Proactive Prediction: Mapping PFAs Risk in Dane County

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Abstract

This paper mapped soil and bedrock characteristics, demographic information and the locations of per and polyfluoroalkyl substance (PFAs) point sources in Dane County, in an attempt to predict municipal wells that would likely test positive for PFAs contamination, and to assess the distribution of exposure risk across different communities. A growing body of research indicates that the ubiquitous dispersal of PFAs in the environment could pose serious harm to humans and other living things, but testing for these compounds is challenging and voluntary. A spatial analysis of PFAs exposure risk in Dane County suggests wells on Madison's East Side are the most likely to be contaminated. We reached this conclusion after assigning contamination probability scores to municipal wells in Dane County, based on their proximity to PFAs point sources and groundwater contamination susceptibility ratings, which we mapped on ArcGIS. The findings of our study were roughly consistent with the results the City of Madison produced after they carried out actual tests on municipal wells over the course of the fall. Based on the City's results, our study appears to have underpredicted the number of wells that tested for high levels of PFAs contamination and overpredicted the number that tested for trace amounts. Our paper offers a geographic approach to managing PFAs that could be applied to other emerging contaminants as well. The availability of city-wide test data provides a valuable opportunity to test our spatial analysis against actual conditions, and to refine our methods in the future.

I. Introduction

Contamination in Context

Across Dane County, a suite of chemicals called polyfluoroalkyl substances, or PFAs, are turning up in waterways, soils and municipal wells. Ongoing research suggests that PFAs pose serious health threats to people and the environment, but the exact magnitude of those risks continues to be understood. Exposure to high concentrations of PFAs can cause cancer, low birth weight, delayed puberty onset and reproductive health problems. (Rappazo, 2017, 2). In Dane County, PFAs have been detected in the municipal water supply at levels high enough to result in well closures.PFAs are a class of roughly 3000 thousand synthetic chemicals (EPA.gov) . These compounds are fire resistant and water repellent, and occur widely in industrial and household goods ranging from the teflon in non-stick pans to the gortex in raincoats to the linings in food wrappers. PFAs are also used in Aqueous Film Forming Foam (AFFF), which is a common firefighting tool used by firefighters and at military airfields (Hu & Lidstrom, 2019, 349). PFAs are resistant to heat, grease, and oil making them excellent fire retardants. PFAs are classified as “forever chemicals” which means they are not biodegradable. They are also known to bioaccumulate — meaning they have a long residence time in living things and can be transferred through food chains.. PFAs act this way in the environment due to their strong fluorine-carbon bond (Darlington & Mckernon, 2019, 58). Regulations regarding PFAs vary globally. Denmark banned them in September 2019, but policy in the United States has lagged behind current research(Hunt, 2019).

PFAs became commonplace in many American industries after WWII. Major manufacturers, including Du Pont and 3M used PFAs in a variety of products. Because PFAs are commonly used for extinguishing fires; these chemicals were also developed for military use. These developments eventually led to the creation of AFFF. AFFF rapidly extinguishes hydrocarbon fuel fires, and soon became required in the use of firefighting training and in emergencies in the military. AFFF also has the additional property of forming an aqueous film on the fuel surface that prevents evaporation and hence, reignition of the fuel once it has been extinguished by the foam (US Naval Research Laboratory). Military bases, naval ships and aircrafts were increasingly using PFAs, which were carried all across the country resulting in the contamination of many wells and exposing people to contamination from these dangerous chemicals. By 2001, the military was aware of the potential dangers posed by PFAs, calling the chemicals "persistent, bioaccumulating, and toxic" (Benesh & Lothspeich, 2019). Despite the mounting evidence of the dangers PFA can cause, the military did not begin to phase out PFAs in AFFF until very recently. The Air Force finished their phase out in 2018, while the army is set to have them phased out by the end of 2019. The navy will continue their usage through 2020. However, the replacement chemicals in the new AFFF may still present similar dangers as PFAs (Benesh & Lothspeich, 2019). In Norway, the contaminant situation at a firefighting training facility (FTF) was investigated 15 years after the use of AFFF products had ceased. Detailed mapping of the soil and groundwater at the FTF field site in 2016, revealed high rates of PFAS (Høisæter, 2019, 115). Wisconsin's neighbor, Michigan was forced to issue fish and deer consumption advisories in several counties in 2012 and 2019 due to runoff from an upstream military base. Starkweather Creek, located near the Dane County Airport was confirmed to have elevated levels of PFAs. While Starkweather Creek is not a drinking water source, fishing is popular in the creek, and consumption of contaminated fish is linked to the same health risks as drinking contaminated water (Christenson & Raymond, 2016, 315). The Truax Air National Guard Base and adjacent training sites used AFFF for decades, where groundwater flows from under the base into the city.

Truax Field Air National Guard Guard Base and its neighbor, the Dane County Regional Airport, are located on the northeast side of Madison and are a known source of PFA contaminants. While these sources are likely the largest and have received the most attention in the media, any small municipal airports that use AFFF for training or practical purposes are potential PFA contamination sources. Additionally, PFAs have spread into the water table where factories and industrial sites were or are located. In Dane County, the old Mautz Paint Company Factory, which was operational from 1928-2002, is another suspected long term consistent contamination source. PFAs were commonly used in the manufacturing of stains, and water repellent coating, which were both manufactured at the factory on the east side of Madison (Wisconsin State Journal, 2017). Another suspected source would be the old Fuller & Johnson factory, which manufactured gas engines on thee Madison's East Side. . Major fires where AFFF was used to extinguish the flames are also potential contamination sources. In the summer of 2019, Firefighters extinguished the large fire at a downtown MG&E substation with AFFF, and the foam subsequently ran off into Lake Monona. PFAs contamination resulting from the fire was publicly confirmed September of 2019 by the DNR, but open records reveal that public administrators were aware that PFAs contamination was possible since late July. (Hubbuch, 2019).

PFAs fall under a class of chemicals known as *emerging contaminants* (Sutherson, 2016, 1). The term refers to any substance known to pose health risks, but where the extent of those risks is still uncertain. This uncertainty can be attributed to many factors, but for PFAs, it is mostly a function of (1) an evolving understanding of the contaminant's distribution in the environment, and (2) new information about the environmental and human health risks these chemicals pose (Suave and Desrosiers, 2014). Because so little is known about the distribution or impacts of PFAs, they pose an especially large challenge to public health officials and regulatory agencies. The EPA is continually refining their consensus on PFA toxicology and safe exposure levels. The evolution of policy, detection methods and treatment technologies has lagged significantly behind research and public understanding of the magnitude of the risks they pose. Both testing for PFAs and remediating contaminated areas proves to be extremely costly. For example, the current EPA-approved drinking water test must be carried out in a lab and can cost between $300 and $600. By comparison, lead contamination tests can be performed at home using a test kit that costs between $12 and $15 (EPA). And because testing for PFAs is voluntary, the extent of the contamination could be far larger than is indicated by existing data.

Research Question and Project Goals

When we began this project, preliminary testing had revealed trace PFA contamination at several municipal wells. It is worth reiterating that all of that testing was done voluntarily, at levels lower than the EPA recommended. But just how much testing would the county have to do to generate an accurate estimate of the extent of PFAs contamination? Principles of spatial statistics offer us tools to consider that question. Since a sample could be represented by a single point, theoretically, there could be infinite sample points across the county. Of course, this degree of sample resolution is not a logical way to test for contamination. However, more comprehensive testing could be largely avoided, since factors like the presence of possible point sources, soil type and depth to bedrock all govern the likelihood of PFAs contamination. An approach that considers interactions between these and other variables could help identify regions where contamination is possible or likely. Such information could then be used to optimize testing resources and expedite remediation efforts. It could also inform decision making on community and county-wide scales. Our project will test this method in order to answer three overarching research questions. First, we will determine if it is possible to predict the extent of PFAs contamination in Dane County using spatial analysis. If it is possible, our second question asks what areas of the county should be prioritized for further testing and remediation, and if some regions are disproportionatly exposed to PFAs. Lastly, our third question wonders how information regarding PFAs contamination risks is communicated to policy makers and impacted community members, and what concerns communities may have regarding PFAs exposure.

As we begin to answer these three questions, we will also meet four specific project goals. First, we will identify potential contamination sites across Dane County, using aerial images, historical records and county databases. We will identify probable PFA sites such as airports, manufacturing sites, and locations of large fires. From these sources, we will use an existing "logical framework" to assess PFAs contamination risk at airports (Miley, 2018, 122). Second, we will map PFA contamination sources in an effort to both analyze and communicate contamination risk. Third, we will generate a list of community-driven concerns and research questions that could be distributed to local agencies and policy makers. Finally, we have also filed an open records request with Public Health Madison & Dane County, in an effort to learn more about how the county decides where and when to sample, and how it decides to make contamination risk information available to the public.

Site Setting

We will be conducting our analysis across Dane County, in Southern Wisconsin. The 1,238 square-mile area contains large population centers like Madison, Verona and Sun Prairie, but most of the land in the county is agricultural. The county can be partitioned into four physiographic regions: (1) The unglaciated, Driftless west, (2) the belt of terminal moraines and the (3) Yahara River Valley in the center , and the (4) marshy, drumlin fields in the east. The eastern margin of the Driftless west slices diagonally through the western third of the county, following the contours of the last glacial maximum. West of this boundary, steep, wooded hills, winding valleys and cool, spring-fed streams compose much of the topography. With the exception of the Wisconsin River in the far north, soils in the Driftless region of the county can be classified as moderately shallow and very well-drained. The Wisconsin River's floodplain is made up of poorly drained soils, and the area experiences frequent flooding(Asplund, 2017). A band of terminal moraines, or vast deposits of debris shovelled into ridges by the glaciers, stretch east of the Driftless Area. This hilly region drains eastward into the Yahara River Valley, which runs through the middle of the county and contains the majority of the county's surface water, as well as its areas of greatest population density. The far eastern margin of Dane County is characterized by drumlin fields and shallow, meandering rivers. As a whole, the land east of the Driftless area sits on moderately well-drained, deep, silt loams and is pocketed with wetland depressions and lakes, another glacial legacy. Across the county, layers of sedimentary sandstone and dolomite comprise the uppermost bedrock boundary. It is within these layers that the region's groundwater is stored and transported. Seven shallow water tables exist just above the surface of the bedrock, and, for the most part, coincide with surface-level topographic basins. The deeper Mt. Simon Aquifer spans nearly the entire state, as well as parts of Illinois, Iowa and Minnesota. It is Dane County's primary water source, with upwards of three dozen high-capacity municipal wells drawing water from it. Precipitation and snowmelt are the aquifer's largest recharge sources. In Dane County's seasonal climate, spring snowmelt and heavy summer rains account for the bulk of that water. Depth to the aquifer is variable across the county, but is generally greatest in the Driftless west and in the north, where sedimentary bedrock begins to transition to Baraboo Quartzite (Schmidt, 2987). In the east, the aquifer is largely unconfined, meaning porous surface conditions allow it to recharge quickly. In the west, a shale formation called the Eau Claire Aquatard dramatically slows surface water recharge. River valleys and wetlands are the most permeable areas, and they function as an interface between surface and groundwater systems. Groundwater flow is roughly coincident with the movement of surface water, but there are a few notable instances where groundwater actually travels opposite to surficial drainage patterns. One example is the area between Fitchburg and Verona. On the surface, this area drains southwest into the Sugar River Watershed, but groundwater in this area flows northeast, back toward the Yahara River. (Asplund, 2017). Dane County's underlying physical geography governs the movement of PFAs in the environment and will help us identify regions that could be more susceptible to contamination.

II. Literature Review

After decades of unregulated use, PFAs have become widely distributed throughout the environment. Even now that research indicates that these compounds could be serious health hazards, PFAs regulation is limited and unstandardized. Due to unclear and evolving policy, as well as cost constraints, testing for PFAs poses particular challenges to public health officials. Mapping PFAs point sources and groundwater susceptibility could be one way to predict areas at heightened risk of exposure. These maps could also establish how PFAs exposure risk is distributed across different Dane County communities, and help convey that risk information to policy makers and the general public. Our literature review traces the behavior of PFAs in the environment, summarizes a few recent regulations and case studies, and highlights the ways maps can be used to both analyse and communicate contamination risk.

PFAs reside in numerous places in the environment, including in soil, sediments, surface and groundwater, and even living organisms. The contaminants enter the environment via point and nonpoint sources, and can be transported readily once they have been introduced to natural systems. However, these contaminants interact with different mediums in unique ways. Globally, oceans and sediments are predicted to be the largest PFAs reservoirs. In all mediums, interactions are governed by factors including temperature, acidity and organic carbon content (Ahrens 2014). Understanding those interactions is key to mapping the spread of PFAs contamination and predicting areas that could be at especially high risk. The next section will detail PFAs residence in aquatic systems, soils, and organic materials. Then, we will explore the transport mechanisms that link all of these systems.

a. Aquatic Systems

PFAs are distributed ubiquitously across aquatic environments, including surface and groundwater systems. Point sources like wastewater outflows and nonpoint sources like contaminated runoff both contribute to the widespread occurrence of these chemicals (Ahrens 2014). PFAs' high water solubility increases their prevalence in aquatic systems, but their residence time in these environments is relatively short. Because of their affinity for organic carbon, PFAs are less likely to be retained in water. Instead, water can be better visualized as a transport medium, which delivers PFAs to organic reservoirs. In fact, it is possible to remove significant levels of PFAs out of water using carbon filtration. There is a distinct positive spatial correlation between known PFAs point sources and contaminated waterways (Rahmahn 2013).

b. Soils

Soil composition has a significant impact on PFAs sorption behavior. Sorption, or the process by which solid or liquid form PFAs substances become chemically incorporated into soil, is largely dependent on the fraction of organic carbon in the soil. Soils with more available organic carbon demonstrate a greater PFAs sorption capacity. Sorption also increases with increasing ionic strength of inorganic salts, like sodium and calcium chloride. Conversely, increased concentrations of humic acids in soils have been shown to decrease the extent of PFAs sorption (Chen 2013). The type of PFA also governs the extent to which it will be incorporated into soils. PFAs with shorter carbon chains accumilate in soils at a greater rate and are also harder to remove. Once PFAs have been introduced into soils, sorption is highly irreversible

(Milinivic 2015). Finally, there is a high degree of spatial correlation between known PFAs point sources and PFAs contamination in soils (Munoz, 2017).

c. *Bioaccumulation*

Because of their structure, PFAs have a tendency to bind with proteins and lipids in living things. In many species, liver and blood tissues are the primary PFAs repositories (Condor, 2008). Organisms that feed in contaminated soil or sediment take up PFAs. In aquatic environments, organisms can be exposed through respiration, as well (Kinsella, 2019). However, not all PFAs are created equal, and different chemicals have different length fluorinated carbon chains. PFAs with longer chains are more likely to bind with proteins and lipids, and have a longer residence time as well (Condor, 2008). Organisms ranging from benthic invertebrates to bald eagles to humans are at risk of exposure (Kinsella, 2019).

Transport

PFAs cycle systematically through the environment once they have been introduced. For places located in close proximity to PFAs point sources, point source pollution is a dominant introduction pathway. But PFAs have also been detected in extremely remote locations, which indicates they can be transported in the atmosphere as well. Water is a primary mode of transportation, whether that is wastewater, surface water or groundwater. Porous media, like sedimentary bedrocks, are especially effective at allowing PFAs to seep from surface waters to deeper aquifers. Seasonality can also impact the rate at which PFAs move through the environment. A study conducted in Scandinavia showed that groundwater recharge — and, subsequently, PFA contamination — is primarily driven by snowmelt. These findings suggest that the way PFAs travel across landscapes is not only dependent on contaminant source and geology, as the above sources suggest, but that transport also depends on seasonal climate variability, and should be thought of as dynamic over time as well as space. Since pore water pressure governs the vertical velocity of groundwater infiltration, higher pore water pressure associated with spring snowmelt causes pulses in PFA transport, which results in the chemical saturation of previously unsaturated regions. Additionally, low pore water pressure during the winter could cause PFA transport to slow (Høisæter, 2019). When PFAs enter the food chain, they both bioaccumulate and biomagnify, meaning they reside in living things, and concentrations of the chemical will be higher in apex predators, including humans(Condor, 2008). Humans reintroduce PFAs to the environment through various waste streams. Contaminated trash has been shown to leech PFAs back into the environment. Contaminated wastewater returns PFAs to aquatic environments, as well as introduces the chemicals to agricultural systems in the form of biosolid fertilizer (EPA, 2019).

Management

PFAs and other environmental contaminants are managed according to two approaches: Prevention and remediation. *Prevention* refers to measures that eliminate a contamination hazard before that hazard can become realized. In the context of PFAs, total prevention would entail a complete halt of PFAs production and use in industry. In contrast, *remediation* assumes some level of contamination and poses solutions after the fact. This approach could include treating drinking water or dredging contaminated soils. In practice, these approaches often operate in tandem. The work of risk management is to determine what amount of contamination risk is acceptable, and to design policy accordingly. The fundamental principle underlying this assessment is the magnitude of the risk compared to the probability that the risk will occur. In the case of emerging contaminants like PFAs, incorporating a geographic perspective is imperative to this decision-making process. First, the probability of a contamination risk being realized has a strong spatial dimension. For instance, groundwater contamination is much more likely to occur in places where the soil and bedrock are porous. Second, the magnitude of PFAs risk is widely unknown. However, the scale of the risk's magnitude increases as the scale and cost of its potential impacts increase. Spatial attributes like population density and natural resource availability are key parameters in this equation. Of course, these parameters introduce inherent ethical questions, cultural biases and value judgments that are beyond the scope of this paper. But we would like to go beyond the risk literature to propose that there is no acceptable population density over which it is acceptable to distribute exposure hazards, and that living things have intrinsic value beyond their ecosystem services

As per the uncertain nature of emerging contaminants, there are conflicting opinions as to how best manage the risks posed by PFAs. There are a number of instances where the threat of contamination is smaller an alternative risk. For example, a large fire, like the one that occurred at the downtown Madison transformer station over the summer, likely posed a larger threat to immediate human safety than the PFAs contained in the firefighting foam used to extinguish it. Still, a growing consortium of scientists call for more restrictions on PFAs. (Gross 2015). Some have gone as far as to argue that PFAs production and use must stop altogether. Cousins et al. suggests that a precautionary approach is the most ethical way to manage contamination risk.

The precautionary principle, which describes the way risks can be mitigated by preemptively avoiding them in the first place, is a classic doctrine in risk literature. In the context of emergeing contaminants like PFAs, this principle would favor complete prevention. Since exposure to PFAs is irreversible, continuous and irreversible exposure risk is implied any time the chemical is used. In addition, the paper suggests that these chemicals can fundamentally destabilize earth systems because of their tendency to bioaccumulate. The paper argues that all these conditions meet the Rio Declaration on Environment and Development, which mandates that, “where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (UNEP, 1992). Therefore, the authors argue that precautionary policies regarding PFA manufacturing and usage are not only justifiable, but urgent. The authors propose “designing for degradation” as a way to avoid future contamination emergencies. Current policies at Federal, state and local levels blend preventative and remedial approaches in efforts to manage PFAs contamination risks (Cousins 2016).

Companies are only required to regulate as far as the EPAs broad guidelines recommend. In Wisconsin, these guidelines are not to the standard needed in order for consumer protection against the detrimental health effects. When the EPA sets non-enforceable limits, “Health Advisory Standards” for PFAs, they are simply providing guidelines for companies and utilities. These guidelines can easily be surpassed without the public's awareness. In WI, if a utility company finds traces of PFAs at a level 1 ppt lower than what the EPA sets, (69 ppt), utilities are *not required* to share this information with the public. This leads to a lack of transparency within the system, as well as lack of communication between utilities, the public, and policy makers.

Information released from MWU

Transparency is a valuable aspect that many companies are not required to disclose to the public. The current level in which PFAs are capped at is 70 parts per trillion (ppt), a level in which all utility companies in Wisconsin follow (Kaeding, 2019). However, companies, such as Madison Water Utility (MWU), are dedicated to having transparency within their practices in order to increase awareness and research around PFAs. MWU, along with several other utility companies across Wisconsin were required by the EPA to test for the 70 ppt that was set for these contaminants. Across the state, utilities tested their levels, and were unable to detect any traces of PFAs.However, MWU decided to go one step further; without any requirements from the DNR, whom MWU reports to, or the EPA, MWU decided to test Well 15, located near Truax Field, at lower levels than what was set by the EPA. After these tests were done, MWU detected trace amounts of the contaminant, and had the resources and power to promptly shut the well down. As the well was shut down, public awareness of PFAs increased, and eventually this matter was brought to closer attention within policy. MWU continues to work closely with University of Wisconsin-Madison professors and other researchers in order to continue their research on PFAs and how to approach these contaminants in regards to mitigation and policy efforts. MWU's decision to report their findings to the public are also demonstrative of the transparency within the company.

Using Madison as a unique case study, demonstrates the ability, resources, a monetary power the city had compared to other smaller utilities across Wisconsin who do not have similar abilities. Many utilities lack the time and availability to take precautionary measures such as Madison Water Utility, however other states should look to Madison, and their actions. Attention can oftentimes fall on water utilities, but there needs to be a shift of attention from utilities to those who are causing the pollution. (Madison Water Utility Interview, 2019).

The Environmental Protection Agency has three main laws and regulations that are important in preventing PFA contamination. The Toxic Substance Control Act (TSCA) encourages companies to voluntarily phase out PFA contaminants within their manufacturing processes, and is significant within the reporting process of this contaminant from manufacturers to the public (epa.gov). The Safe Drinking Water Act (SDWA) is another important regulator of contaminants through EPA regulation. Within the SDWA, the EPA is required to publish a list of contaminants in which states have to follow. Within the SDWA, the EPA can set Drinking Water Health Advisory, which are unenforceable levels that are set. This is the category in which Wisconsin falls under. Additionally, a more enforceable standard under the SDWA are the Maximum Contaminant Levels (MCLs), in which enforceable levels are set for contaminants that states must follow. Within this regulatory process for public drinking water supplies, EPA can order manufacturers to take recommended action for clean up efforts in case any situation occurs.

Lastly, the Superfund, otherwise known as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) which is responsible for the “clean up” of contaminants. It is also important to note how, “PFAS...are not listed as CERCLA hazardous substances, but in some circumstances could be responded to as CERCLA pollutants or contaminants” (epa.gov). While the research for these contaminants are still in the beginning stages, these contaminants are still considered hazardous and a risk for public health and the environment (epa.gov). This process demonstrates the continued efforts that will be needed in order for mitigation efforts to be efficient.

Other states' policies dealing with PFA contamination

In order to have better general understanding of the current policies and actions happening within Wisconsin, it is important to be familiar with policies within other states in order to better understand how Wisconsin's policies compare to the rest of the U.S. States with notable PFA contamination and policies are Michigan, New York, and New Hampshire. After a closer look at the policies within these states, one can have a better perspective of how Wisconsin's policies compare:

a. Michigan

Michigan was known as one of the worst states within the U.S. in regards to their PFA contamination levels (Matheny, 2019). Along with this recognition however, Michigan quickly acted, and are currently known as having one of the most innovative and efficient approaches to mitigating the effects of PFA contamination. The state is notable for their Michigan PFA Action Response Team, a group dedicated to research, education, and spreading awareness of the effects of this contaminant. With the help of this team, as well as public recognition of PFA contamination that this team contributed towards, the state soon established enforceable PFA limits (Westrick, 2019). Several other states, including Wisconsin and other midwest locations have started taking note of the actions within Michigan and began to introduce similar methods of mitigation within state policy and other alternative actions.

b. *New York*

New York established MCLs similarly to how Michigan did. As citizens were expressing concern over their water, health, and PFA contaminants, New York state created a board dedicated to eventually establishing more enforceable limits on PFA contaminants. As a result, the New York State Drinking Water Council became influential within policy and decision making and eventually the state created more enforceable limits (Ong, 2018).

c. *New Hampshire*

New Hampshire is an example of a state in which "split" policies are enacted. These "split" policies mean that the state may excel in one area of written policy, however, fail to approach policy in a broader and inclusive way. This is evident in the way the state eventually set enforceable limits on ground water and drinking water, however failed to include air, soil, and surface water within this policy. In failing to establish enforceable limits on surface water, the state was not approaching mitigation methods in a holistic way. With the exclusion of surface water, the state was failing to provide the highest level of protection and enforcement that other states (ex. Michigan) established (Ropeik, 2019). To this day, there is an ongoing court case between citizens of New Hampshire and the state in regards to the health issues that are growing amongst those living with high PFA levels in the air and surface water.

With the broad range of action across the U.S. in regards to policies and actions surrounding PFA contamination, a similar process is visible. Not only do community concerns raise the attention of policy makers and individuals with access and privileges, but these concerns are eventually acknowledged by decision makers which can lead to efficient and enforceable policies.

Wisconsin Policy Initiatives

Wisconsin has yet to set any enforceable standards on PFAs, however, there continues to be an ongoing conversation between the Department of Health Services and Department of Natural Resources. Through continued expressions of public concerns over the safety of their drinking water and PFAs effects, the DNR department secretary proposed enforceable limits over the summer of 2019 (Bergquist, 2019). While these limits have yet to be solidified and enforced, the long lasting process is expected to make their final decisions on the proposal by the summer of 2020. Not only do these enforceable limits require the approval of various decision makers, however they also require a wide array of resources, including expensive testing and time in order to make scientific arguments as to why the current limit needs to be decreased.

Governor Evers has been extremely influential in the process of setting enforceable standards of PFAs. After the gubernatorial election, there became an increased focus in environmental and clean water policies and initiatives. Gov. Evers officially declared 2019 to be the “year of clean drinking water” (Bergquist, 2019). The Governor signed an Executive Order #40 directing the DNR and Dept. of Agriculture, Trade, and Consumer protection to work together on advocacy and policy surrounding PFAs (Evers, EO #40, 2019). Additionally, Gov. Evers encouraged the DNR to set up PFAs Coordinating Council, dedicated to research and advocacy around PFAs in

Wisconsin (Kaeding, 2019). According to the previous states and their own policies and actions taken in order for enforceable limits to be set, Wisconsin seems to be headed in the right direction in order for their to be stronger limits and better protection for individuals concerning their health and PFA contamination.

Three scope statements have been introduced in order to make changes to the current regulations surrounding PFAs. These scope statements involve making changes to the ground water, surface water, and drinking water in an effort to protect public health and any further damage these contaminants will have on the environment. “SS O80-19” was proposed in order to establish maximum contaminant levels, enforceable limits which most states currently have (DNR, 2019). “SS 090-19” was proposed in order for there to be standards set for groundwater, and finally “SS 091-19” was proposed in order for surface water quality criteria to better protect public health (DNR, 2019). These scope statements are a start to the process of better regulating PFA contamination within Wisconsin, however this is a long process, and these statements if approved would not go into effect until Winter of 2022 (Hamilton-Consulting, 2019).

Testing v Modeling

An assumption that patterns observed on the ground can be statistically predicted and repeated can help geographers understand the distribution of events over space using model-based approaches. Across many fields, researchers have demonstrated that is is statistically possible to use real sample points to inform border geospatial analysis and interpolation (Brus 1997). In the context of our research, this means that patterns observed at known PFAs contamination sites could be used to identify possible contamination risks at sites that have not yet been tested. Combining observational and modeling approaches offers a way for geographers to ground and test their models against actual data, and also provides a way to fill in testing gaps.

Testing for PFAs poses three distinct sets of problems. The first challenge is collecting test samples themselves. Because PFAs are present in so many places and can be transported so easily, a location that tested negative for contamination in the past could easily become contaminated in the future. Second, testing is extremely cost prohibitive, and must be done in a laboratory setting. Third, there is no conclusive way to analyze the results of a test. Because PFAs represent a family of thousands of chemicals, many be identified using unique sets of tests. Currently, the EPA's approved method only detects 14 contaminants in drinking water. The technical chemistry may be beyond the scope of our research question, being aware of it helps put the challenges and threats posed by emerging contaminants like PFAs into context. The current EPA-approved PFAs detection method only identifies 14 out of 3,000 compounds, so it likely underestimates contamination levels. But even for the concentrations of contaminants this method can detect, there is no enforceable standard to test against, which makes interpreting results difficult. And because testing is done voluntarily and on local scales, it is hard to understand the spatial scope of the problem. A community that appears to have no PFAs contamination may simply not have tested for any (EPA).

In addition to serving as a useful analytical tool, maps also present a powerful way to synthesize and convey complex information about risk. A literature review compiled by risk communication specialists was especially instructive to us on this topic. This literature review compared over 250 chemical contamination maps and evaluated their effectiveness as tools of risk communication. In this paper, risk is defined as “the probability of an adverse effect on man or the environment resulting from a given exposure to a chemical or mixture.” The paper emphasised that strong risk communication underlies decision making and risk management, but that maps are an underexplored way to convey and simplify complicated information about risk and risk outcomes. One particular setback is navigating the interdisciplinarity of cartography and risk communication. But as GIS technology becomes more accessible, the authors anticipate that mapping will become an increasingly widespread way of describing risk. The paper identifies several different types of risk maps, including contamination maps, exposure maps, hazard maps, vulnerability maps and ‘true’ risk maps. It also discusses best practices for risk communication in the context of cartography. To bridge these gaps, the authors suggest that cartographers must become familiar with crafting more interactive messaging, and must understand that risk perception is a function of many complex social factors. Risk communicators should think more critically about the objectives of their maps, tailor their maps to be appropriate and engaging for impacted communities, and choose symbology that reflects risk in context (Lahr, 2010).

Because it is so challenging to test so many sites for so many different types of chemicals, the full degree of PFA contamination remains unknown in many places. Therefore, logical and spatial modeling could present a more efficient, cost-effective way to asses PFAs risks, prioritize testing and inform community action. To inform our methods, we studied examples of these techniques at work in other places. One especially notable study conducted in Canada offers a solution posed by the immense PFA identification and monitoring challenges. To identify areas that should be prioritized for testing and remediation, this paper suggests taking a geographic approach instead, and proposes that a logical decision tree model is effective for evaluating the distribution of many types of emerging contaminants. This paper looked for red flags like military bases or airports, which are known to be PFA contamination sources, but also considered physical factors like hydrology and surficial geology. By comparing all of these factors on a site-by-site basis, the authors were able to forecast areas that were more vulnerable to contamination and thus, should be prioritized for testing (Milley 2018).

In addition to serving as a useful analytical tool, maps also present a powerful way to synthesize and convey complex information about risk. A literature review compiled by risk communication specialists was especially instructive to us on this topic. This literature review compared over 250 chemical contamination maps and evaluated their effectiveness as tools of risk communication. In this paper, risk is defined as “the probability of an adverse effect on man or the environment resulting from a given exposure to a chemical or mixture.” The paper emphasised that strong risk communication underlies decision making and risk management, but that maps are an underexplored way to convey and simplify complicated information about risk and risk outcomes. One particular setback is navigating the interdisciplinarity of cartography and risk communication. But as GIS technology becomes more accessible, the authors anticipate that mapping will become an increasingly widespread way of describing risk. The paper identifies several different types of risk maps, including contamination maps, exposure maps, hazard maps, vulnerability maps and ‘true’ risk maps. It also discusses best practices for risk communication in the context of cartography. To bridge these gaps, the authors suggest that cartographers must become familiar with crafting more interactive messaging, and must understand that risk perception is a function of many complex social factors. Risk communicators should think more critically about the objectives of their maps, tailor their maps to be appropriate and engaging for impacted communities, and choose symbology that reflects risk in context (Lahr, 2010).

Impacted Communities

We also will use our maps to guide our project's outreach goals. While specific trends in PFAs exposure are still emerging, our literature review revealed that attempts to study environmental toxins in communities often ignore the voices, concerns and worries of the impacted communities themselves. A growing movement of researchers suggest that a "Participatory Community-Based Research" model is the best, most ethical way to approach academic research and outreach regarding PFA contamination. One review advocated for research rooted in long-term, place-based relationships between communities and research institutions, and searched for ways to overcome the knowledge access barriers that make scientific processes less inclusive. The engaged sociology suggested in this paper is founded on the belief that all environmental health research should be oriented toward social justice. One way to meet this objective is by collecting and privileging community-driven research questions and designs (Cordner, 2019).

While the exact geography of PFA contamination will become more clear to us as we continue to study it, research does suggest that some populations experience more risk than others. A study, "Maternal Concentrations of Polyfluoroalkyl Compounds during Pregnancy and Fetal and Postnatal Growth in British Girls" was done by Maisonet et. al. on maternal health impact from PFAs contamination. This study concluded that, "Girls born to mothers with high serum concentrations of PFOS, PFOA, and PFHxS during pregnancy appear to be smaller at birth and heavier at 20 months" (Maisonet, 2012, pg 7). In displaying the negative effects that these contaminants can have on the reproductive system, the study fails to notice the disproportionate effects that PFA contamination could have on marginalized communities. This study also brings attention to the lack of attention that women of color have within research. This research is important in order to understand the effects of PFA contaminants on women's bodies, as well as how women's bodies are affected by their geographies. However, the study contributes towards a narrative focused on white women and excludes institutionalized racism that is constantly in effect. Within Wisconsin, women of color have a significantly higher rate of infant mortality than white women, and this statistic is the worst within the U.S (Mills, 2018). Considering this statistic, one can attribute that poor environmental conditions disproportionately affect women of color at a significantly higher rate than white women.

III. Methods

Our GIS aspect of the project seeks to identify areas and demographics in Dane County that are at an increased risk of PFA contamination using spatial analysis. As discussed earlier, it is unrealistic and expensive to properly test all wells in Dane County for all classes of PFA contamination. Spatial Analysis can help us determine the highest areas of risk and therefore determine appropriate areas to focus future testing and outreach on. Our GIS will use several data layers from the Wisconsin DNR, Wisconsin Geological and Natural History Survey, census data, and data layers that are originally constructed.

The first layer is a groundwater contamination susceptibility map created in 1987 and obtained from the Wisconsin Department of Natural Resources. The DNR defines contamination susceptibility as, "...the ease with which a contaminant can be transported from the land surface to the top of the groundwater" (Schmidt, Kessler 1989). In order to make the susceptibility map, the DNR looked at data on depth to bedrock, type of bedrock, soil characteristics, depth to water table and characteristics of surficial deposits. These characteristics were then overlaid on top of each other to create the map itself. The map was made in 1989 and a model usable for GIS could not be obtained. In order to conduct analysis in GIS, our group digitized the map.

Digitizing in GIS is the process of converting a scanned map into vector data by assigning coordinates to corresponding features on the scanned map (Huisman, 2009). We chose 16 different coordinates to ensure optimal accuracy of the newly digitized map. Now that the scanned map has the correct coordinates, it is necessary to draw polygons and assign a score to those polygons reflecting the different levels of susceptibility in Dane County. Drawing accurate polygons proved to be a time consuming and difficult process. The original map displayed 20 levels of susceptibility non-numerically via a color coded scale and contained hundreds of unique polygons. Additionally, the boundaries between areas that had slightly different susceptibility scores were difficult to detect. In order to simplify the process, we reduced the number of susceptibility scores. While this made the digitization process easier, it also reduced the overall accuracy of the newly digitized map. We also digitized a 2016 map of public wells in Dane County which was retrieved through the Wisconsin Geological and Natural History Survey. The digitizing process for this map was much less complex. We repeated the process of assigning 16 coordinates to features on the scanned well map, but instead of drawing polygons, we created points for well locations. This was simply done by clicking on the wells location of the scanned map once the coordinates had been properly assigned.

It is important to remember that The Groundwater Contamination Susceptibility does not show, "...areas that will be contaminated, or areas that cannot be contaminated" (Schmidt, R., and K. Kessler. 1989). Contamination also relies on probability of contaminants, the type of contaminants released and the sensitivity of the area to the contamination. The DNR's map only shows the sensitivity of the area to the contamination and lacks information about the locations of potential contaminants**.** In our GIS, we will seek to address the probability that contaminants were released and how PFA contaminants were released to determine a more specific and accurate susceptibility score solely focused on PFA susceptibility (Schmidt, R., and K. Kessler. 1989)**.** For example, the location of PFA contamination sources can help us identify specific areas more susceptible to PFA contamination. As described earlier, a PFA point source is a location where PFAs were present and possibly made their way into the water table. After inputting the PFA point sources and well locations into our GIS, we overlay our point sources and well maps on the groundwater contamination susceptibility map to create a new susceptibility score for PFAs specifically. Additionally, PFA point sources were weighted based on the likelihood of PFA contamination from the respective source. For example, Truax, which has been consistently using chemicals with PFAs for decades is weighted far more heavily than a one time fire, where AFFF was potentially used. As a result, Truax, a consistent possible contaminant source, will affect the overall susceptibility score far more than a one-time contamination incident. This new susceptibility score would be based on a wells distance from the weighted PFA sources and the locale's general susceptibility to groundwater contamination.

The new susceptibility score will rank wells into three categories: likely contaminated, possibly contaminated, and not likely contaminated. Considering that PFAs are forever chemicals these scores will never go down, and only stand to increase if more contamination occurs (Boone & Vigo, 2019, 365). Well 15 is already shut down because of contamination and will be labeled as such.

With the new susceptibility score, we would then seek to overlay various demographic categories on the PFA susceptibility map to determine whether PFA contamination disproportionately affects certain groups. The four demographics we seek to overlay are median household income, percentage below the poverty line, percentage of minority residents, and percentage of black residents living in a respective census tract. In order to do this, we will utilize the census tract. A census tract is a small, and usually permanent statistical subdivision of a county. Census tracts are divided by population, rather than land area and generally have around 5000 people in each tract. A census tract is brought into our GIS by joining the corresponding demographic data in each tract to the correct tract on a map in the GIS. The demographic data was found using "American Fact Finder", a database run by the United States Census Bureau with data on many different types of demographics. Before even conducting a spatial analysis, we can recognize that Truax (a major PFA source) is surrounded by neighborhoods that significantly exceed the average rate of poverty and minority communities in Dane County (US Census, 2010).[1]

I. Data Analysis

Maps

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[1] See appendix for GIS Implementation and Conceptualization Diagrams.

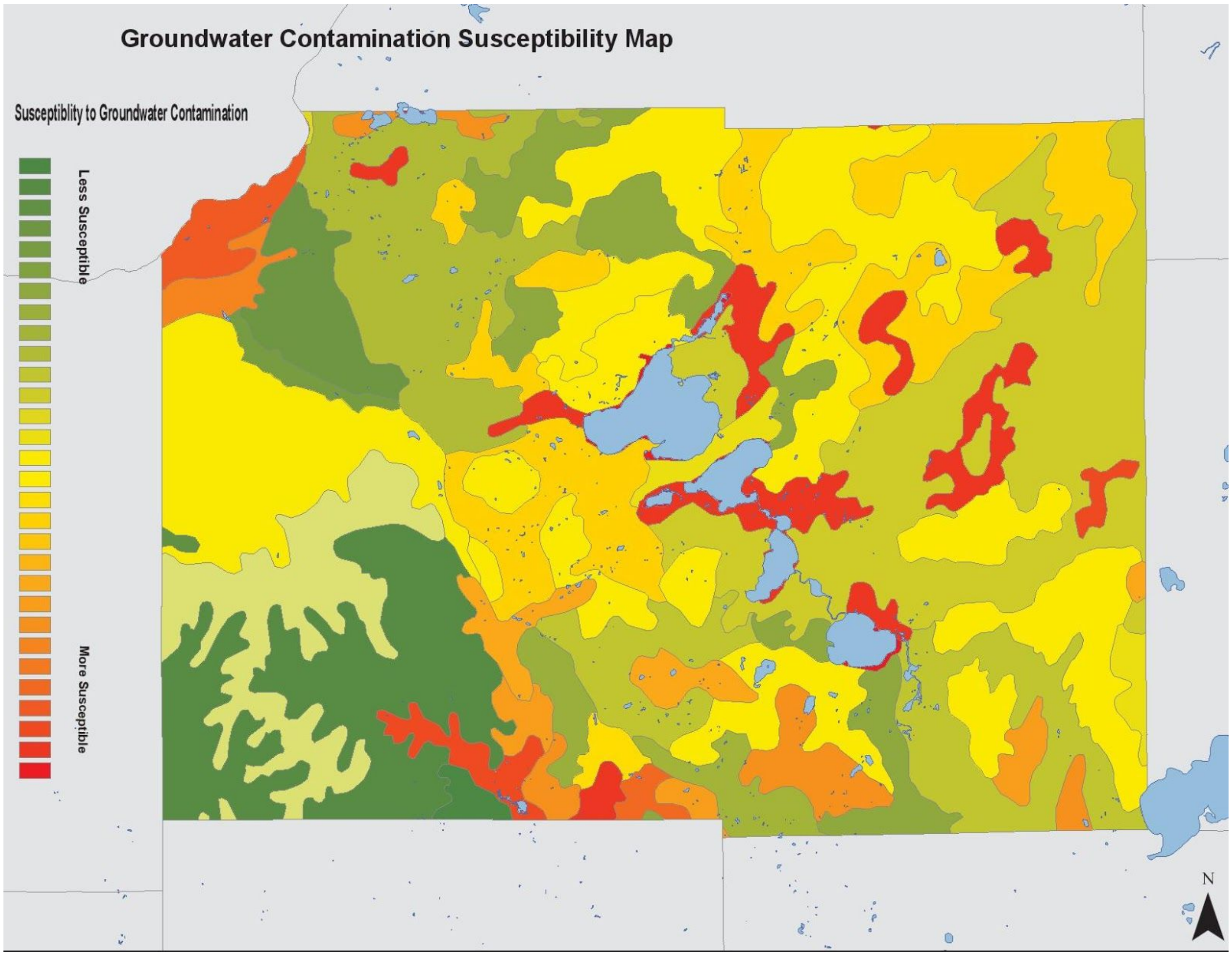


Figure 1

The first map compares groundwater contamination susceptibility to the location of Madison's municipal wells (*Figure One*). We observed that groundwater contamination susceptibility was very low in the Driftless Area in the western part of the state. Contamination risk was higher and more randomly distributed throughout the other regions of the county. The areas draining into the Yahara Lakes are at a higher risk for contamination, but the places which ranked highest for susceptibility are pocketed throughout the Eastern quarters of the county, as well as along the Wisconsin River. We also included possible contamination sources, like airports or places where there have been large fires. Well sites have been overlaid on this map, in an effort to predict the likelihood of well contamination across the county. Wells located in areas with low contamination scores are predicted to be at low risk for contamination, while wells located in places where contamination is likely may be at higher risk. In all, wells were ranked as not likely contaminated, possibly contaminated, likely contaminated and contaminated. Our analysis determined that contamination was definitely occuring at one municipal well, was likely occurring at four wells, was possibly occurring at seven wells and that five wells were likely not contaminated. Well 15, which is the only one that was scored as probably contaminated, is located in close proximity to Truax Airfield, which is a known contamination source. Additionally, Truax Airfield is located in an area highly susceptible to groundwater contamination, further increasing the likelihood of PFA's reaching the water table in that area.

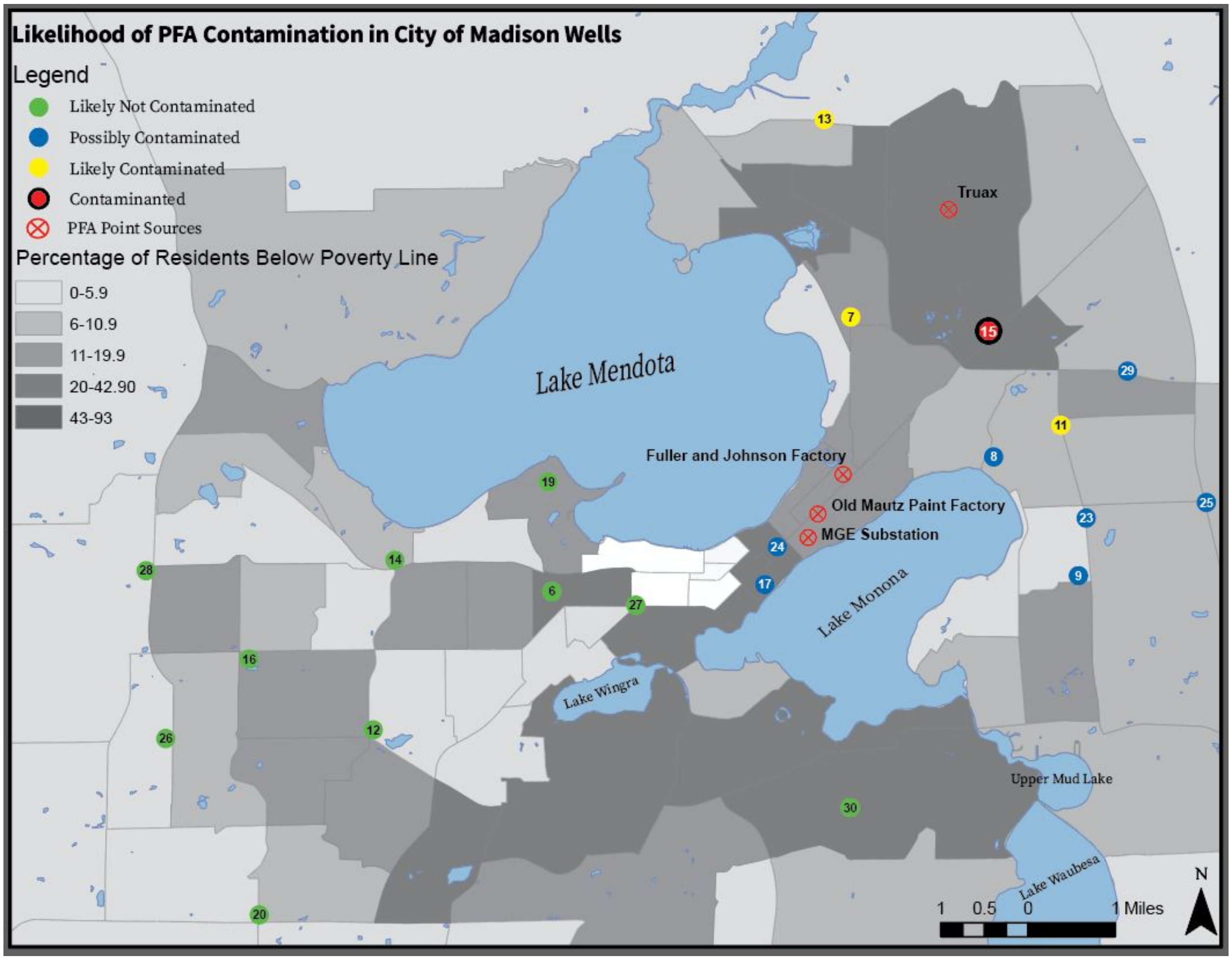


Figure 2

The second map (figure 2) is comparing percentage living below poverty and these individuals situatedness to potentially contaminated wells. The northeast side of the map displays darker shades of grey, indicating that higher levels of individuals living below the poverty line are within this area. It is also central to where three of the wells labeled as “likely contaminated” are located. Additionally, the highest percentage of individuals living below the poverty line are surrounding well 15, which was shut down due to high levels of PFA contamination. This same area is surrounding point source areas, increasing the risk for contamination within public water supplies. It is also important to note that campus area has darker shades of grey, however this area is not included within our research. The poverty rate for that area is heavily skewed due to the student population of UW-Madison and is not an accurate reflection of the actual socio-economic demographics in those tracts.

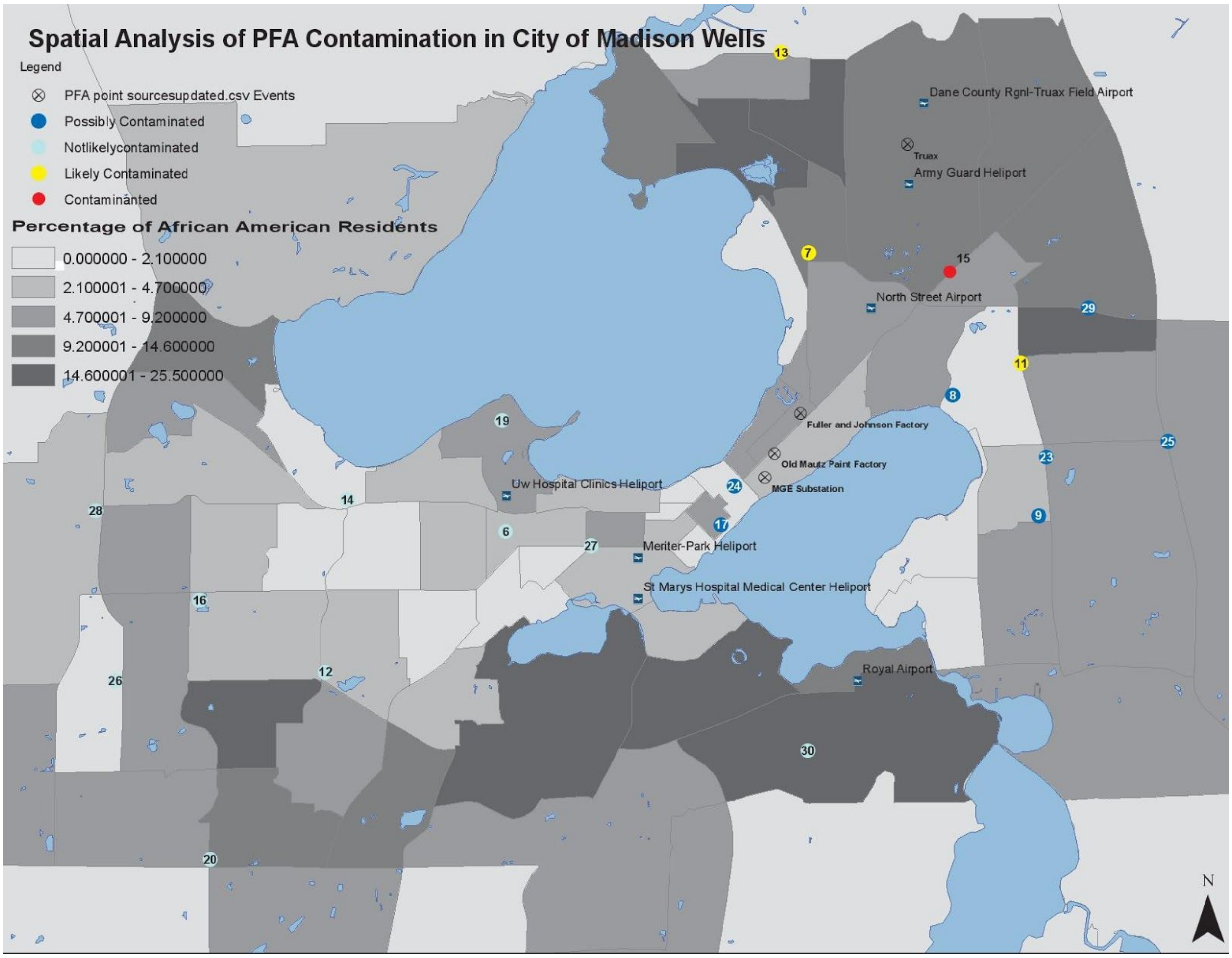


Figure 3

This map (figure 3) is comparing percentage of African American residents and their situatedness to wells in the city of Madison. The darker shade of grey as displayed in the map is representative of higher percentages of American American residents living within the area. The point source locations for the wells, Truax, is located in an area with a higher percentage of African American residents. Three likely contaminated wells, well 7, 11, and 13, are all within areas of darker grey shadings, indicating that the areas in which potentially contaminated well are located are areas with higher minority populations. Additionally, the Maple Bluff area located on the Eastern side of Lake Monona, is populated by the lowest percentage of African Americans, however their water is supplied by private wells. This indicates that even though these residents within the Maple Bluff area are located directly next to well 7, they are unaffected by the potential contamination as their water wells are private.

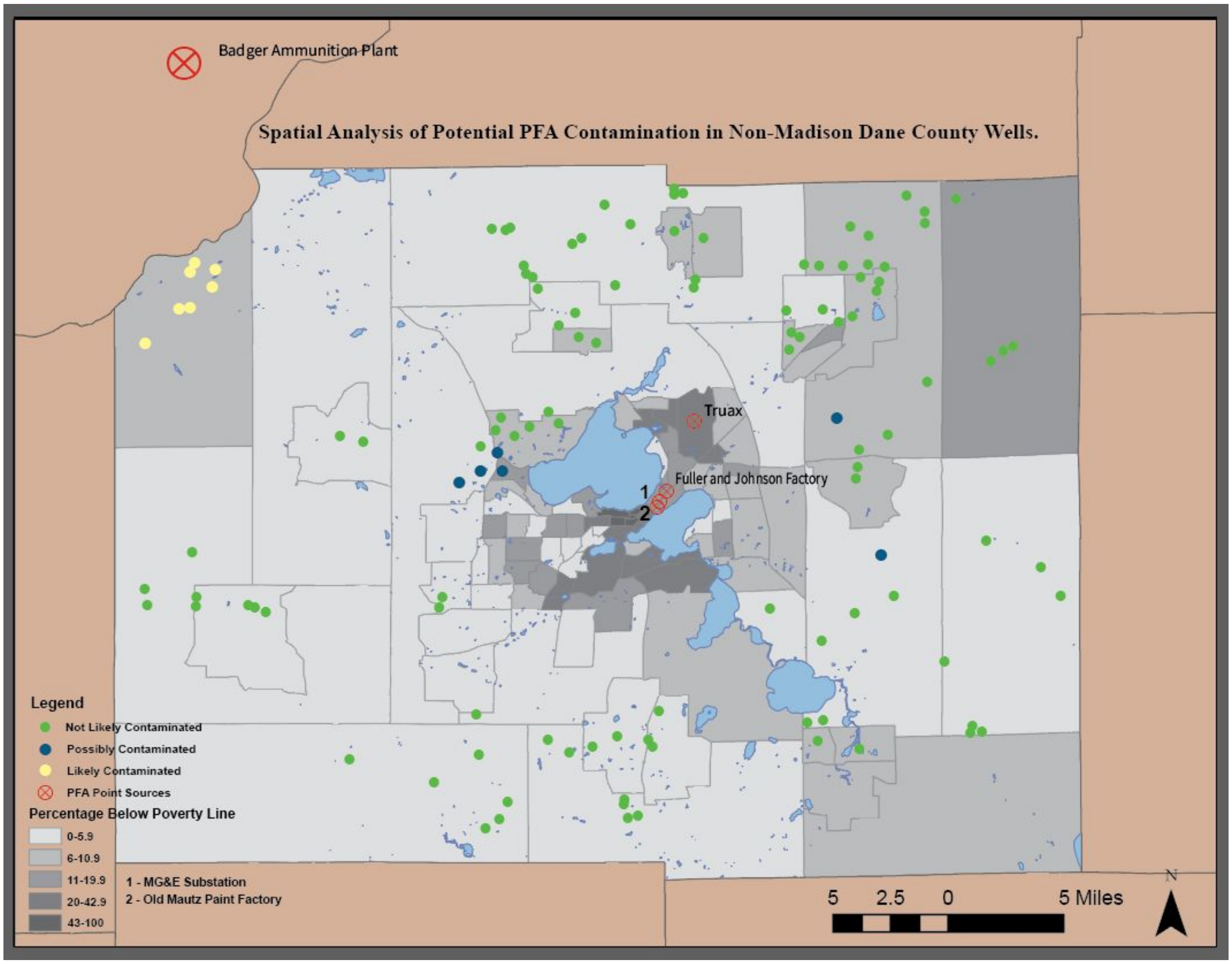
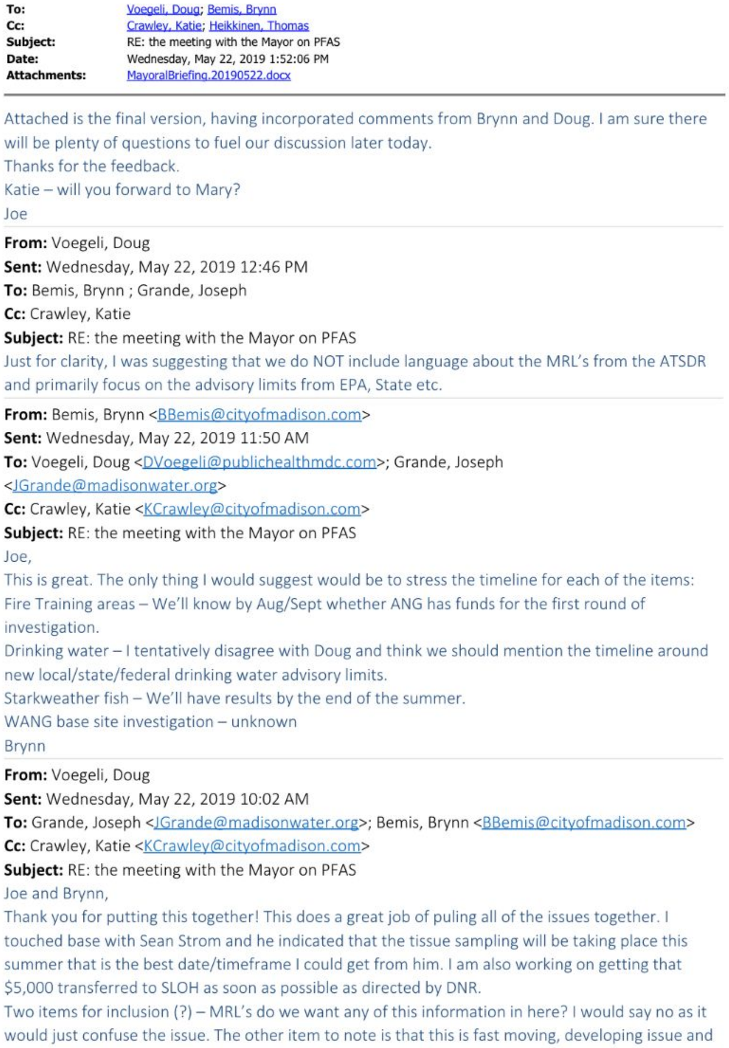


Figure 4

This map (figure 4) displays possible well susceptibility in municipal wells outside of Dane County. Only one major PFA source is located outside the city limits of Madison, and is actually located northwest in Sauk County near the county line border. That PFA source is the former Badger Army Ammunition Plant. This plant was operational from World War II through the Vietnam War, and has been determined to be major source of groundwater pollutants in the area. This PFA source causes the wells in the northwestern portion of Dane County to be more prone to contamination. Several wells outside of Madison that are in close proximity to Truax are potentially contaminated by PFA contamination.

Open Records

Our open records request yielded 1,800 pages of emails and other documents exchanged within the Dane County Public Health Department over the last 12 months. Unfortunately, the records we requested at the beginning of the semester did not arrive until early December, which did not give us enough time to analyze them as thoroughly as we had hoped. However, an overview of these documents reveals that public health officials are cautious about what information they convey to the public, perhaps due to the uncertainty surrounding PFAs. The following email demonstrates that caution.



To: Voegeli, Doug; Bemis, Brynn
Cc: Crawley, Katie; Heikkinen, Thomas
Subject: RE: the meeting with the Mayor on PFAS
Date: Wednesday, May 22, 2019 1:52:06 PM
Attachments: MayoralBriefing.20190522.docx

Attached is the final version, having incorporated comments from Brynn and Doug. I am sure there will be plenty of questions to fuel our discussion later today.
Thanks for the feedback.
Katie – will you forward to Mary?
Joe

From: Voegeli, Doug
Sent: Wednesday, May 22, 2019 12:46 PM
To: Bemis, Brynn ; Grande, Joseph
Cc: Crawley, Katie
Subject: RE: the meeting with the Mayor on PFAS
Just for clarity, I was suggesting that we do NOT include language about the MRL's from the ATSDR and primarily focus on the advisory limits from EPA, State etc.

From: Bemis, Brynn <BBemis@cityofmadison.com>
Sent: Wednesday, May 22, 2019 11:50 AM
To: Voegeli, Doug <DVoegeli@publichealthmdc.com>; Grande, Joseph <JGrande@madisonwater.org>
Cc: Crawley, Katie <KCrawley@cityofmadison.com>
Subject: RE: the meeting with the Mayor on PFAS
Joe,
This is great. The only thing I would suggest would be to stress the timeline for each of the items:
Fire Training areas – We'll know by Aug/Sept whether ANG has funds for the first round of investigation.
Drinking water – I tentatively disagree with Doug and think we should mention the timeline around new local/state/federal drinking water advisory limits.
Starkweather fish – We'll have results by the end of the summer.
WANG base site investigation – unknown
Brynn

From: Voegeli, Doug
Sent: Wednesday, May 22, 2019 10:02 AM
To: Grande, Joseph <JGrande@madisonwater.org>; Bemis, Brynn <BBemis@cityofmadison.com>
Cc: Crawley, Katie <KCrawley@cityofmadison.com>
Subject: RE: the meeting with the Mayor on PFAS
Joe and Brynn,
Thank you for putting this together! This does a great job of puling all of the issues together. I touched base with Sean Strom and he indicated that the tissue sampling will be taking place this summer that is the best date/timeframe I could get from him. I am also working on getting that $5,000 transferred to SLOH as soon as possible as directed by DNR.
Two items for inclusion (?) – MRL's do we want any of this information in here? I would say no as it would just confuse the issue. The other item to note is that this is fast moving, developing issue and

Community Research Goals

We asked several neighborhood associations and local environmental advocacy groups what worried them most about PFAs and what the university could do to help. Frequently occurring community concerns can be summarized in the following research questions:

- How have PFAs impacted biota in local streams?
- What concentration of PFAs are entering local food systems through fertilizer application?
- What restoration methods would be most appropriate for addressing Dane County's most contaminated waterways?
- How can contamination risk information be communicated to a diverse audience of Yahara Lakes users, and anglers in particular?
- How does the emergence of contaminants like PFAs impact the way communities interact with each other and with their environment?
- Are there ways to monitor for PFAs without testing? For example, could the disappearance of certain species or changes in water chemistry indicate potential contamination?

They also suggested that more fish from popular fishing spots be tested for contamination and that Citizen Scientists be enlisted to monitor either for PFAs or for their impacts.

Future Research

As we completed our project, we found many more avenues for future study. One thing that caught our attention in particular is that Truax Field is located on a Native burial ground. We want to spend more time thinking about the implications of toxic environmental colonialism as they apply to Madison as well as other sites across the world. The alignment of the City of Madison's study with ours also presents a valuable opportunity to test the accuracy of or predictive maps. Although there are not nearly enough test sites to perform any statistical analysis, future research could still compare the observed and predicted results, and use that information to create more accurate models. But even without making those comparisons, we believe considering more point sources as well as groundwater flow would have enhanced our map. Future studies could also investigate the records we assembled, in order to learn more about how contamination risk is communicated to the public. The community research goals we gathered also offer many ideas and directions for future study. Any future PFAs research that happens at the university regarding PFAs should work to include the perspectives and questions of impacted communities.

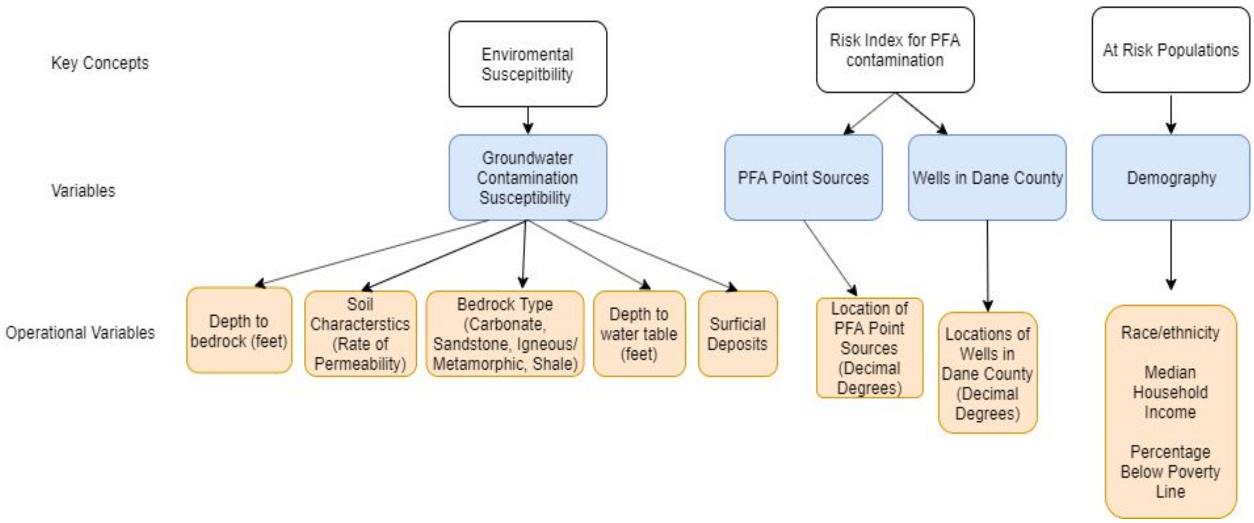
Conclusion

The models we have grade have allowed the possibility to predict future contamination sites that could be of use to policy makers and citizens. Our models have further demonstrated the impact of PFAs on low income and minority populations in addition to these marginalized groups being at a higher risk for the negative health effects of these contaminants as well, which can especially be seen on the east side of Dane County. The census averages we looked at however also need to be addressed, especially as some of the census data we looked at are not accurately representative of locations. This is especially seen when one analysis effects of gentrification on locations in Madison, demonstrating how certain locations may appear to be wealthier but do in fact hold low income populations as well.

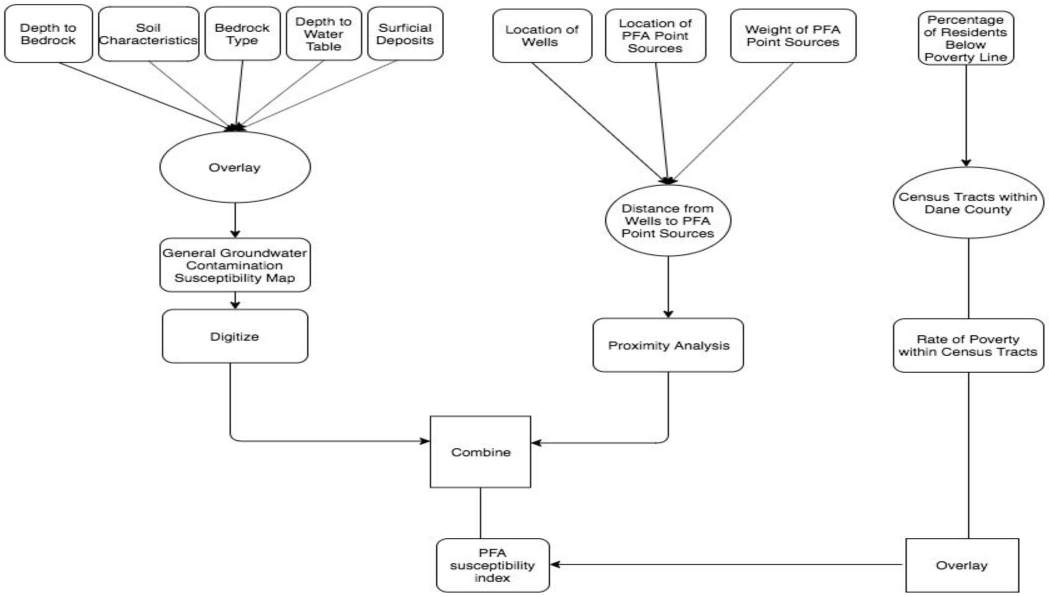
In addition to the models that have been created, the open records have also allowed us to conclude that the vague language involved in regulating and discussion PFAs can create confusion and complication when these contaminants are being discussed. Further, there is a need to expand upon how PFA contamination in Dane County is contributing towards environmental racism within the state. While policy initiatives continue to progress and expand on these contaminants, there needs to be solidified focus on transparency and the communication of risk.

Appendix

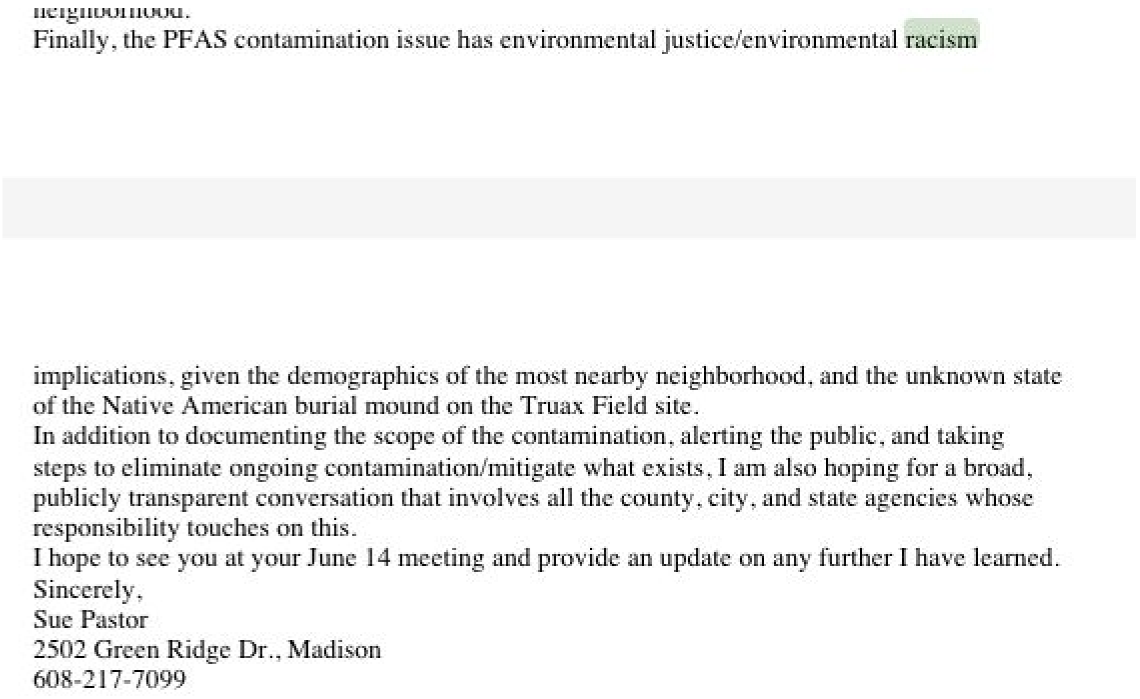
<u>GIS Conceptualization Diagram</u>



<u>GIS Implementation Diagram</u>



Letter from open records with only mention of Truax Field on burial ground and environmental racism.



neighborhood.
Finally, the PFAS contamination issue has environmental justice/environmental racism

implications, given the demographics of the most nearby neighborhood, and the unknown state of the Native American burial mound on the Truax Field site.
In addition to documenting the scope of the contamination, alerting the public, and taking steps to eliminate ongoing contamination/mitigate what exists, I am also hoping for a broad, publicly transparent conversation that involves all the county, city, and state agencies whose responsibility touches on this.
I hope to see you at your June 14 meeting and provide an update on any further I have learned.

Sincerely,
Sue Pastor
2502 Green Ridge Dr., Madison
608-217-7099

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