SPRING 2019 ISSUE

Environmental Science and Policy PULSE

Addressing PFAS in the state of Michigan

An ESPP policy paper by:
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Kayleigh Ward

Environmental Science and Policy Program
MICHIGAN STATE UNIVERSITY

environment.msu.edu

Summer Research Fellowships

Congratulations to the students chosen to receive ESPP Summer Research Fellowships for 2019:

SUYUG CHAUDHARI (CIVIL AND ENVIRONMENTAL ENGINEERING) "SUSTAINABLE HYDROPOWER DEVELOPMENT IN THE AMAZON BASIN"

MOHSEN GOODARZI (PLANNING, DESIGN AND CONSTRUCTION) "THE IMPACTS OF PHYSICAL ENVIRONMENT OF NET-ZERO WATER AND ENERGY NEIGHBORHOODS ON HUMAN WELLBEING"

JOSEPH LEE-CULLIN (EARTH AND ENVIRONMENTAL SCIENCE, ESPP) "HOMOGENIZATION OF LANDSCAPE DERIVED DISSOLVED ORGANIC CARBON WITHIN THE SEDIMENT WATER INTERFACE"

KATELYN KING (FISHERIES AND WILDLIFE) "CROSSING SCALE AND ECOSYSTEM BOUNDARIES TO BETTER UNDERSTAND MACROSCALE FISH"

KYLE REDICAN (GEOGRAPHY, ENVIRONMENT AND SPATIAL SCIENCES) "STRUCTURAL AND SPATIAL ANALYSIS OF COMMUNITY WATER SYSTEMS"

GABRIELA SHIRKEY (GEOGRAPHY, ENVIRONMENT AND SPATIAL SCIENCES, ESPP) "LINKING GLOBALIZATION TO PRIVATE LAND MANAGEMENT: A NOVEL APPROACH TO HISTORICAL GLOBAL WARMING"

XINYI TU (PLANT, SOIL AND MICROBIAL SCIENCES, ESPP) "IDENTIFYING CHALLENGES TO BUILDING A SOIL HEALTH DECISION TOOL"

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MESSAGE FROM THE DIRECTOR:

Dr. Jiaguo Qi

As many of you are intimately aware, this has been a great year of transitions for the Environmental Science and Policy Program. A year ago, we were bidding farewell to our director of six years, Dr. Jinhua Zhao. Then in the fall, we began a new era of ESPP as a Dual Major program, and I began my new role as Director of ESPP.

In addition to leading ESPP, I am also the co-Director of the Office of China Programs, Director of the Center for Global Change and Earth Observation and Professor of Geography, Environment and Spatial Sciences. I believe that my experience in these areas allow me to bring together the resources of not just ESPP but of the CGCEO and other programs at MSU to break down barriers between departments and disciplines to create a powerful, interdisciplinary research program that is capable of addressing more complex challenging issues facing the world.

My vision for the future of the ESP program is "Synergy for Excellence." I believe in synergy not only between departments but between disciplines. I envision all people - students, faculty, staff and researchers from different departments, different universities and international partners - coming together to become stronger and better.

I see my role as coordinating and leading this synergy to take us all to the next level by building on existing strengths such as ESPP's funding programs and our strong engagement with faculty around campus. The next step is to focus on a key priority areas and initiate a limited number of undertakings that none of us could do individuality but together, we can be successful and impactful.

ESPP is gifted with talented faculty, staff and students. Synergized and coordinated, we can achieve something bigger and more impactful. By enabling a collegial platform through synergy among participating units with shared vision and goals, we can become a global leader in environmental science and technology. This will allow us to address key emerging environmental challenges in the face of increased globalization, climate change and social unrest.

Working closely with Deans, the Faculty Advisory Council, and faculty, I plan to create a world class platform passionately committed to excellence in knowledge generation interwoven with research and a graduate education in environmental science, technology and policy.

I hope to promote and enable cutting-edge environmental education program at MSU to address national and global research priorities, build and ensure a successful campus wide graduate education program interwoven with research and engagement. My goal is to establish MSU as a global leader in global environmental research, education and engagement.

For all of this, I need your help. Please take a few minutes to send me your thoughts on the future of the Environmental Science and Policy Program to espp@msu.edu. And also keep an eye open for a survey coming later this spring to more extensively solicit ideas on how to make ESPP even more innovative and impactful.

Saying Goodbye: Dr. Shengpan Lin (1981-2018)

Dr. Shengpan Lin, an assistant professor in the Social Science Data Analytics Initiative at MSU, died Sept. 2 in a vehicle crash near Uncle John's Cider Mill in Clinton County.

Lin, 37, received his doctoral degree in Integrative Biology and Environmental Science and Policy at MSU in 2017. During his time studying and working at the university, Lin met colleagues who would eventually become his close friends. Several of them talked about the impact Lin had on their lives.

Lin was a kind friend and a bright student in the eyes of many people, according to his friends and colleagues. Ashton Shortridge, a professor in the Department of Geography, met Lin in China in 2012.

"It was obviously a terrible shock when he died," Shortridge said.

Shortridge encountered Lin while he was teaching at Zhejiang University in Hangzhou, China, where Lin had studied for his first graduate degree.

"He was great," Shortridge said. "I was there with my family and he spent a lot of time to make sure that my kids, my wife and I were comfortable and felt supported."

Lin decided to work toward earning a second graduate degree at MSU and began attending the university in fall 2012.

"I was not on his Ph.D committee, but I met with him and chatted about life here. After he graduated last year, I worked with him. He was associate director for me of the Social Science Data Analytics Initiative," Shortridge said.

Shortridge said Lin was a people person who enjoyed bringing people together.

"He was great at his job here with me the last year, in terms of getting people from across campus to get together to learn more about analysis methods to study problems," Shortridge said.

Article by Malaika Allen and Zimo Wang, The State News Sept. 20, 2018.

Distinguished Partnership Award for Community-Engaged Teaching

COMMUNITY ENGAGEMENT AND PARTICIPATORY MODELING OF URBAN FOOD SYSTEMS

Laura Schmitt Olabisi, College of Agriculture and Natural Resources

FoodPLUS | Detroit

The partnership between MSU associate professor of community sustainability Laura Schmitt Olabisi and Renée Wallace of FoodPLUS | Detroit began in 2014 through an established community process for soliciting information on a proposed urban livestock ordinance in Detroit. Their objective was to develop a collaborative vision for and improved understanding of food systems in Detroit. The community partners were key participants in all stages of the project, the collaborative research yielded new insight into the potential to directly affect the design and implementation of the ordinance, and the results demonstrated that rapid growth in livestock keeping could generate negative externalities for the City.

This project has led to additional benefits for both partners. A field school is planned in Detroit for 2019, with the dual goals of training community partners in systems modeling and training modelers in community engagement techniques. The partnership also was a catalyst for a $2 million grant for a four-year project that aims to use community-based participatory modeling to analyze the food system in Flint and catalyze collaborative relationships between the two cities for better understanding of urban food systems.

KO1 Mentoring Grant from NIEHS

Congratulations to Dr. Jennifer Carrera who was recently awarded the prestigious KO1 mentoring grant from the National Institute for Environmental Health Sciences (NIEHS). Carrera uses water as lens to focus on differential access to environmental resources and its impact on the well-being of individuals in marginalized communities. The grant will be used to work with residents in Flint, Michigan to develop novel, low-cost resources for environmental monitoring with the aims of enhancing self and community-efficacy towards protecting public health. Carrera is jointly appointed in the Department of Sociology and the Environmental Science and Policy Program and she is part of the campus-wide Global Water Initiative.

FEATURED FACULTY:

Dr. Kurt Rademaker, Department of Anthropology

ESPP is pleased to welcome Dr. Kurt Rademaker to Michigan State University as a new affiliated faculty and environmental archaeology assistant professor.

Rademaker's primary interests are in hunter-gatherers, settlement of the Americas, lithic technology, geographic information systems, interdisciplinary collaboration and education. He conducts field research in the highlands of the Peruvian Andes.

Previously an assistant professor in the Department of Anthropology at Northern Illinois University, Rademaker has worked as an archaeologist in the Eastern Woodlands and Great Basin regions of the U.S., in Mexico and in Chile, in addition to carrying out quaternary studies in Peru and Scotland.

In Peru, his team searches for and investigates hunter-gatherer sites from the Pacific coast to the high-elevation Andes. His ongoing collaborations with earth science colleagues are producing high-resolution paleo-environmental records for comparison with cultural sequences. Other current collaborative research with physical anthropologists and paleogeneticists is focused on understanding how humans have adapted to live in high-elevation mountain regions, some of the most challenging environments on Earth.

In addition to his faculty appointment at MSU, Rademaker is Affiliated Assistant Professor of Prehistory at the University of Tübingen in Germany..

He received his bachelor's degree in Anthropology from the University of Kentucky and a MS in Quaternary and Climate Studies and PhD in Quaternary Archaeology from the University of Maine.

Rademaker accepted the position at MSU because of its reputation as a great research school, he said. He is undertaking a new project to research classic high-elevation Andean cave sites that were first excavated in the 1970s in central Peru.

He has been reconnecting with the original site investigators who began the project in the 1970s and 1980s but whose work was interrupted by terrorist activities. He plans to continue the research which was never completed and to apply new methods at these sites to study long-term human-environment relationships .

Outside of his research, Rademaker enjoys hiking, backpacking, canoeing, and climbing with his wife Erica and dog Cowboy.

Rademaker's research can be found online at www.paleoandes.com

Photo courtesy of Sapiens.org

Dr. Rademaker's primary interests are in hunter-gatherers, settlement of the Americas, lithic technology, geographic information systems, interdisciplinary collaboration and education.

FEATURED STUDENT:

Patricia Jaimes, Earth and Environmental Science & Environmental Science and Policy

By Sierra Jankowski, ESPP Student Aide

Patricia (Paty) Jaimes is a fourth-year PhD student in the Geocognition Research Laboratory housed in the Department of Earth and Environmental Sciences. She received her BS in Earth Science from Northeastern Illinois University in May 2015. Jaimes was born and raised in Chicago, Illinois, is a first-generation American and a first-generation college student. Jaimes is fluent in both English and Spanish. She entered her first year at MSU with a College of Natural Sciences Early Start Fellowship and a University Fellowship package. In 2016, she was a recipient of a prestigious National Science Foundation Graduate Research Fellowship and has received numerous additional awards during her time at MSU. Jaimes is currently the Vice President of the Society for the Advancement of Chicano/Hispanic and Native Americans in Science (SACNAS) chapter on campus.

Her dissertation research focuses on finding innovative solutions for effectively increasing diversity in the scientific workforce. Her personal interests include spending time with her family, baking, reading fiction, and mentoring high school and undergraduate students.

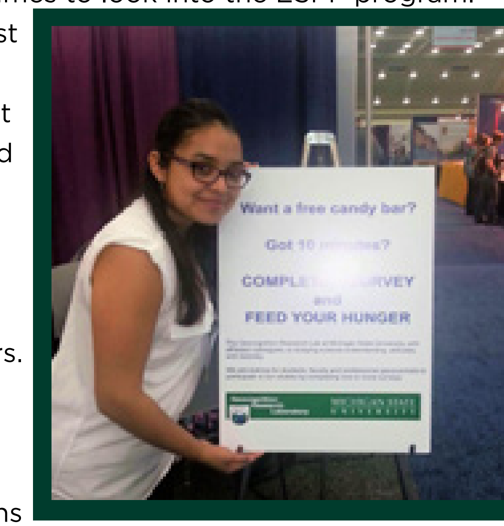
When deciding which institution to go to for her undergraduate studies, Jaimes had to take many things into consideration. Jaimes had her daughter while in high school, so it was of the utmost importance for Jaimes to stay close to home so that she would be able to raise her daughter and earn her education with the help of her family and friends. Northeastern Illinois University (NEIU) in Chicago was the most affordable school for her to attend and she said, "the campus itself was wonderful…it was the best choice for me."

When Jaimes first started her journey at NEIU, she wanted to study Sociology because she has a passion for working with people and she aspired to work for the federal government someday. She was under the impression that to work for the federal government you needed to study Sociology. She soon found out that other majors could also lead to careers in the federal government.

As a freshman at NEIU, Jaimes decided to take an Earth Science course because when she was in high school she had taken an Earth and Space Science class and enjoyed it. At the end of her freshmen year of college, Jaimes found out that NEIU students who had taken one of the two FYE Earth Science courses, had the opportunity to apply for a paid summer research experience doing agricultural research. Jaimes applied and was accepted into this research program. During the research program, Jaimes also learned about potential Earth Science careers. While learning about all of the possibilities within the Earth Science discipline, Jaimes decided that she wanted to major in Earth Sciences instead of Sociology. However, Jaimes also enjoyed learning about sociology and so she continued to take many elective Sociology courses throughout her undergraduate career at NEIU.

When Jaimes was looking at institutions for her graduate studies, she was looking for one with a Geoscience Education program that was not too far from home. At first, she was only considering Northern Illinois University which was an hour to an hour and a half from home. As her undergraduate advisor was reading her application to Northern Illinois University, the advisor mentioned that Michigan State University had a Geoscience Education Program that she should look into. Her advisor also mentioned Dr. Julie Libarkin (a member of ESPP's affiliated faculty) and that MSU wasn't too far from Chicago. With a little push, Jaimes contacted Dr. Libarkin. Through a video interview with Dr. Libarkin, they "automatically clicked." She shared her research, interests, and personal responsibilities to Dr. Libarkin and Dr. Libarkin was very supportive. Dr. Libarkin helped Jaimes with her application and once she was accepted MSU, she brought Jaimes out to visit. MSU offered a generous package: funding for five years, health insurance, and support from Dr. Libarkin. In the end Jaimes knew that she would enjoy the research that was being done in the Geocognition Research Laboratory. That, combined with the university fellowship offer, made her feel that coming to MSU to complete her graduate education was the best decision for her and her family.

Knowing Jaimes's interest in working at the intersection of natural science and social science, Dr. Libarkin encouraged Jaimes to look into the ESPP program. Jaimes's interest in working for the government one day melded well with the integration of science and social science that ESPP offers. After meeting with Karessa Weir, ESPP's Communications and Outreach Specialist, as well as with others within the department, Jaimes decided that ESPP would be a good fit for her research and career goals.



As a PhD candidate in EES, investigating diversity in STEM and getting a dual degree in Environmental Science and Policy (ESP), Jaimes wants to use her expertise to develop inclusive and accessible science education and outreach programs that will lead to increased diversity in STEM.

"I want to utilize my training in environmental policy to help write policy recommendations for improving STEM research and education programs at the government levels," she said.

Although Jaimes desires a career in science education and outreach, she still wants to work for the government in some capacity. Upon graduation, she plans to to continue working as a university researcher and educator. She envisions working her way up to a university program administrator and eventually working for the state or federal government doing science education policy and advocacy work.

Upcoming Events

WIN-WIN OPPORTUNITIES IN ENVIRONMENTAL POLICY

APRIL 15, 2019

ORGANIZED BY ESPP AND ECONOMICS DOCTORAL CANDIDATES DYLAN BREWER AND HAOYANG LI.

2 P.M. 273 GILTNER HALL

A panel discussion with **Dylan Brewer** (starting Assistant Professor at Georgia Tech); **Haoyang Li** (starting Assistant Professor at Shanghai University of Finance and Economics); Dr. **Patrick Doran** (PhD Ecology at Dartmouth, Associate Director of the Michigan Nature Conservancy); Dr. **Jill Deines** (PhD Fisheries and Wildlife and Environmental Geosciences at MSU, Postdoctor Researcher at Stanford)

SUSTAINABLE COFFEE DEVELOPMENT IN RWANDA

APRIL 16, 2019

ORGANIZED BY ESPP AND COMMUNITY SUSTAINABILITY DOCTORAL CANDIDATE ANDREW GERARD.

12 P.M. 201 INTERNATIONAL CENTER

A panel discussion with Dr. **Ameet Morjaria**, Assistant Professor of Managerial Economics & Decision Sciences, Northwestern University; Dr. **Maria Claudia Lopez**, Assistant Professor of Community Sustainability, MSU; and Dr. **David Ortega**, Associate Professor of Agriculture, Food and Resource Economics, MSU.

FROM THE GROUND UP: IMPROVING SOIL HEALTH IN AFRICA THROUGH PARTNERSHIP

APRIL 19, 2019

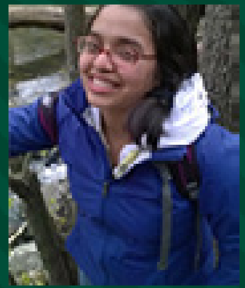
ORGANIZED BY ESPP AND PLANT, SOIL AND MICROBIAL SCIENCES DOCTORAL CANDIDATE XINYI TU.

9 A.M. 303 INTERNATIONAL CENTER

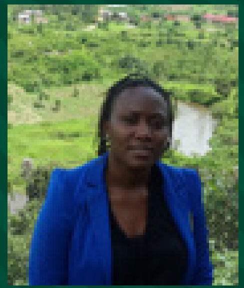
Opening Keynote speaker Dr. **Saweda Liverpool-Tasie**, Associate Professor of Agriculture, Food and Resource Economics; panelists Drs. **Cynthia Donovan, Lisa Tiemann, Joseph P. Messina, Timothy Harrigan**, **Wenda Bauchspies, Leo Zulu** and **Nicole Mason-Wardell**; closing keynote speaker Dr. **Sieglinde Snapp**. Professor of Plant, Soil and Microbial Science.

ESPP Research Colloquia Committee

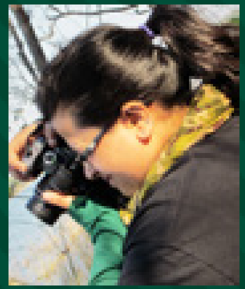
These are the hardworking students who coordinate and moderate our Spring 2019 Colloquia Series. ESPP is grateful for their dedication, excellence and continued service to the ESPP community.



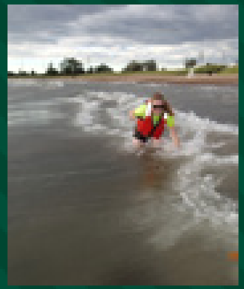
PATRICIA JAIMES
Earth and Environmental Sciences, ESPP



JUDITH NAMANYA
Geography, Environment and Spatial Sciences, ESPP



APOORVA JOSHI
Journalism, ESPP



CHELSEA WEISKERGER
Civil and Environmental Engineering, ESPP

ESPP
Alumni News

Bob Drost- Assistant Professor split between the Department of Earth and Environmental Science and the Center for Integrative Studies in General Science at MSU

Ran Duan- Visiting Assistant Professor in the Reynolds School of Journalism at the University of Nevada, Reno

Rich Grogan: Executive Director- Community Development Finance Institution (CDFI) in Vermont

Ryan Gunderson- Assistant Professor in the Department of Sociology and Gerontology and an Affiliate of the Institute for the Environment and Sustainability at Miami of Ohio

Erin Haacker: Postdoctoral researcher at Nebraska Water Center

Maria Rojas- Downing: Postdoctoral Research Associate at MSU Department of Biosystems and Agricultural Engineering

Sam Smidt- Assistant Professor in the Soil and Water Sciences Department at the University of Florida

Leigh Whittinghill- Assistant Professor of Urban Agriculture in Kentucky State University

A DAMMING TREND

MSUToday article by Layne Cameron and Yadu Pokhrel.

Hundreds of dams are being proposed for the Mekong River basin in Southeast Asia. The negative social and environmental consequences – affecting everything from food security to the environment – greatly outweigh the positive changes of this grand-scale flood control, according to new research by Michigan State University.

The results, published in the current issue of Nature Scientific Reports, are the first to tackle the potential environmental changes that the overall basin could experience from harnessing the region's hydropower.

"The Mekong River is one of the few large and complex river systems that remains mostly undammed," said Yadu Pokhrel, assistant professor of civil and environmental engineering and the study's lead author. "However, the rapid socio-economic growth, increasing energy demands and geopolitical opportunities have led to basin-wide construction of large hydropower dams."

In the basin's upper portion, dozens of mega dams are in the process of being built. In the lower region, hundreds of tributary dams are planned, and some larger ones also are being constructed.

While there are many positive effects of flood control, the researchers focused on the reduction of monsoon-driven floods that would be held back by the dams. These annual pulses provide much-needed water and nutrients to downstream regions.

"Any major alterations of the seasonal pulses could easily change the area's floodplain dynamics," Pokhrel said. "This could severely affect a wide range of ecosystems and undermine regional food security."

ESPP Director Jiaguo Qi, together with ESPP Affiliated Faculty Yadu Pohkrel, studied the negative social and environmental consequences of dams in the Mekong River

ADDRESSING PFAS IN THE STATE OF MICHIGAN

Contributors:

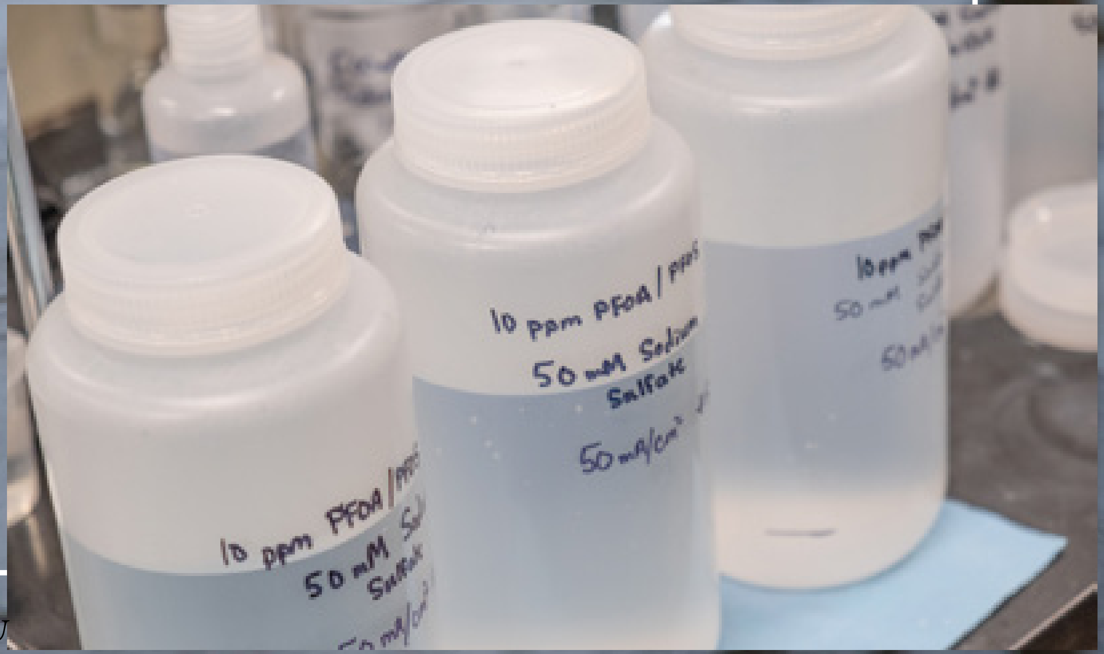
Noleen Chikowore, Department of Community Sustainability and the Environmental Science and Policy Program, Michigan State University

Jennifer Collier, Department of Civil and Environmental Engineering, Michigan State University

Ida Djenontin, Department of Geography and the Environmental Science and Policy Program, Michigan State University

Yingjie Li, Department of Fisheries and Wildlife and the Environmental Science and Policy Program, Michigan State University

Kayleigh Ward, Department of Sociology and the Environmental Science and Policy Program, Michigan State University



Photos courtesy of MSU

Executive Summary

Since the 1930s, American industries have effectively used a wide collection of perfluoroalkyl and polyfluoroalkyl substances, generally referred to as PFAS. PFAS are used in applications from food wrappers and Teflon coatings in cookware to aqueous substances in firefighting foams. However, the ubiquitous use and application of PFAS across major industries is now a major concern as the chemicals threaten both human and ecological health. PFAS threats are of concern due to the highly stable carbon-fluorine backbone that characterizes their chemical composition making them persistent in the environment. Even when some PFAS break down, they typically become shorter-chain PFAS and do not necessarily degrade. As a result, PFAS used over the last 80 years has spread over the world, even to remote regions like the Arctic. To date, it is estimated that one-third of all US groundwater is contaminated with PFAS. The concentration of PFAS in these waters ranges from very small to the tens of thousands. Due to concerns with drinking water, the EPA has set a lifetime health advisory of 70 ppt for PFAS. This means any person drinking water with 70 ppt of PFAS over their lifetime will likely not suffer from negative side-effects.

With PFAS being a group of emerging contaminants, it is vital to understand their effects on the environment and on humans and our ability to manage them. To this end, the recent research conducted on aquatic and terrestrial ecosystems was reviewed, along with currently known human health effects and potential remediation approaches. Findings suggest a growing consensus that PFAS do have deleterious effects on organisms due to their bioaccumulation and biomagnification potential. Current implementable remediation strategies include sorption and filtration. These ex-situ remediation methods are useful in the short term but require transporting the contaminants from one location to another but does not actually degrade the compounds. In-situ or on-site remediation techniques are also being investigated as they appear more environmentally friendly (i.e. smaller carbon-footprint) but economically infeasible. More work is needed to clarify the extent to which PFAS may increase certain cancers, heart issues, digestive tract disruptions, hormone disruption, and other vital organ dysfunctions in humans and animals and provide alternative remediation techniques that can break down the PFAS compounds.

Given the increasing salience of PFAS as a hazard, detail is provided on how the state of Michigan may manage the issues presented by PFAS. As of October 2018, there are 34 different sites with PFAS levels well-above the 70 ppt guideline in Michigan. These sites are currently managed by the Michigan PFAS Action Response Team (MPART), which was put into effect in 2017. MPART responds to and manages all PFAS concerns with drinking water, fish populations, and terrestrial populations. Comprised of multiple state agencies and departments, the team is well prepared to intervene when PFAS is a threat to Michigan residents and the environment.

To support the actions of MPART, it is recommended that the state of Michigan pursue policies to address both the source of PFAS and existing contamination. Seven policy options at the state-level were evaluated and two are recommended to manage both of these issues. Pursuing rigorous voluntary agreements with

PFAS-using industries and companies to mitigate the amount of PFAS being released into the environment will help Michigan prevent new sites from becoming contaminated. These voluntary agreements have been historically successful in stopping the use of PFAS substances and by their voluntary nature, support Michigan's economic interests in protecting industry. Creating a public tax to generate funds for MPART's remediation efforts when a responsible party is not clearly identifiable is also recommended to help existing contamination be addressed in a timely manner. By combining these two policy measures, it is our assessment that responses to PFAS contamination would involve both the public and industry in equitable ways to reduce future and current threats presented by PFAS.

1. Introduction

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a group of emerging contaminants found across the globe, and they represent a threat to human health and ecosystem security. Work has already been done to limit or eliminate the use of two of these substances, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), but thousands more are still in use and the chemicals are persistent in the environment (Buck et al., 2011).

1.1 What are PFAS?

PFAS are aliphatic compounds where all of the hydrogen atoms on at least one carbon atom have been replaced with fluorine, giving them the perfluoroalkyl moiety 2 +1−. Compounds are referred to as perfluoroalkyl substances when this is the case for every carbon atom in the structure, except those in functional groups; otherwise they are classified as polyfluoroalkyl substances. These carbon-fluorine bonds are very stable and difficult to break, which is what causes these substances to be persistent in the environment (Buck et al., 2011).

PFAS are also grouped based on their chain length. Long-chain PFAS are those with 7 or more of the fluorinated carbons, 7 15− (Buck et al., 2011). These have generally been viewed as the more concerning types of PFAS due to their ability to bioaccumulate. However, it has been realized that short-chain PFAS are also problematic due to their mobility and persistence. It is unknown what effect long-term exposure to these short-chain PFAS will have on organisms (Brendel, Fetter, Staude, Vierke, and Biegel-Engler, 2018).

1.2 Sources, fate, and transport of PFAS substances

PFAS are used for surfactant products, surface protection products and fluorotelomer processing aids. This means they are present in a wide range of consumer products from textiles to food-contact paper. Additionally, they are in aqueous film-forming foams (AFFFs), which are used for fighting fires, and are used in some manufacturing processes (Buck et al., 2011). This wide range of applications for PFAS have contributed to their widespread contamination.

PFAS can be released to the environment either directly or indirectly. Direct emissions include those related to the manufacture, use and disposal of the PFAS compound or products that contain it as an impurity. Indirect emissions are those of precursor compounds, which are chemicals that break down to form other types of PFAS (Buck et al., 2011). Generally, polyfluorinated compounds are precursors to perfluorinated and long-chain are precursors to short-chain.

Emissions of PFAS to the environment may be to the air, water or soil, and through these media they may enter plants, animals and humans. Volatile PFAS, such as PFOA, are likely to be emitted to the air (Prevedouros et al., 2006), while nonvolatile PFAS, such as PFOS, are more likely to be discharged to water during their manufacture and use (Paul et al., 2009). Prevedouros et al. (2006) reported evidence of PFOA release into the atmosphere by fluoropolymer manufacturing facilities and noted that other precursors in the air may degrade into PFOA. For PFOS, atmospheric transport is less likely because of its low vapor pressure, but the degradation of its precursors in the atmosphere may increase its ability of long-range transport through this medium and thus its contamination potential (Paul et al., 2009). Regarding aquatic transportation, Prevedouros et al. (2006) estimated that about 2-12 tons/year of PFOA chemicals are transported to the Arctic through oceans waters because of their high solubility in water. Other PFAS substances that are directly discharged into waters could also travel such long distance to reach oceans and remote regions. Finally, the disposal of products containing PFAS in landfills also introduces PFAS to soil (Hamid et al., 2018). Once present in the environment, PFAS may be transported through and move between the atmosphere (air), hydrosphere (surface water, runoff, and groundwater), lithosphere (soil and rocks), and biosphere (plants, animals and humans), and these interactions are depicted in Figure 1. The presence of PFAS in surface water, groundwater, sediments, and the atmosphere have been reported extensively across the world (Campo et al., 2016).

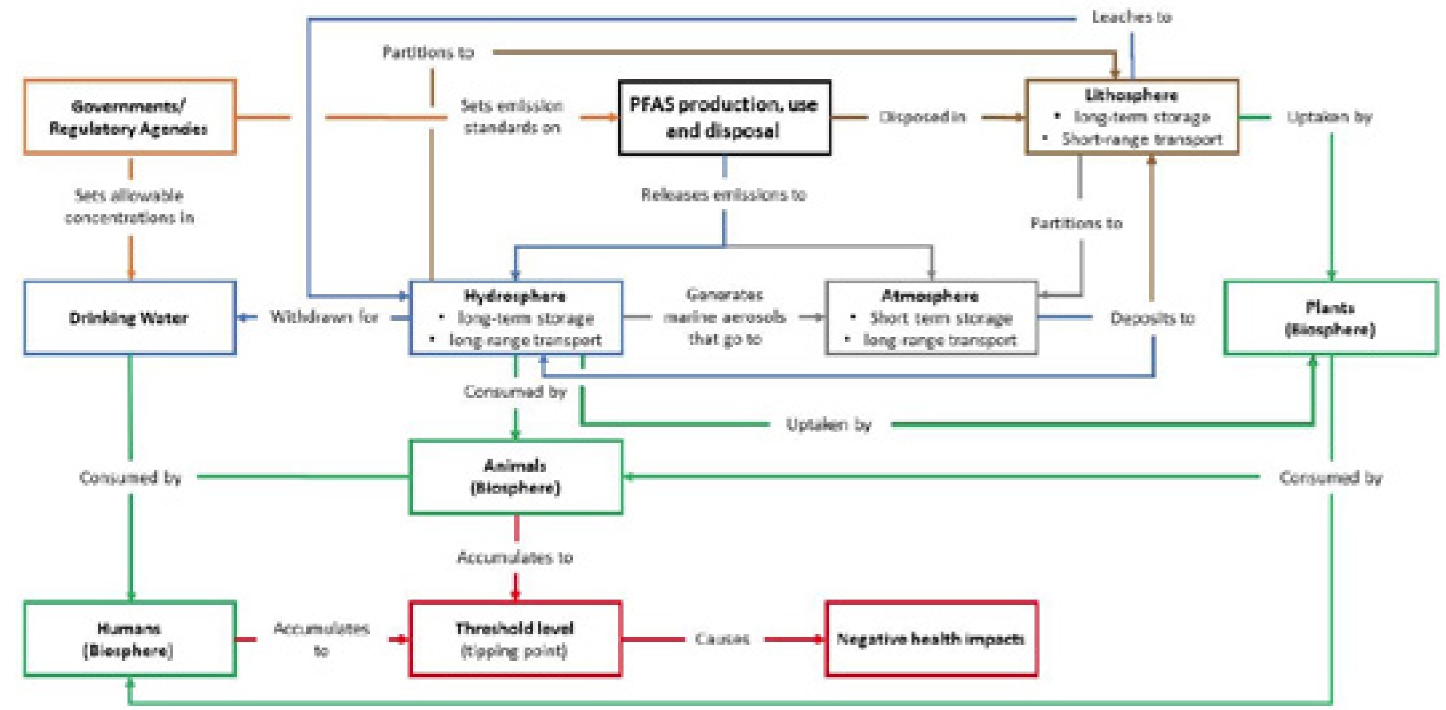


Figure 1. Transport and Storage of PFAS

1.3 PFAS Threats and why they are of concern

There is rising concern regarding the negative effects that PFAS may have on human health. The cocnern lies with the risks that consumption of PFAS-contaminated food and water, as well as other forms of exposure, present to humans (Christensen et al., 2017). Indeed, similar to their accumulation and persistence in the environment, PFAS substances can have long-lasting effects in the human body because of their bioconcentration/bioaccumulation and biomagnification properties (Olsen et al., 2007); thus, multiplying their impacts on human health. Their half-life estimates in the body before elimination is estimated at 8 years for PFOA and 4-5 years for PFOS (Olsen et al., 2007; ATSDR, 2018).

There are several exposure routes of PFAS to humans, including through food, water and air (Tittlemier et al., 2007). The wide range of sources of PFAS and their ability to move through the environment suggest that many people have been exposed to these contaminants, at varying degrees of exposure. More than 95% of the United States (US) population might be exposed to PFAS according to the National Conference of State Legislature. Low degrees of exposure come with the food route, including the consumption of fish (Berger et al., 2009; Christensen et al., 2017; Squadrone et al., 2015). Another exposure occurs when PFAS is released during the use, biodegradation, or disposal of PFAS-based consumer products. Humans are also exposed in occupational settings or contaminated air at PFAS-related facilities and industries. Finally, high levels of exposure occur through contaminated drinking water supply systems (US EPA, 2016). This last exposure route catches the most attention, and has gathered the most concern from local communities in the US. Such widespread contamination of drinking water by PFAS has led to recent wake up calls by the clean water activists and the local communities, who are pressuring lawmakers in the Senate and Congress, and the technical environmental protection body, the US Environmental Protection Agency (EPA), for action.

While work is still being done to ascertain the human and ecological health effects of PFAS, the US EPA has set a lifetime health advisory level at 70 parts per trillion (ppt) (or 0.070 g/L) for PFOA and PFOS, representing the level, or amount, below which is expected little harm from these chemicals to humans (Daly et al., 2018). Additional actions and policy are needed to address the widespread contamination from these emerging contaminants and mitigate their negative impacts. This policy paper provides some comprehensive recommendations for Michigan policymakers to address PFAS contamination.

1.4 Objectives

In this policy paper, the existing knowledge related to PFAS is reviewed and the terminology, sources, impacts, and promising remediation treatments are summarized. The State of Michigan, one of the most prevalent PFAS states in the US, is then used as an illustration to identify affected sites, involved stakeholders, and finally offer policy options for addressing the PFAS issue.

2. PFAS in the literature

2.1 Current knowledge production of PFAS

From the Web of Science Core Collection, nearly 60 percent of all PFAS research is concentrated in the US, quickly followed by China, Canada, Japan, Sweden, and Germany. On a grand scale, developed countries such as the US, are working to eliminate the use of PFAS and PFAS-related chemicals in their products and emissions from their facilities. We can infer that many other less developed countries may still emit substantive harmful PFAS into the environment, threatening human and other biotic health.

For the US then, it is urgent to pursue initiatives that help monitor PFAS in the environment. Monitoring PFAS can help reduce the risk of its spread within and beyond country's borders as consumer goods that contain PFAS are still produced internationally. In line with this, various groups have begun monitoring PFAS in the US and in other countries. The Social Science Environmental Health Research Institute (SSEHRI) at Northeastern University took the initiative to monitor the spread of the problem by developing the PFAS Contamination Site Tracker. This database provides information such as PFAS concentrations, suspected PFAS sources (such as industrial plants and dumps, military air bases, civilian airports and fire training sites) and government and community responses for 94 industrial or military contamination sites in 19 states and Guam, plus sites in Australia, Canada, Italy, Germany and the Netherlands (but the information is very limited for countries outside of the US) (Pistocchi and Loos, 2009),. The Environmental Working Group (EWG) keeps updating an interactive map based on this database. This map is the most comprehensive resource available to track PFAS pollution in the US.

2.2 Ecological Health

PFAS affect the biota of aquatic (marine and freshwater) and terrestrial ecosystems, particularly fish, wildlife, and plant species, in which they have the ability to build up and persist over time. Effects on the ecological health of communities is of concern due to PFAS being an endocrine disruptor (i.e., hormone disruptor). This disruption can lead to higher rates of diseases, cancers, and defects in species in affected ecological communities through bioaccumulation.

2.2.1 Aquatic populations

PFAS are found in fish species and other aquatic organisms in the US. Most investigations made are to understand the critical contaminants of the PFAS group and their concentration levels in fish species from toxicology-oriented studies. Commonly studied fish species in the US include bluegill (Lepomis macrochirus), black crappie (Pomoxis nigromaculatus), and pumpkinseed sunfish (Lepomis gibbosus) (Delinsky et al., 2010). The national fish-tissue monitoring initiated in the US has found widespread concentrations of a large variant of PFAS in different fish species of the Great Lakes and urban rivers across the country, with PFOS (median levels of 10,700 ppt) as the most predominant (De Silva, Spencer, Scott, Backus, and Muir, 2011; Stahl et al., 2014). The presence and concentration of PFAS in the waters of the Great Lakes (Lake Superior, Lake Huron, Lake Michigan, Lake Erie, and Lake Ontario) have been spatially mapped (Figure 2) to give a glimpse of where fish contamination may occur (De Silva et al., 2011).

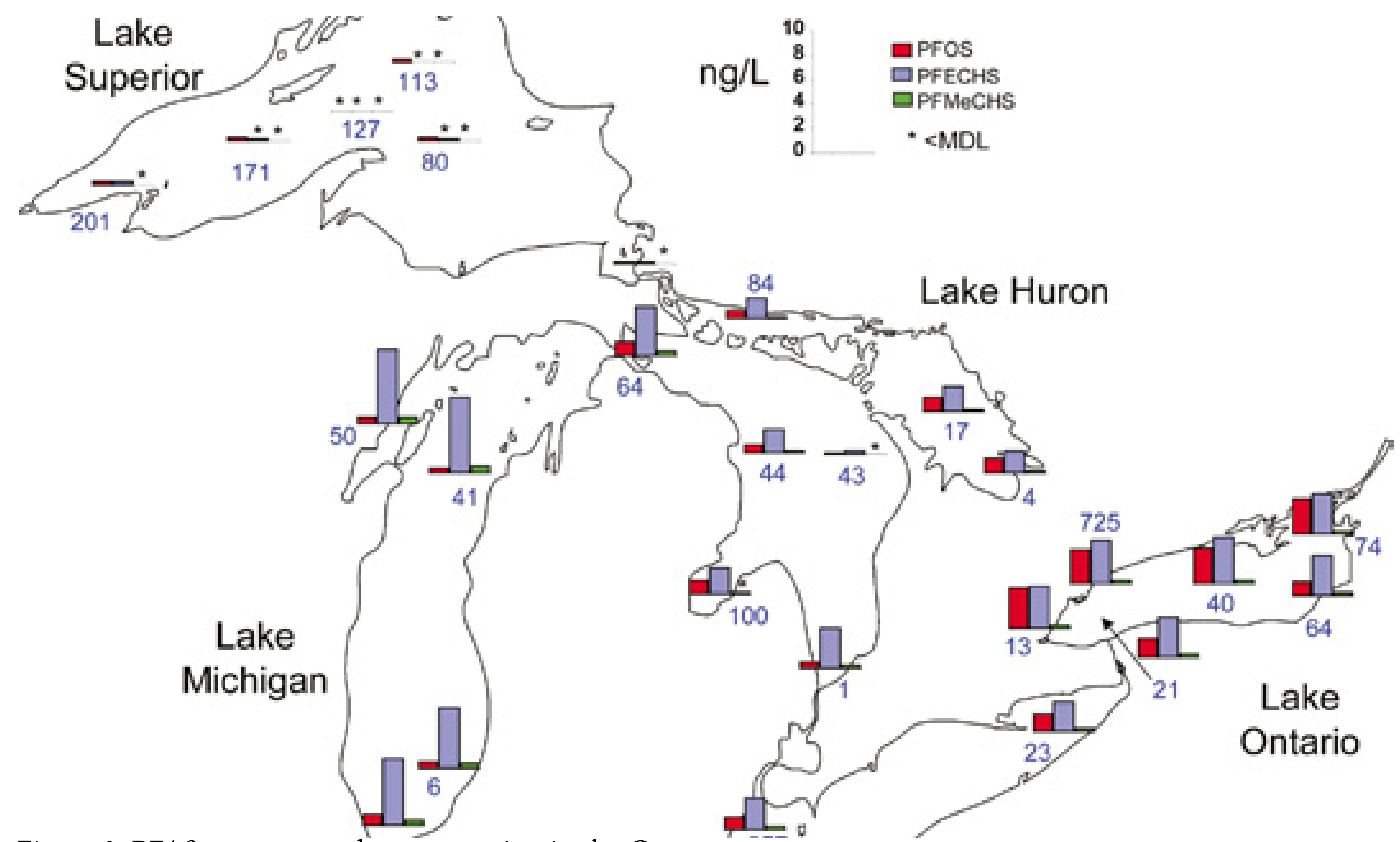


Figure 2. PFAS presence and concentration in the Great Lakes (de Silva et al., 2011)

PFAS concentration levels are determined by their bioaccumulation (direct uptake from water), biomagnification (accumulation from food), and the trophic level transfer in those surface waters' organisms. Concentration levels reported in the US are similar to those in European studies of aquatic organisms, in the range of <1,000 ppt fresh weight (f.w.) to >100,000 ppt f.w. (Haukås et al., 2007), which indicates the bioaccumulation potential in fish muscles. The biological determinants of concentration patterns of PFAS are biotransformation, feeding ecology, migration, and size/age of fish species. However, it is noted that the bioconcentration factors (BCFs) are lower than expected because PFAS substances bind to protein albumin in blood, liver, and eggs and do not accumulate in fat tissues (Kissa 2001; de Vos et al. 2008). Biomagnification factors (BMFs) have been estimated based on predator-prey relationships from a study in Norway. Trophic biomagnification for PFOS and long-chain PFCA was revealed in monitoring Arctic food webs (But et al., 2010;

Haukås et al., 2007).

In terms of how long PFAS persist in fish muscles before elimination, Johansson et al. (2014) reported a 18% and 4.3% mean annual decrease in PFOS and PFHxS levels from farmed rainbow trout in Sweden (Johansson et al., 2014; Martin et al., 2003). Martin et al. (2003) reported biological half-lives of certain PFAS in rainbow trout of Canadian waters to range from 3.9 to 28 days (Martin et al., 2003). No study has reported massive death of contaminated fish populations or risk of extinction. There are no clear-cut thresholds reported from the different concentration levels depicted for the safety of fish species, although their contamination denotes their vulnerability. However, there is a concentration limit in fish tissues that prevents humans from consuming the fish. For Michigan in particular, there are noticeable efforts to protect residents from consuming contaminated fish with the annual release of a guideline for fish consumption – "Eat Safe Fish Guides", including some emergency advisories by the Michigan Department of Health and Human Services (MDHHS). Michigan has been doing routine activities of testing fish filets for PFAS since 2012 and they have proceeded to test for PFAS in almost all fish species across the state.

2.2.2 Terrestrial populations

Current studies available on the bioaccumulation of PFAS in terrestrial systems show that more research is needed (McCarthy et al., 2017). As PFAS can become concentrated in animal and plant tissues, consumption of crops and meat contaminated with PFAS is of concern. For terrestrial mammals, when considering bioaccumulation, there have been warnings issued in Michigan by the DEQ to not eat deer from the Upper Peninsula. Terrestrial mammals, like cattle and poultry, are a relatively smaller contributor to human exposure to PFAS than fish (Ghisi et al., 2018; McCarthy et al., 2017). Other studies measured PFAS in the eggs of wild avian species and reported concentrations around 250,000 ppt (3,000 times more than the suggested threshold) (McCarthy et al., 2017).

For studies on crops, other plants, and soils, cereal crops present lower concentrations and a higher number of non-detects compared to fruits and vegetables, when testing for PFAS contamination (Ghisi et al., 2018). This is likely due to the water content of fruits and vegetables being higher than cereal crops. While plants and crops may be exposed to PFAS through irrigation, they are also susceptible to contaminated fertilizer applications. Most concerning are biosolid applications, which can harm soil composition and lead to high levels of PFAS in shallow groundwater located under farms (Sepulvado et al., 2011). After one biosolid application, PFOS and PFOA can reach concentrations of 7,200 ppt and 1,600 ppt respectively, since PFAS directly adsorbed by the soil is low (Hundal, et al., 2011). However, studies show that when PFAS is present in the soil, from biosolid applications, that it is transferred to plants in high concentrations, in some cases up to 232000 ppt or 232 ng/g (Blaine et al., 2014).

2.3 Human Health

In order to understand the human health effects of PFAS contamination, several studies have been conducted on animals. These studies indicate that there are a wide range of health effects related to growth and development, and humans may experience similar effects (Webster, 2010). For instance, PFAS studies on rats have found that exposure to PFAS leads to liver toxicity, which results in liver cancers, hormonal changes, behavioral changes and effects on the immune system (DeWitt et al., 2012). However, experimental studies on rats have proven difficult for making conclusions regarding human health. The Assistant Secretary of the Navy Scientists are not sure how animal data applies to humans because PFAS behave differently in humans than they do in animals and may therefore be harmful in different ways.

According to the Agency for Toxic Substances and Disease Registry (ATSDR) some studies with humans have shown positive correlations between

Photo courtesy of MSU Photos.

PFAS exposure and negative health effects. PFAS contamination has been linked to lower birth weights in newborn babies, and studies have also indicated that PFAS exposure reduces human fertility (Stein et al., 2009). A review of related literature by Rappazzo et al. (2017) highlights various studies in the US and Taiwan that show an association of effects of PFAS on young children's immunity and asthma (Rappazzo et al., 2017). Another systematic literature review found some evidence of a positive association between PFAS exposure and thyroid-stimulating hormone (TSH) levels measured in maternal blood, and PFAS and TSH levels measured in the blood of boys aged ≥11 years (Ballesteros et al., 2017). In addition, communities exposed to high levels of PFAS in drinking water have shown a positive relationship with bad cholesterol levels across the US (Rappazzo et al., 2017). High exposure to PFAS also results in increased uric acid, a risk factor for hypertension (ATSDR, 2018). In another study, a strong association between the length of employment and prostate cancer were observed in workers exposed to PFOA (Grandjean and Clapp, 2015).

2.4 Remediation Approaches

The unique properties of PFAS,particularly the strong carbon-fluorine (C-F) bonds, challenge efforts for their removal and degradation. Remediation of PFAS susbstances from water is limited by the poor understanding of their physicochemical properties and their fate and transport in groundwater (Grandjean and Clapp, 2015; Kucharzyk et al., 2017). What makes the treatment a conundrum is the high solubility, non-volatility, and persistence in water. So far, the literature support that existing remediation solutions are sometimes not efficient, or many uncertainties remain about the end results and the research body on this aspect is fast growing. There are two approaches for remediation: in-situ treatments (operated directly at the contaminated facilities or sites) and ex-situ treatments (involving transport of the contaminated elements to another appropriate site). We provide here, a snapshot of existing remediation technologies based on the literature for these two approaches.

Ex-situ methods for PFAS removal from groundwater are relatively well-established with tangible results at full-scale treatment systems, especially for PFOA and PFOS (Kucharzyk et al., 2017). These methods include (1) sorption, particularly with activated carbon (granular activated carbon (GAC) is preferred to powdered activated carbon (PAC)) and ion exchange resins ; (2) filtration methods with reverse osmosis and nanofiltration; (3) thermal and non-thermal degradation, especially incineration and thermal chemical reaction, sub- or supercritical treatment, microwave-hydrothermal procedure, high-voltage electric discharge; and (4) sonochemical destruction (Kucharzyk et al., 2017; Merino et al., 2016). These latter (3 and 4) technologies are limited by the fact that they can produce toxic by-products and greenhouse gases during the treatment process (Merino et al., 2016). Also, ex-situ remediation technologies are relatively high cost and their effectiveness may be compromised by other contaminants in groundwater (Kucharzyk et al., 2017). Sites that are already utilizing ex-situ treatment systems for other contaminants, are more appropriate for ex-situ PFAS remediation because it is better to modify the process to include treatments for PFAS at lower cost. The most promising ex-situ technologies based on performance are already being used at pilot scale and include sorption with GAC and filtration with either reverse osmosis or nanofiltration.

In-situ methods for removing PFAS are still embryonic and mostly at the level of laboratory research. The preference for these technologies over the ex-situ approach is based on their shorter operational timeframes, low life-cycle costs, and their little carbon footprints (Kucharzyk et al., 2017). This category includes: (1) advanced chemical oxidation processes (AOPs), (2) advanced chemical reduction processes (ARPs), (3) bioremediation (BR), and (4) treatment train approaches (TTA). AOPs are conducted with reagents such as hydrogen peroxide, ozone, potassium/sodium permanganate, sodium persulfate, and ozone peroxide (Dombrowski et al., 2018; Kucharzyk et al., 2017). AOPs may be used either single or in combination and are the most promising technologies in terms of performance, so far. Recently, it was found that heat-activated persulfate might be the best AOP-based degradation method for PFAS, not only for PFOA and PFOS, but also for other PFAS analytes (Dombrowski et al., 2018). ARPs are implemented with aqueous iodide or dithionite and sulfate, but this process is non-selective and needs more research. Bioremediation occurs with microbial destruction of essentially polyfluoroalkyl substances with C-H bonds (Liu and Avendaño, 2013; Merino et al., 2016) and fungal degradation (still at experimental level only and in progress). The treatment train approach consists of combining multiple technologies and one example is the combination of sorption method using GAC with the heat-activated persulfate method. This TTA experiment is one of the most promising remediation techniques being investigated.

2.5 Summary and Future Trajectories

Within PFAS research, it is important to note that findings across all categories of ecological and human health have pointed to significant PFAS contamination possibly contributing to bodily harm. Despite these findings, more is needed to reach a strong consensus about what harms are to be expected with PFAS present in the environment. To this extent, it is now necessary to extend investigations of the ecological impacts of these contaminants, considering the widespread contamination of PFAS and their human health risks (Liu and Gin, 2018). Despite overwhelming evidence of effects of PFAS, the uncertainties of long-term PFAS effects remain high. This is because the current half-life estimate of PFAS is 8 years for humans (ATSDR 2018) but estimates for other invertebrate and aquatic species is still unknown. If the half-life of PFAS is longer this may mean, there will be lifetime effects from high PFAS exposure.

Although PFAS substances are a global issue, most of the current research is scattered at the local scale or even smaller sites, such as Chesapeake Bay, the Coosa River of Georgia and some farms (McCarthy et al., 2017). This is partly because PFAS monitoring systems while present, are still not well

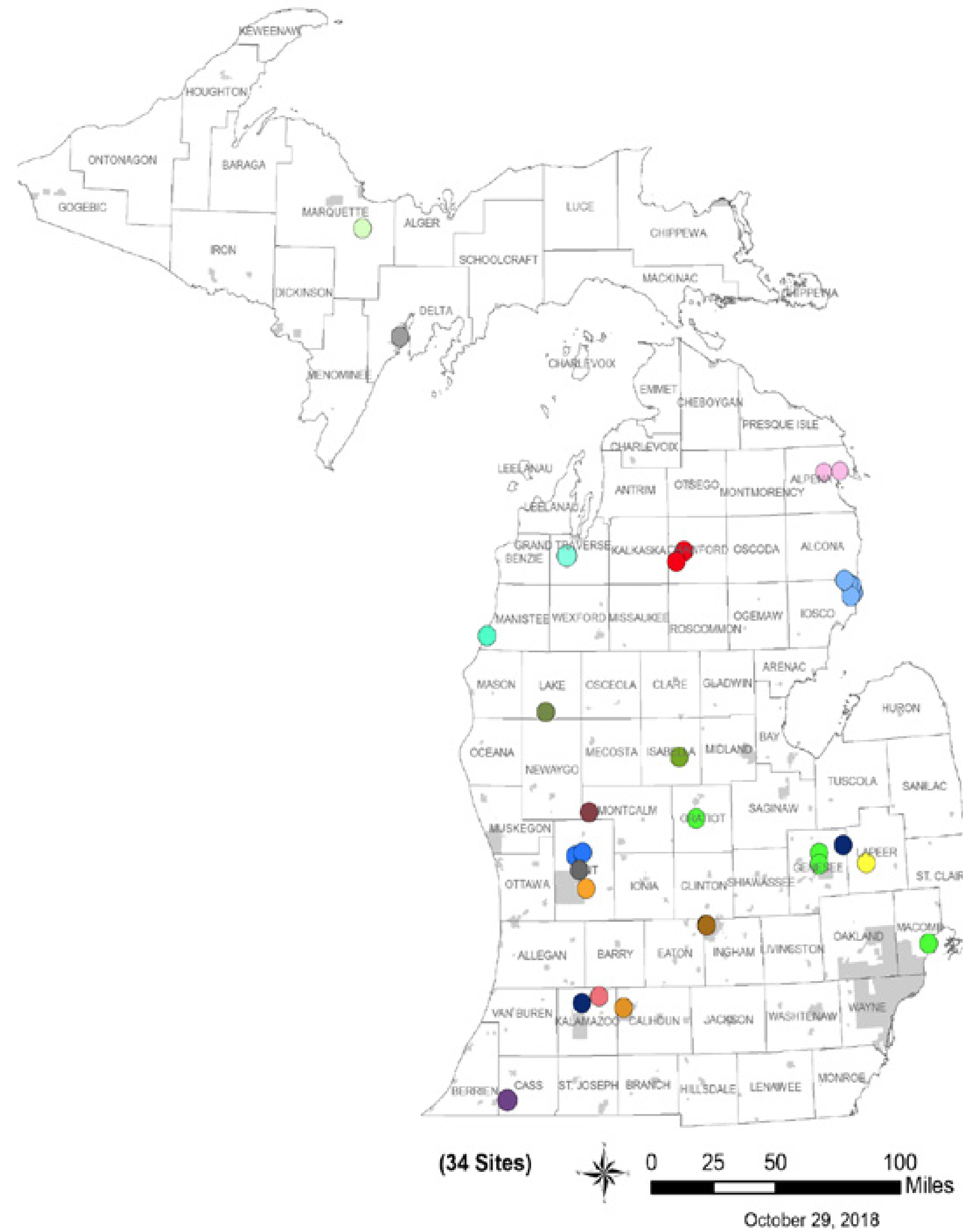


Figure 3. Michigan PFAS sites being investigated by county (adapted from Michigan Department of Environmental Quality)

established nationwide and worldwide. To address the prevalent PFAS issues, the first step is to know where and how much the contaminants are. Adding more sites to the PFAS monitoring network will help stakeholders identify locations of concern and take action early.

3. PFAS in Michigan

3.1 Current Status in Michigan

The Michigan Department of Environmental Quality (MDEQ) has created a spatial distribution of contaminated drinking water sources in Michigan (Figure 3). PFOA and PFOS have been found in about 34 drinking water sources due to localized contamination.

3.2 Current PFAS Response in Michigan

The Michigan PFAS Action Response Team (MPART) formed in November of 2017 from executive action by Governor Rick Snyder (MPART, 2018). MPART is comprised of multiple departments, agencies, and experts within the state. Primary are the Department of Environmental Quality (DEQ), Department of Health & Human Services (DHHS), and the Department of Natural Resources (DNR). The team functions to address PFAS issues that arise all over Michigan, including in drinking water, groundwater, lakes & streams, soils, sediments, wastewater, and the PFAS foam that was used in firefighting.

The Michigan DNR and DEQ specifically addresses fish populations and other wildlife, such as deer, and Michigan DHHS is the primary arm for informing necessary health advisories. MPART also includes two advisory committees, the Scientific Advisory Committee and the Local Public Health Advisory Committee. The first focuses on recent scholarship on PFAS to strengthen review of both health and environmental recommendations in Michigan. The second handles information exchanges between experts and the public. MDEQ specifically hired two additional public relation personnel to help facilitate these exchanges. Changes have also been made to have public meetings be attended by both a panel of local officials and by a panel of experts to address community concerns that public officials may not have knowledge of. This task force is well equipped to handle emerging PFAS issues.

MPART currently follows three tiers of response for PFAS contamination in drinking water supplies: 1) PFOA/PFOS detections of less than 10 ppt warrant a notification to the responsible utility. 2) PFOA/PFOS detections of 10-70 ppt are monitored and re-tested in quarterly increments (winter/spring/fall/summer). Notifications of these concentrations happens within 48 hours to a week. 3) PFOA/PFOS detections greater than 70 ppt are subject to immediate shut-off. A drinking water advisory is put in effect where only bottle water should be used, and the water source would ideally be switched to another water supply in the meantime.

3.2.1 PFOS in Parchment, Michigan - contamination upwards of 1,520 ppt - Tier 3 response

One of the most recent actions taken by the MPART team was in response to high levels of PFOS and PFOA contamination of the drinking water in Parchment. The source of drinking water contamination was a landfill that was formerly used by parchment paper mills. Overtime PFAS seeped into the surrounding groundwater. Remediation of the groundwater in Parchment will take years. In this case, Parchment was switched over to Kalamazoo's municipal water within 48 hours, and still relies on Kalamazoo's municipal water as of 2018.

3.2.2 PFAS Wolverine Worldwide - contamination upwards of 27,600 ppt - Tier 3 response

The Wolverine Worldwide PFAS investigation began in 2017 after the discovery of contaminated wells near the company's old sludge waste dump in Plainfield. The contamination has also spread to Algoma Township, the city of Rockford, and the nearby Rogue River. On its first round of testing, PFOA was found at 4,600 ppt, and PFOS at 23,000 ppt in wells. MDEQ re-tested wells in the area since PFAS levels can be very volatile and fluctuate quickly. However, re-tests showed similar levels of PFAS contamination, between 117 and 1,420 ppt. At 27,600 ppt, this is the highest combined PFOS and PFOA concentration that the MDHHS toxicologists have seen. To address this contamination MPART and the company are working together to provide residents with GAC filters, and a strict water advisory has been put in place to not drink unfiltered water. At the Wolverine Worldwide old tannery and dumping site, liners are being installed and soil along the Rogue River is being removed to help limit PFAS sedimentation.

3.3 Stakeholders

3.3.1 Residents, local communities, and organizations

Residents of Michigan are forming community organizations and groups in response to PFAS contamination. These groups are commonly located in PFAS hot-spots in Michigan, where contamination concentrations are above the 70 ppt threshold. In these areas, residents are key stakeholders as they take issue with the lackluster early response to revealed contamination sites and to contaminated drinking water. This grew as in July of 2018 it became known that one of Michigan's state departments learned about PFAS risks and contamination in 2012 but did not act. The lack of action in 2012 was revealed when DEQ said they had attempted to warn state officials of PFAS risks to residents, but the document was kept as internal and was not actually shared. As a result, residents are a necessary group

Policy Options	Political Feasibility	Administrative Feasibility	Environmental Impact	Economic Impact	Equity
1. Do Nothing	=	+	-	=	-
2. Provide state funding for research	+ (using existing funds) - (increasing budget)	+	-	=	-
3. Regulate PFAS production	+ (public support) - (industry support)	-	+	-	+
4. Regulate PFAs emissions	+ (public support) - (industry support)	_	+	-	+
5. Voluntary agreements with PFAS industries	+	+	+/-	=	-
6. Tax PFAS industries to provide funds for cleanup	+ (public support) - (industry support)	+	+	-	+
7. Tax public to provide funds for cleanup	+ (public support) - (industry support)	+	+	=	+
8. Federal Regulation	- (requires support outside of MI)	=	+	=	+

Table 1. Evaluation of policy options. "+" indicates the policy option is feasible or has a positive impact, "-" indicates it is not feasible or has a negative impact, and "=" is neutral.+ (using existing funds)

to consider in policy options and recommendations to avoid mistrust of state action on PFAS. In addition to residents and local communities, a variety of state environmental organizations and other non-governmental organizations are key to consider at the table. These organizations, like Safer States, has as their goal to obtain drinking water not affected by PFAS or other chemicals. They continue to partner with communities to help create policies centered on resident health interests. It is vital that in Michigan that any affected resident or community as well as relevant organizations are included during public meetings or hearings on PFAS to facilitate their inclusion in the decision-making process. Additionally, stakeholder support from these groups is crucial to support any new policy the state of Michigan decides to pursue as there may be push back from other stakeholders, such as industry, against policies regulating or otherwise changing how PFAS is used in manufacturing and production.

3.3.2 Federal and State Departments and Agencies

As a result of these concerns, federal and state agencies are responding to the emerging PFAS contamination. Stakeholders here include those active in the MPART team and policymakers in the state government. In addition, relevant stakeholders include national groups who are assisting state actors. These include the National Center for Environmental Health (NCEH) and the Agency for Toxic Substances and Disease Registry (ATSDR) which are housed under the Center for Disease Control (CDC). Those listed here specifically inform health advisories and focus primarily on environmental hazards. In the case of PFAS in Michigan they have been active at the 34 contaminated sites in Michigan by providing additional expertise and support to state agencies. Within Michigan the DEQ, HHMS, and DNR are most active in working to address the concerns of the state, which include managing human and environmental risks.

3.3.3 Industry and Military

As PFAS is a man-made substance, PFAS currently present in the environment comes from a variety of industries using different manufacturing processes. In addition to industry, military bases and sites also use PFAS products, such as foams and protective coatings on military air and land crafts. As a result, industry and the military are also stakeholders in any PFAS regulation that is pursued. In Michigan, currently 32 percent of all contamination has been linked to industries. Another 30 percent is contributed by military sites. In total industry and military sites comprise approximately 60 percent of all identifiable contamination, with another 16 percent being comprised of landfills and airports, and the last 22 percent of PFAS contamination sources currently unidentifiable.

In some cases, industry has responded well once PFAS contamination was linked to them, such as with Wolverine Worldwide where much of the remediation cost is being paid for by them. However, since PFAS is used in innumerable applications, policies to change PFAS use, production, and remediation may be met with challenges. Some states outside Michigan have begun the process to manage PFAS in a variety of products, but many of these have gone back for revision. To date there are 38 policies across 11 states, but only 11 of these have been adopted in 8 states. Most recently was a California bill requiring the disclosure of PFAS in food packaging or cookware, but not the banning of PFAS (which was originally pursued). As a result, policies regulating the management of PFAS are relatively new. To ensure that policies are sustainable and comprehensive, industry stakeholders must be included as changes to PFAS use may cause economic damages to them.

Table 2. Stakeholders' perspective on policy options. "+" indicates the stakeholder group is expected to support the policy option, "-" indicates they are expected to oppose it and "=" indicates a neutral view.

Policy Options	Stakeholders The Public	Industry
1. Do Nothing	-	+
2. Provide state funding for re-search	+/-	=
3. Regulate PFAS production	+	-
4. Regulate PFAS emissions	+	-
5. Voluntary agreements with PFAS industries	+	+
6. Tax PFAS industries to provide funds for cleanup	+	-
7. Tax public to provide funds for cleanup	-	+
8. Federal regulation	+	-

4. Policy Options for addressing PFAS issues

A variety of options are available to Michigan policymakers to address the issue of PFAS contamination (see table 1). With the existence of MPART, policymakers may choose to leave the situation as is and do nothing further than continuing to use MPART for PFAS response (Policy 1). To better understand PFAS contaminants, develop new technology to manage it, or create a substitute for PFAS, the state may pursue state funding for research on PFAS (Policy 2). Regulations on PFAS production or emissions could be implemented to address the issue at the source and reduce or prevent future contamination (Policy 3 and 4). Similarly, policymakers could opt to encourage companies in the state to enter into voluntary agreements to reduce their use of PFAS in products or address PFAS emissions (Policy 5). To address existing contamination, a fund could be created, similar to SuperFund, to cover the costs of clean up. This fund could be supported either through taxes on PFAS industries or the public (Policy 6 and 7). Lastly, Michigan policymakers may choose to involve the federal government to facilitate a nationwide policy on PFAS management (Policy 8).

4.1 Evaluation of policy options

To help policymakers make feasible and effective policies on PFAS management, we selected five criteria (political feasibility, administrative feasibility, environmental impact, economic impact, and equity) to evaluate the eight above mentioned options in Table 1. Political feasibility is the likelihood of policymakers to be able to pursue the policy option, and this is dependent on the approval of the public and industry. Policymakers will likely contend with mixed responses from these two groups. Administrative feasibility considers the ability of the policy to be implemented with current personnel, resources, and agencies. How the policy option would affect the status of PFAS contamination and the Michigan economy are considered in the environmental impact and economic impact criteria, respectively. Lastly, the ability of the policy to protect all people in the state equally from PFAS is evaluated with the equity criterion. Judgement used to evaluate each policy option with these criteria was based on the current knowledge of PFAS, as discussed in the preceding sections of this paper, and historical policies implemented in the United States.

4.2 Stakeholder perspective on policy options

The public and industry are the main stakeholders to address when it comes to developing policy on PFAS contamination in Michigan. Judgment was used to evaluate the responses of these groups to the various policy options based on their respective interests. For the public, these interests include being protected from the risk of negative health effects caused by PFAS contamination and having the parties responsible for the contamination pay to remedy it. Industry, on the other hand, is generally concerned with keeping their costs down and being able to operate freely. Table 2 below illustrates these stakeholders' perspectives on the proposed policy options.

4.3 Policy Recommendations for Michigan

From the 8 policies evaluated above, the two extremes are policies 1 (do nothing and only use MPART) and 8 (federal regulation). With all the uncertainty regarding PFAS and fear among the public regarding these unknowns, it is likely that doing nothing is an unfeasible and untenable option for Michigan policymakers. While MPART is working to protect Michigan residents from PFAS in drinking water, the current remedy involves using GAC (granular activated carbon) to remove the PFAS. This creates a waste problem as the GAC must be stored properly to prevent the PFAS from reentering the environment. Also, there are other routes of exposure that need to be considered, such as dietary intake from contaminates meats, grains, and vegetables.

The other extreme, federal regulation, also poses challenges for Michigan policymakers, though this would be the ideal policy approach since PFAS contamination may come from outside of Michigan's borders. A consistent regulation on all industries using PFAS in the US will protect Michigan from the potential negative economic effects of instituting regulations on PFAS in their state alone. The concern is that industries may opt to leave the state if policies targeting manufacturing are implemented as there is currently no implementable substitute to PFAS in production. However, this policy approach would require Michigan policymakers to garner the support of other states and lobby the federal government to take actions. There is also the risk of the federal regulation taking longer to be instituted than if Michigan acted on its own. Therefore, it is recommended that Michigan policymakers advocate for federal regulation, but actively pursue state-level approaches to addressing the issue of PFAS at the same time with consideration for policy options 2 through 7.

Photo courtesy of MSU Photos.

4.3.1 Considerations for policy options 2-6

The remaining 6 policies either focus on addressing the source of PFAS (policies 2-5) or managing PFAS already present in the environment (policies 2, 6, and 7). These are both important approaches as PFAS are already present in the environment and needs to be addressed, but this will be an uphill battle without addressing the source. Funding research on PFAS (policy 2) can target both since new technologies preventing PFAS emissions may be developed or more efficient in-situ remediation techniques could be investigated for use at PFAS-contaminated sites. However, this approach is unlikely to show immediate results so stakeholders, especially the public, are likely to want other actions to be taken. Other options to address current PFAS sources and presence in the environment could be sought through regulating the production (Policy 3) or emission (Policy 4) of PFAS. Right now, there are a variety of bills being presented to Michigan lawmakers. However, none of these policies have been adopted. Additionally, none of the current policies in discussion directly ban other PFAS substances in industrial use, only those used in firefighting. It is our recommendation that policies focused on production and emissions continue through the Michigan House and Senate with support, but that other options may be more tenable and face less opposition. For example, to address the source of PFAS, the US EPA has already proven that voluntary agreements with manufacturing companies using PFAS are possible and effective. The current agreement has only been done with the two most commonly used PFAS compounds (PFOA and PFOS), but these agreements could be expanded.

Thus, it is recommended that Michigan policymakers continue this approach to gradually phase out all PFAS chemicals from industry (Policy 5). This can have positive results by reducing the amount of PFAS being released into the environment and remove the threat of industries leaving the state, which instituting strict regulations may cause (Policy 3 and 4). This would also allow time for new technologies to develop to support new, less harmful PFAS substitutes. Agreements will be viewed positively by the public as action is being taken immediately to address the issue.

For managing PFAS already present in the environment, the two options to provide the funds needed for cleanup are either taxing PFAS industries (policy 6) or the public (policy 7). Generating a fund for cleanup is expected to be necessary for the state to be able cleanup sites where the responsible party is not clear or is no longer present. While the public will likely be opposed to taxes for this, it does again protect the state from potential economic and environmental impacts if industries were to choose to move elsewhere to avoid the taxes. This is also the approach used by the federal government for the SuperFund program under CERCLA. While some PFAS sites may qualify under the SuperFund program, creating a fund for Michigan will enable the state to more quickly address the PFAS contamination in its borders and not have sites in other states prioritized over its own. Additionally, there is a bill currently moving through the Michigan legislature to provide a wastewater treatment fund to support new infrastructure to filter out PFAS substances. In its current state, the bill is framed to receive funding from the Michigan Treasury which may require new taxes.

Therefore, it is recommended for Michigan policymakers to pursue both voluntary agreements with PFAS industries to reduce or eliminate their use of PFAS substances beyond PFOS and PFOA (policy 5) and to tax the public to provide funds for cleanup (policy 7) in order to address the issue of PFAS both at the source and after its release to the environment in a quick manner. In comparison to all other policy options, we suggest that these are currently more politically and administratively feasible options as well. The intention of these recommendations is to provide immediate action on PFAS which may not be possible through the other policies presented herein.

5. Conclusion

PFAS are present everywhere in the environment and their persistence makes them a long-term threat to both ecological and human health. While there are still uncertainties regarding the exact impacts PFAS have, they have been determined to be bioaccumulative in wildlife and are connected to some types of cancer, developmental delays in children, and decreased fertility. Based on current knowledge, the US EPA set the recommended lifetime health advisory level at 70 ppt for PFOA and PFOS. Work is ongoing to identify sites contaminated with PFAS and implement remediation strategies to bring levels down below this threshold. Adsorption with activated carbon is the main method used currently to remove PFAS from drinking water, but other promising technologies are being investigated that can actually break down the PFAS compounds, including chemical reduction and oxidation processes.

In Michigan, MPART is currently working to identify and address the existing PFAS contamination, particularly in drinking water supplies. It is proposed that a tax on the public be added for PFAS cleanup to help augment the work currently being done by MPART. This tax will provide funds for cleaning up contamination when a responsible party is not able to be identified. In addition to manage existing contamination, it is necessary to also address the sources of PFAS to prevent more from entering the environment. Thus, it is recommended that the state of Michigan pursue voluntary agreements with companies to gradually phase out more PFAS from industry. This strategy has worked before for PFOA and PFOS, and it protects Michigan from the potential negative economic impacts that stricter regulation may have. However, the ability of PFAS to be transported over long distances means that there may be sources outside of the state of Michigan that are contributing to the contamination here. It is vital, therefore, to actively advocate for the federal regulation of these chemicals, in addition to these state-level efforts, to address these outside sources.

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