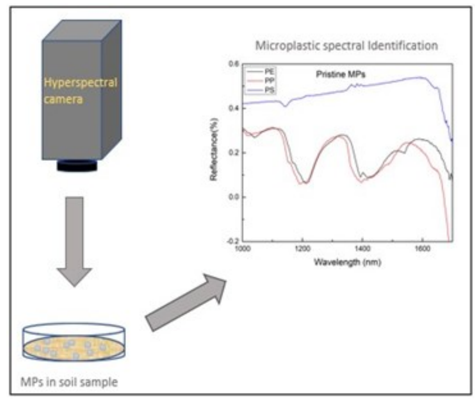
Per- and polyfluoroalkyl substances (PFAS) are synthetic organofluorine chemicals that have been mass-produced since the 1950s for a variety of high-temperature resistant products, such as nonstick cookware and aqueous film-forming foams (AFFFs) for firefighting devices. Remediation of PFAS-contaminated sites is currently a national priority in the United States. Thermal treatment is one of the technological solutions that is commercially available and has the capacity to degrade or manage the migration of PFAS in contaminated materials. However, a few key parameters that may affect the thermal remediation of PFAS-contaminated soils have been understudied and the effect of the temperature−time profile were unclear. In this project, 18 PFAS chemicals in six classes as well as 2 AFFF samples were included. The effects of different factors such as thermal parameters (heating temperature and heating time), PFAS properties, soil texture, and PFAS concentration in soil were analyzed in order to improve thermal treatment efficiency of PFAS-contaminated soil. Our findings demonstrated that thermal treatment of soil at an appropriate heating temperature (≥500 °C) and time (≥30 min) leads to a near-complete decomposition of the studied PFAS in the soil. Lastly, we investigated that the emission of Fluoride radicals (which is a technological challenge in thermal treatment) can be significantly reduced with the presence of kaolinite or soil. This result could be extremely beneficial for decision makers in thermal remediation facilities, equipping them to effectively combat PFAS contamination within soil substrates.

2021-2022 NDWRRI Fellowship Research Highlights

Fate and Transport of Microplastics in Natural Environment

Mansurat Abdulmalik Ali (Fellow) & Dr. Feng Xiao (Advisor), University of North Dakota

Microplastics is steadily evolving to be the most numerically abundant items in the natural environment, its quantities will continue to increase as the concentration of large plastic items degrades into millions of microplastic pieces by weathering, by chemical or biological processes. Plastics has become essential feature of human life. The steady increase on the use of plastics as production increases has drastically increases the rate of plastic waste generated via primary and secondary sources in turn enhances the influx disposable plastics of all shapes and sizes clogging our waterways and polluting the earth. As microplastics is ubiquitous and have been found in many water systems, its fate and transport in the aquatic environment are still very understudied, a gap this project intend to fill.



Thermal Stability of Per– and Polyfluoroalkyl Substances and the Impact on the Aquatic Environment

Pavankumar Challa Sasi (Fellow) & Dr. Feng Xiao (Advisor), University of North Dakota

Poly- and perfluoroalkyl substances (PFAS) are a large group of organic contaminants that have been detected nationally in the aquatic environment. Two PFAS compounds, perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), have been observed in >95% of the blood samples collected during multiple U.S. national surveys at health-relevant concentrations. Contaminated drinking water is a major source exposure to PFAS for the general public. The U.S. EPA has recently set a drinking water advisory on the combined level of PFOA and PFOS at 0.070 μg/L, making removal of PFAS from drinking-water sources a priority issue. The goal of this project is to develop a thermal remediation method that can effectively and practically remove PFAS from contaminated soils in order to protect the groundwater. The results of this project have important implications for technological improvements in soil/aquifer remediation. Environmental consulting firms, water resources personnel, and the broader education and research communities who are concerned about PFAS contamination would benefit from the results of this proposal.

NDWRRI State Advisory Board Committee

Joel Galloway, Section Chief, U.S. Geological Survey, Dakota Water Science Center, Bismarck, ND

Andrew Nygren, Hydrologist, Water Appropriation Division, North Dakota Department of Water Resources, Bismarck, ND

Peter Wax, Environmental Scientist, North Dakota Department of Environmental Quality, Bismarck, ND

Recent Publications and Presentations by Institute Fellows and PIs

Journal Papers

Alinezhad, A., Challa Sasi, P., Zhang, P., Yao, B., Kubátová, A., Golovko, S.A., Golovko, M.Y. , & Xiao, F. (2022). An investigation of thermal air degradation and pyrolysis of per-and polyfluoroalkyl substances and aqueous film-forming foams in soil. *ACS ES&T Engineering.* (https://doi.org/10.1021/acsestengg.1c00335)

Atashi, V., Gorji, H. T., Shahabi, S. M., Kardan, R., & Lim, Y. H. (2022). Water level forecasting using deep learning time-series analysis: a case study of Red River of the North. *Water,* 14(12), 1971.

Atashi, V., Barati, R., & Lim, Y. H. (2023). Improved river flood routing with spatially variable exponent muskingum model and sine cosine optimization algorithm. *Environmental Processes*, 10(3), 42.

Bazrkar, M. H., & Chu, X. (2021). Ensemble stationary-based support vector regression for drought prediction under changing climate. *Journal of Hydrology* 603, 127059, 1-14, doi:10.1016/j.jhydrol.2021.127059.

Bazrkar, M. H., & Chu, X. (2022). Development of category-based scoring support vector regression (CBS-SVR) for drought prediction. *Journal of Hydroinformatics* 24(1): 202-222, doi:10.2166/hydro.2022.104.

Bhushan, S., Rana, M. S., Bhandari, M., Sharma, A. K., Simsek, H., & Prajapati, S. K. (2021). Enzymatic pre-treatment of algal biomass has different optimal conditions for biogas and bioethanol routes. *Chemosphere*, *284*, 131264, https://doi.org/10.1016/j.chemosphere.2021.131264

Bhushan, S., Eshkabilov, S., Jayakrishnan, U., Prajapati, S. K., & Simsek, H. (2023). A comparative analysis of growth kinetics, image analysis, and biofuel potential of different algal strains. *Chemosphere*, 139196, https://doi.org/10.1016/j.chemosphere.2023.139196

Bhushan, S., Jayakrishnan, U., Shree, B., Bhatt, P., Eshkabilov, S., & Simsek, H. (2023). Biological pretreatment for algal biomass feedstock for biofuel production. *Journal of Environmental Chemical Engineering*, *11*(3), 109870, https://doi.org/10.1016/j.jece.2023.109870

Hu, K., Mushet, D. M., & Sweetman, J. N. (2022). Multiproxy paleolimnological records provide evidence for a shift to a new ecosystem state in the Northern Great Plains, USA. *Limnology and Oceanography*. https://doi.org/10.1002/lno.12218

Khani, D., Lim, Y.H., & Malekpour, A. A. (2021). Mixed flow analysis of sewer pipes with different shapes using a non-oscillatory wwo-component pressure approach (TPA). *Modelling* 2021, 2, 467-481. https://doi.org/10.3390/modelling2040025

Khani, D., Lim, Y.H., & Malekpour, A. (2022). Calculating column separation in conduit systems using an innovative open channel based model. *ASCE Journal of Hydraulic Engineering*, 2022. https://doi.org/10.1061/JHEND8.HYENG-13197

Khani, D., Lim, Y.H., & Malekpour, A. (2022). Calculating column separation in liquid pipelines using a 1D-CFD coupled model. *Mathematics* 2022, 10, 1960. https://doi.org/10.3390/math10121960

Khani, D., Lim, Y.H., & Malekpour, A. (2023). Investigating the performance of the modified two-component pressure approach in capturing column separation with large vapor cavities. *Journal of Hydraulic Research*, 2023. https://doi.org/10.1080/00221686.2023.2231397

Koyuncu, B., & Le, T. (2022). On the impacts of ice cover on flow profiles in a bend. *Water Resources Research* 58(9). https://doi.org/10.1029/2021WR031742

Koyuncu, B., & Le, T. (2022). On the impacts of ice cover on flow profiles in a bend. Water Resources Research, https://doi.org/10.1029/2021WR031742.

Koyuncu, B., & Le, T. (2024). Modeling shear stress distribution in ice-covered streams. Geological Society, London, Special Publications, https://doi.org/10.1144/SP540-2022-161

Recent Publications and Presentations by Institute Fellows and PIs

Journal Papers

Odili, F., Bhushan, S., Hatterman-Valenti, H., Magallanes Lopez, A. M., Green, A., Simsek, S., Vaddevolu, U., & Simsek H. (2023). Water table depth effect on growth and yield parameters of hard red spring wheat (*Triticum aestivum* L.): a lysimeter study. *Applied Water Science* 13:65 https://doi.org/10.1007/s13201-023-01868-8

Vaddevolu, U.B.P., Lester, J., Jia, X., Scherer, T.F., & Lee, C.W. (2021). Tomato and watermelon production with mulches and automatic drip irrigation in North Dakota. *Water* 13(14): 1991. https://doi.org/10.3390/w13141991. https://www.mdpi.com/2073-4441/13/14.

Waraniak, J. M., Mushet, D. M., & Stockwell, C. A. (2022). Over the hills and through the farms: Land use and topography influence genetic connectivity of northern leopard frog (*Rana pipiens*) in the Prairie Pothole Region. *Landscape Ecology* 37(11): 2877-2893, https://doi.org/10.1007/s10980-022-01515-8

Conference/Seminar Presentations

Ali, M.A. & & Xiao, F. (2022). A review of the fate and transport of microplastics in the natural environment. ND EPSCoR 2022, Established Program to Stimulate Competitive Research (Virtual), April 06-22, Grand Forks, ND.

Ali, M.A. & Xiao, F. (2022). Exploring a new method of microplastic identification. Sustainable Infrastructure Research Initiative, College of Engineering and Mines (UND), July 22-22, Grand Forks, ND.

Alinezhad, A., Challa Sasi, P., Zhang, P., Yao, B., Kubátová, A., Golovko, S.A., Golovko, M.Y., & Xiao, F. (2021). Thermal remediation of soil-borne per- and polyfluoroalkyl substances. Inaugural North Dakota Regional Environmental Conference, October 7, 2021, Bismarck, ND.

Alinezhad, A., Challa Sasi, P., Zhang, P., Yao, B., Kubátová, A., Golovko, S.A., Golovko, M.Y. & Xiao, F. (2022). Investigation of thermal air degradation and pyrolysis of PFAS and PFAS alternatives in soil. ACS Spring Meeting, March 20-24, 2022, San Diego, CA.

Atashi, V., Rosati, M., Lim, Y. H., & Taufique, M. Characteristics of seasonality on 3D velocity and bathymetry profiles in Red River of the North. In World Environmental and Water Resources Congress 2022 (pp. 252-263).

Bazrkar, M. H. & Chu, X. (2021). Category-based scoring support vector regression (CBS-SVR) to overcome mis-categorization in drought prediction. AGU Fall Meeting, December 13-17, 2021, New Orleans, LA.

Bazrkar, M. H. & Chu, X. (2022). Application of a window-based change point detection technique to remove non-stationarity in drought prediction. ASCE 2022 World Environmental and Water Resources Congress, June 5-8, 2022, Atlanta, GA.

Cornish C., Yuan Y., Sauskojus W., Otte M., Sweetman J. 2022. Herbicides in wetlands: The importance of sediments. North Dakota Water Quality Monitoring Council Conference. March 21, 2022, Bismarck, ND. Presentation by Cornish.

Eshkabilov, S., Bhushan, S., Prajapati, S. K., & Simsek, H. (2023). A comparative analysis of growth kinetics, image analysis, and biofuel potential of different algal strains. ASABE 2023 Annual International Meeting, July 8-12, Omaha, Nebraska.

Hu, K., Mushet, D.M., & Sweetman, J.N. (2021). Understanding the impacts of hydrology on seasonal and spatial water chemistry changes in two adjacent prairie potholes in North Dakota using stable isotopes. PALS, May 4-5, 2021. Virtual Meeting.

Hu, K., Mushet, D.M., & Sweetman, J.N. (2021). Multi-proxy paleolimnological record provide evidence for a shift to a new ecosystem state in the Northern Great Plains Society for Freshwater Science, May 23-27, 2021. Virtual Meeting.

Recent Publications and Presentations by Institute Fellows and PIs

Conference/Seminar Presentations

Hu, K., Mushet, D.M., & Sweetman, J.N. (2021). Using stable isotopes to better understand hydrological impacts on water chemistry in prairie-pothole wetlands of the Northern Great Plains, USA. Great Plains Limnology Conference, Oct 23, 2021. Virtual Meeting.

Hu, K., Mushet, D.M., & Sweetman, J.N. (2022). Using stable isotopes to better understand hydrological impacts on water chemistry in prairie-pothole wetlands of the Northern Great Plains, USA. North Dakota Water Quality Monitoring Conference, Mar 21-23, 2022. Bismarck, ND.

Hu, K., Mushet, D.M., & Sweetman, J.N. (2022). Multi-proxy paleolimnological records provide evidence for a shift to a new ecosystem state, Northern Great Plains. Joint Aquatic Science Meeting (JASM), May 14-21, 2022. Grand Rapids, MI.

Koyuncu, B., & Le, T. (2022). The impact of ice cover on the secondary flow structures at the bend apex. APS Division of Fluid Dynamics, November 20-22, 2022, Indianapolis, IN.

Koyuncu, B., & Le, T. (2022). Secondary flow structures in ice-covered bend. AGU Fall Meeting 2022, December 12-16, 2022, Chicago, IL.

Le, T., & Koyuncu, B. (2022). Three-dimensional structures of ice-covered flow in a river bend storage of depression-dominated regions for macro-scale hydrologic modeling, River Flow 2022, November 8-10, 2022, Kingston and Ottawa, Canada.

Le, T., & Koyuncu, B. (2022). Large eddy simulation of ice-covered flows in a river bend. AGU Fall Meeting 2022, December 12-16, 2022, Chicago, IL.

Khani, D., Lim, Y.H., & Malekpour, A. (2021). Evaluating the performance of a non-oscillatory TPA approach in mixed flow analysis of sewer pipes with different shapes. The ICWMM Conference Feb. 24 – 25, 2021.

Khani, D., Lim, Y.H., & Malekpour, A. (2021). Towards a comprehensive model for analyzing transient flow in sewer pipe systems. The ASCE EWRI Conference June 7 - 11, 2021.

Khani, D., Lim, Y.H., & Malekpour, A. (2023). An innovative open channel flow-based model for calculating column separation. 14th International Conference on Pressure Surges, Pressure Surge 2023, Eindhoven, NL:12th-14th April 2023. pressuresurges14.win.tue.nl.

Odili, F., Bhushan S., Magallanes López, A. M. & Simsek, H. (2021). Impact of groundwater tables on yield, water use, root distribution, and seed quality of hard red spring wheat (Triticum aestivum L.). 3rd International Water and Waste Management conference (Virtual). Feb 24 – 26, 2021.

Odili, F., Bhushan S., Magallanes López, A. M. & Simsek, H. (2021). Impact of groundwater tables on yield, water use, root distribution, and seed quality of hard red spring wheat (Triticum aestivum L.). American Chemical Society, Fall 2021 Conference. Aug 22 -26, 2021. Atlanta, Georgia.

Sullivan, J.B., & Lim, Y.H. (2022). Use of LiDAR and Synthetic Bathymetry to Develop Stream Cross Sections for Alternative Modeling of Streamflow Using HEC-RAS. American Water Resources Association 2022 Geospatial Water Technology Conference, May 9-12, 2022, Austin, TX.

Vaddevolu, U.B.P., & Jia, X. (2021). Soil moisture sensor-controlled drip irrigation for watermelon production in North Dakota. 2021 South Dakota Student Water Conference. October 19, 2021, Brookings, SD. Presentation by Vaddevolu.

Vaddevolu, U.B.P, & Jia, X. (2022). Comparison of measured and simulated soil water dynamics in a drip-mulch field. 2022 ASABE International Meeting, July 16-21, 2022. Houston, TX. [Oral].

Recent Publications and Presentations by Institute Fellows and PIs

Reports

Sauter, J. (2019). 2022 Pesticide Sediment Monitoring Pilot Report. North Dakota Department of Agriculture, Pesticide and Fertilizer Division, Bismarck, ND (available at: https://www.ndda.nd.gov/sites/www/files/documents/files/2022%20Sediment%20Report.pdf).

Theses and Dissertations

Atashi, V. (2023). Dynamics of flood flow in Red River Basin (Doctoral dissertation, The University of North Dakota). (available at: https://www.proquest.com/openview/1b191286a983a49cf9f35ff70db38b06/1?pq-origsite=gscholar&cbl=18750&diss=y).

Bazrkar, M. H. (2021). Identification, categorization, and prediction of drought in cold climate regions. Ph.D. Dissertation. Civil Engineering, College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND. ProQuest Dissertations Publishing, 2021. 28646651.

Bhushan, S., (2023). Enhancement of biofuel production through pretreatment strategies using algae as a substrate. PhD Dissertation. Environmental and Conservation Sciences. College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND

Khani, D. (2022). A Novel numerical model for transient mixed-flow analysis in pipe and conduit systems. Ph.D. Dissertation, School of Graduate Studies, The University of North Dakota, Grand Forks, ND (available at: A Novel Numerical Model for Transient Mixed-Flow Analysis in Pipe and Conduit Systems - ProQuest).

Odili, F. E. (2021). Impact of groundwater table on yield, water use, root distribution, and seed quality of hard red spring wheat (*Triticum aestivum* L.). M. S. Thesis. Environmental and Conservation Sciences, College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND (available at: https://library.ndsu.edu/ir/handle/10365/32738)

Sasi, P.C. (2022). Thermal stability and decomposition of per-and polyfluoroalkyl substances (PFAS) using granular activated carbon and other porous materials. https://commons.und.edu/theses/4329/

Sullivan, J.B. Use of LiDAR and synthetic bathymetry to develop stream cross sections to alternative modeling of stream flow in North Dakota using HEC-RAS: A case Study on the Tongue River in North Dakota.

Vaddevolu. U. B. P. (2023). Automatic soil water potential sensor-based irrigation system for tomato and watermelon production. Ph.D. Dissertation. Agricultural and Biosystems Engineering. College of Engineering. North Dakota State University, Fargo, ND.

Waraniak, J. M. (2023). Conservation Genetics of the Northern Leopard Frog in North Dakota: Connectivity, Local Adaptation, and Phylogeography. Ph.D. Dissertation. Environmental and Conservation Sciences Program, College of Graduate and Interdisciplinary Studies, North Dakota State University, Fargo, ND (available at: https://www.proquest.com/docview/2822219245)

Conference/Seminar Presentations

Waraniak, J.M., Mushet, D.M., & Stockwell, C.A. (2022). Population connectivity in agricultural landscapes: land use affects gene flow in northern leopard frog (Rana pipiens) in the Prairie Pothole Region. 2022 Joint Aquatic Sciences Meeting, May16-20, 2022, Grand Rapids, MI.

Waraniak, J.M., Mushet, D.M., & Stockwell, C.A. (2022). Population connectivity in agricultural landscapes: land use affects gene flow in northern leopard frog (Rana pipiens) in the Prairie Pothole Region. 2022 American Society of Ichthyologists and Herpetologists Annual Meeting, July 25-31, 2022, Spokane, WA.

Awards

Berkay Koyuncu: 2021, awarded with a travel grant by American Physical Society (APS) for the conference (DFD 2021) participation.

David Khani: 2023, Nominated for the Doctoral Excellence in Dissertation Writing Award

Kui Hu: 2021, Harvey K. Nelson scholarship, North Dakota State University, USA.

Kui Hu: 2022, Global Lake Ecology Observation Network (GLEON) travel support for GLEON All Hands' Meeting, New York, USA.

Featured Author:
Khani, D., Lim, Y.H., & Malekpour, A. (2022). A new method to calculate column separation and surge in conduit systems. Advances in Engineering, 2022. A New Method to Calculate Column Separation and Surge in Conduit Systems - Advances in Engineering (advanceseng.com)

In the News:
Khani, D. 2023. Civil Engineering doctoral graduate's paper showcased as Editor's Choice in ASCE Journal Civil Engineering doctoral graduate's paper showcased as Editor's Choice in ASCE Journal - College of Engineering & Mines (und.edu).

Recent USGS Publications

USGS Dakota Water Science Center Publications can be found at https://www.usgs.gov/centers/dakota-water/publications:

Awasthi, C., Archfield, S.A., Ryberg, K.R., Kiang, J.E., & Sankarasubramanian A. (2022). Projecting flood frequency curves under near-term change. USGS Scientific Investigations Report 70238066, doi: 10.1029/2021WR031246.

Norton, P.A., Delzer, G.C., Valder, J.F., Tatge, W.S., & Ryberg, K.R. (2022). Assessment of streamflow trends in the eastern Dakotas, water years 1960-2019. USGS Scientific Investigations Report 2022-5055, doi: 10.3133/sir20225055.

Marti, M.K., Ryberg, K.R., & Levin, S.B. (2023). Flood-frequency analysis in the Midwest: addressing potential nonstationarity of annual peak-flow records. USGS Scientific Investigations Report 70246314.

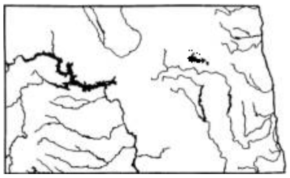
Marti, M.K., & Ryberg, K.R. (2023). Method for identification of reservoir regulation within U.S. Geological Survey streamgage basins in the Central United States using a decadal dam impact metric. USGS Scientific Investigations Report 2023-1034. doi: 10.3133/ofr20231034.

Recent ND Department of Water Resources Publications

North Dakota Department of Water Resources Biennial Report 2019-2021. https://www.swc.nd.gov/info_edu/reports_and_publications/bieenial_reports/pdfs/2019-2021.pdf

North Dakota Department of Water Resources 5 Year Strategic Plans 2022 – 2027. https://www.swc.nd.gov/info_edu/reports_and_publications/pdfs/2022%205%20Year%20Strategic%20Plan.pdf

North Dakota Department of Water Resources Alternative Funding Sources. https://www.swc.nd.gov/pdfs/alterantive_sources_funding_brochure.pdf



North Dakota Water Resources Research Institute
North Dakota State University
P.O. Box 6050 Dept. 2890
Fargo, ND 58108-6050

Phone: 701-231-6453
E-mail: Xinhua.Jia@ndsu.edu
Website: www.ndsu.edu/wrri

North Dakota Water Resources Research Institute (NDWRRI)

The Institute was founded in 1965 by authority of Congress as one of the 54 Institutes throughout the nation and is administered through the United States Geological Survey. The NDWRRI receives funding through section 104 of the Water Resources Research Act of 1984 and it applies its Federal allotment funds to 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 the public.