Muddying the Waters: The Upper Mississippi River, Nitrates, and Environmental Regulation in Minnesota, Wisconsin, and Iowa

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Abstract

Nitrates in the Upper Mississippi River continue to pose a threat to aquatic life and are associated with a growing number of human health risks including cancer, despite measures taken by state and federal agencies to reduce nutrient loading. Although states like Minnesota, Wisconsin, and Iowa are part of a task force that aims to reduce the size of the hypoxic zone in the Gulf of Mexico, the efficacy of their environmental regulations is unclear. These states are particularly important to compare as they sit on the Upper Mississippi River, where the hypoxic zone starts, and each adheres to a political ideology that impacts its distinct environmental policies. This project used data from the EPA and the USGS to examine nitrate contamination within states, and also to document the number of nitrate contamination violations that are reported to NWIS. Additionally, this project used data from each state's environmental department to compare budgets and enforcement measures by state. Results showed Minnesota had the biggest budget, the strongest measures of enforcement, and the least amount of nitrate contamination, while Iowa had the smallest budget and the greatest area of contamination; although Wisconsin was worse than both Minnesota and Iowa in terms of number of violations, other metrics put Wisconsin ahead of Iowa. These trends also correspond with the political affiliation of state leadership, giving cause to believe that there is a relationship between political ideology and nitrate contamination. Proposed policies to mitigate nitrate contamination in state waterways are to update water quality laws, implement regional water quality trading across states, prioritize transparency in state decision making, and introduce precision agriculture.

Keywords: nitrates, water quality, pollution, nutrient loading, hypoxia, human influence, government regulation, EPA, enforcement, Upper Mississippi River

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Every year, thousands of fish die in the low-oxygen waters of the hypoxic zone in the northern region of the Gulf of Mexico. Aptly labeled a dead zone, the area of hypoxia, where life cannot be sustained, fluctuates from fewer than 5,000 square kilometers to approximately 22,000 square kilometers (National Geographic, 2023). These seasonal fish kills have incredibly detrimental consequences, leading to destabilization in the fishing industry, severe ecological damage, and worsening economic and health outcomes for bordering human populations at risk of pollution (Rabalais et al., 2002; Wisconsin Department of Health Services, 2020; Pennino et al., 2017). The origin of these fish kills is evident: human activity in the form of farming and industry leads to nutrient loading and a surplus of nitrates in our waters. This, in turn, causes plant life to bloom in overabundance. When the algae die and decompose, it takes away oxygen from aquatic animals that support the ecological systems of the Gulf.

The main contributor of nitrates in the Gulf of Mexico comes from the Mississippi River (MR) and its tributaries. The MR basin contains waters from 31 states, and the river itself flows through ten: Minnesota, Wisconsin, Iowa, Illinois, Missouri, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana. These states are all major agricultural and industrial producers for the United States, and as such, require high amounts of nutrients to tend to the land. Runoff from farms and industrial complexes, including compounds of nitrogen and phosphorus, choke the waters of the river with plant nutrients. Nutrient loading, also known as eutrophication, leads to algal blooms, which ultimately take up much of the oxygen in the Gulf and suffocate aquatic life (Rabalais et al., 2002). Nutrient loading has not only become a problem because of the application of nutrients to farms and subsequent runoff, but also because of historical human activity along the MR that prevented the natural processes that originally filtered out these nutrients, such as closing off marshes and swamps, digging the river deeper to facilitate navigation and trade, and flood prevention by federal and state agencies (Niebling et al., 2014). Nutrient loading, which leads to degraded water quality, is a problem that stems from its historically anthropogenic origins, which requires human intervention to rectify. Unfortunately, policies that target current production do not see results in a timely manner because of historical contributions of nutrients; in other words, even if farming and industrial activity along the MR was halted, the problem of the dead zone would still persist for a time after because of how much nutrients already saturate the waterways. So, policies must be implemented consistently and for a lengthy amount of time to truly reduce the size of the hypoxic zone. The main ways that the federal government does this along the MR is through supporting the adoption of mitigation strategies by farmers, and more directly, through regulating the amount of nitrates in state waterways.

Three major contributors to degraded water quality in the Upper MR are Minnesota, Wisconsin, and Iowa. These three states are important members of the EPA's Hypoxia Task Force to reduce the size of the hypoxic zone, as they sit at the beginning of the dead zone. The effectiveness of the Hypoxia Task Force, the collaborative state/federal partnership co-led by EPA to address nutrient pollution in the Mississippi-Atchafalaya River Basin, may be called into question as progress has not been sufficient to reach its stated goals (Turner et al., 2008). The main limitations that the government has faced in improving water quality is owed to a deficit in funding for inland waterway projects and a lack of political will to invest in these projects (Niebling et al., 2014). Nonetheless, states face pressure from constituents to consider the effects of pollution, and so implement further regulation or enforcement measures according to the level of priority given to environmental quality. Therefore, the goal of this paper is to evaluate the effectiveness of these three states' environmental regulations that limit the levels of nitrates in the MR, which ultimately contribute to the size of the dead zone in the Gulf.

Nitrates (NO_3^{-}) are the main compound that I evaluate, as its presence stresses fish and stunts growth, contributes to a range of human health problems, and is one of the primary culprits of fish kills. Nitrates have many sources, the main one being agricultural production, primarily from corn and soybean cultivation (Alexander et al., 2008). It is difficult to identify specific sources of nitrate in drinking water because of the amount and scale of possible pollutant sources. However, environmental regulation of pollution applies to the volume of chemicals regardless of source. Thus, I focus on the level and scope of nitrates collected in water quality tests instead of identifying sources of pollution. Agricultural states are suitable for this type of study because they are guaranteed to have higher levels of nitrate runoff. At the same time, each state has different methods of dealing with nutrient runoff due to the decisions made at the state level, such as budget allocations, enforcement measures, and targeted programs. It is for this reason that Minnesota, Wisconsin, and Iowa make a good case study for policy and pollution. More specifically, these states are a good comparison for each other because of the political leadership that dictates the budget and regulation, which is likely to influence the level of nitrate contamination. Each state holds leaders of opposing political ideologies—Minnesota largely Democrat, Iowa largely Republican, and Wisconsin mixed—that influences the budget and the agenda, which has implications for policy decisions regarding water quality.

I. Background and Context

Between the leadership of Minnesota, Wisconsin, and Iowa can be found a combination of different political ideologies. These political leanings shape the context within which laws are created and upheld to promote environmental management and protect water quality. Generally, Minnesota is viewed as more liberal/left-leaning, while Iowa is more conservative/right-leaning. Wisconsin is viewed as a middle ground between the two, with a mixture of Democratic and Republican leadership. All three states have large agriculture and manufacturing sectors, in addition to abundant natural resources like forests, lakes, and wetlands that support tourism and recreation.

Minnesota has been historically a majority-liberal state, with two Democratic senators and a Democratic governor, and prioritizes environmental concerns. The Democratic party also controls both chambers of the state legislature (Ballotpedia, 2024). Minnesota supports environmental regulation at the state level and leads efforts to protect people from harmful chemicals. For example, the Minnesota bill to reduce or ban PFAS, a class of chemicals linked to several health risks, is the most comprehensive of any state and has stricter definitions of what constitutes nonessential use (Guy, 2023). In terms of water quality, Minnesota has established its own monitoring services at certain points of the MR to further its research goals and commitment to improving water quality (MWMO, 2023)

Wisconsin is a swing state, currently with one Republican and one Democratic senator, and a Democratic governor. A more helpful description of the Wisconsin legislature is that in 2023, the Republican party controlled both chambers, with 21 of the 33 Senate members and 64 of the 99 Assembly representatives belonging to the Republican party (Felone, 2023). This breakdown is especially important because it may lead to a difference in the Governor's requested budget allocation for environmental funding, and the actual results of the funding and policies that are able to pass in a majority-Republican legislature. Wisconsin may spend less money per capita on water protection or have weaker policies even with a Democratic Governor, due to this factor. Indeed, this seems to be the case in a macro-analysis of the state's environmental condition. According to the Environmental Law and Policy Center, a comparison shows that Minnesota is transitioning quickly to a healthy clean energy economy, while Wisconsin has made much slower progress (VanDyke and Olsen, 2020). The Wisconsin legislature partisan breakdown shows that the state can be seen as a middle-ground between conservative and liberal ideas in policy space, which has the effect of a slower progress in environmental health policies compared to the agenda of a more broadly Democratic state, such as Minnesota.

Iowa, while it had historically been a swing state, has been majority-Republican since 2004, with two Republican senators and a Republican governor, as well as the Republican party controlling both chambers of the state legislature (FEC, 2020). Additionally, waterways in Iowa have had a history of degraded water quality due to nutrient loading; in the past the EPA has declared water in the Des Moines River undrinkable due to the levels of nitrates being over the statutory maximum limit for drinkable water supplies (Hallberg, 1987; Turner and Rabalais, 2003). Even more so, the water treatment facilities are often called upon to filter out nitrates—technology which not every treatment facility is equipped with or able to operate, owing to the high cost of operation (Terry, 2022; Jones, 2021).

It can be seen that these states are a suitable comparison for one another because of differences in government administrations that control environmental regulation and enforcement. They are also important to monitor because of their geographical positioning at the Upper MR, which sets a precedent for states farther downriver. Their nature as contiguous agricultural states in the Midwest further contributes to similarities between the states in culture and production.

II. Overview of Research and Conceptual Framework

In this paper, I evaluate the comparative contribution of nitrates to the MR from Minnesota, Wisconsin, and Iowa. The offices of the environmental departments are headed by secretaries which are appointed directly by the governor, and therefore environmental policies likely reflect the political ideologies of the state executive branch. The amount of literature that attributes environmental quality, in part, to political ideology of a state means that a comparative review of Minnesota, Wisconsin, and Iowa, which have similar cultures and agricultural practices but differing political ideologies, are appropriate comparisons in evaluating regulation and enforcement.

Next, I evaluate the levels of enforcement by each state. Much alike to evaluating levels of regulation, enforcement determines if regulations are being followed. Without enforcement, there will be no power to determine the impacts of regulations on pollution. To put it another way: if water quality standards are not being enforced, then regulation means nothing. Enforcement is usually manifested as fines or jail time, which varies both by state and by the severity of the pollutants. The effectiveness of enforcement should reflect in the number of reported incidents that occur. There have been established differences in the number of annual violations each of the three states has in regard to drinking water (Pennino et al., 2017). For this reason, a comparison of each state's environmental policies should reveal differences in state policy that is due to the differing views of the policymakers in power rather than another factor such as state culture or major differences in agricultural production. Policy differences will likely be reflected in the data regarding the levels of nitrates in the water. If so, there is reason to suggest that political ideology influences water quality, and thus has further ramifications for the environmental quality and public health of the state.

I speculate that more lax policies are associated with a larger area of nitrate contamination. Nitrate contamination data informs the extent to which state waters are over the limit or within the standards of the regulation. I am investigating this question at the state level because states are the primary enforcers of regulation. Budget trends are a factor that is likely to reflect the effect that political ideology has on water policies, and furthermore, the ability of the state agency to enforce regulations. Comparing state budgets with nitrate levels indicates whether budgets are successful in combating water pollution. It is important to know whether current regulations are adequate in reducing the amount of contaminated water, and ultimately eutrophication. This will inform policy recommendations for punitive measures of enforcement for states that seek to reduce nitrate pollution in state waterways and the Gulf. For example, a state with low nitrate contribution has different policies or enforcement measures than a state with higher contribution—what are the policies that are likely to be associated with a lower nitrate contribution? If it is a political difference, then a state may be able to implement that solution to assist in water pollution reduction goals.

The remainder of this paper is structured as follows. First, the next section delves into a review of the literature regarding the Gulf hypoxic zone and nutrient loading. The literature review also identifies the gap in current research regarding political ideology, environmental regulation, and water quality, where this paper seeks to contribute. Then, the data and methodological approach is discussed. Next, the results are reported and interpreted. Policy recommendations and implications are given. The final section summarizes and concludes.

III. Literature Review

The review of the literature regarding nitrates and environmental policy will focus on a few relevant topics, supported by peer-reviewed research and official government sources. These sources broadly draw from scientific and social scientific fields. First, defining the problem of the hypoxic zone in the Gulf is important to understand how and why nitrate pollution requires government intervention, starting at the origin of eutrophication. Second, the literature establishes a relationship between political ideology and environmental policies, which justifies a comparative study between Minnesota, Wisconsin, and Iowa. Finally, the literature review justifies the need for subsequent research into the politics of water quality, because there are few studies that dive into the direct relationship between environmental regulation and water quality. This link is important to identify and explore, because if one political ideology's policies tend to be healthier and more environmentally sound than another, policies should lean in that direction.

The Gulf Dead Zone: Origins and Systems

To understand the magnitude of the problem, it is important to reiterate the processes that form the Gulf dead zone. Fish kills in the Gulf of Mexico are the result of hypoxia: limited oxygen in the water. Hypoxia happens in this case due to a few reasons. First, the conditions in the Gulf are often calm (Swarzenski et al., 2008). During calm conditions, deep water and shallow water are unable to mix, which sequesters the oxygen (Gobler and Baumann, 2016). This occurs because deep water is saltier and therefore denser, while shallow water contains fresher water injected from rivers; the less dense freshwater floats above the saltier water, forming layers (Gobler and Baumann, 2016). In the Gulf, when there is little wind or current to whip up the water, the oxygen-rich shallow waters fail to penetrate the oxygen-deprived lower layers, and oxygen cannot be diffused; this physical structure of the water column in the Gulf is one factor that leads to the annual formation of the hypoxic water mass (Rabalais et al., 2002).

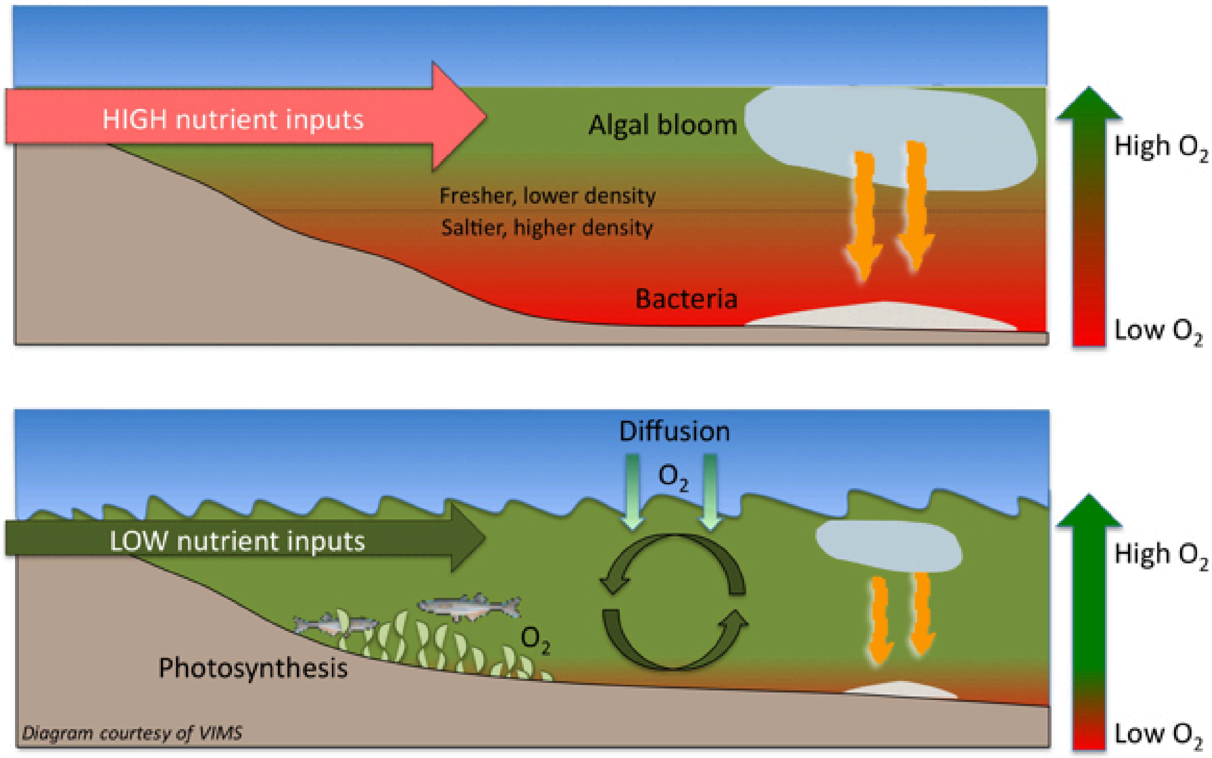

Figure 1. *High nutrient inputs, calm conditions, and stratification (top panel) encourage the formation of dead zones. Graphic credit: Virginia Institute of Marine Science, 2023.*

The other factor, which is largely the result of human activity, is nutrient loading, also known as eutrophication (Burkart and James, 1999; David et al., 2010). Nutrients that are swept into the shallow water from rivers promote an overabundance of productivity in the area (Gobler and Baumann, 2016). Algae take up the nutrients and the oxygen from the water and bloom in large quantities; when they die, the decomposition process uses up oxygen, causing hypoxia in deeper waters (Gobler and Baumann, 2016; Rabalais et al., 2002). This stresses fish and other marine life such as crabs and clams, leading to the eradication of marine life in the hypoxic zone (Rabalais et al., 2002). The physical structure of the Gulf has existed since its formation, and calm conditions are not uncommon (Rabalais et al., 2002). Eutrophication, on the other hand, was something exacerbated through human activities that promoted the use of nutrients on land: farming and industry (Gobler and Baumann, 2016; Rabalais et al., 2002).

Policy efforts to reduce the size of the dead zone should focus on controlling eutrophication, as a human-caused problem. To identify progress (or barriers) in water quality management, reports by the National Ocean Service and the EPA typically measure the area of the hypoxic zone and oxygen levels near the benthic zone (see Figure 2). However, this is a flawed approach for studies that aim to measure and reduce nitrate concentration, because the size of the hypoxic zone is influenced by a variety of factors besides nutrients, including water level, flow, temperature, and weather. For example, the graphic in Figure 2 shows that 2023 had a smaller hypoxic zone than previous years, though it did not hit the goal of the Hypoxia Task Force. But the likely reason for this was the drought that the Midwest faced, leading to less water flow, and ocean temperature fluctuation, rather than regulatory success in limiting nutrient contributions (Sprague, cited in Dryfoos, 2023). Furthermore, the nutrients that gather in the dead zone are an accumulation of the entire Mississippi River basin, so states share responsibility—and may, in fact, be able to shirk responsibility—for nitrate loads. Therefore, measuring the area of state groundwater with excess nitrate concentrations would give a more accurate measure of Gulf nitrate contribution by each state, which is especially useful for evaluating policies focused on reducing nitrate levels.

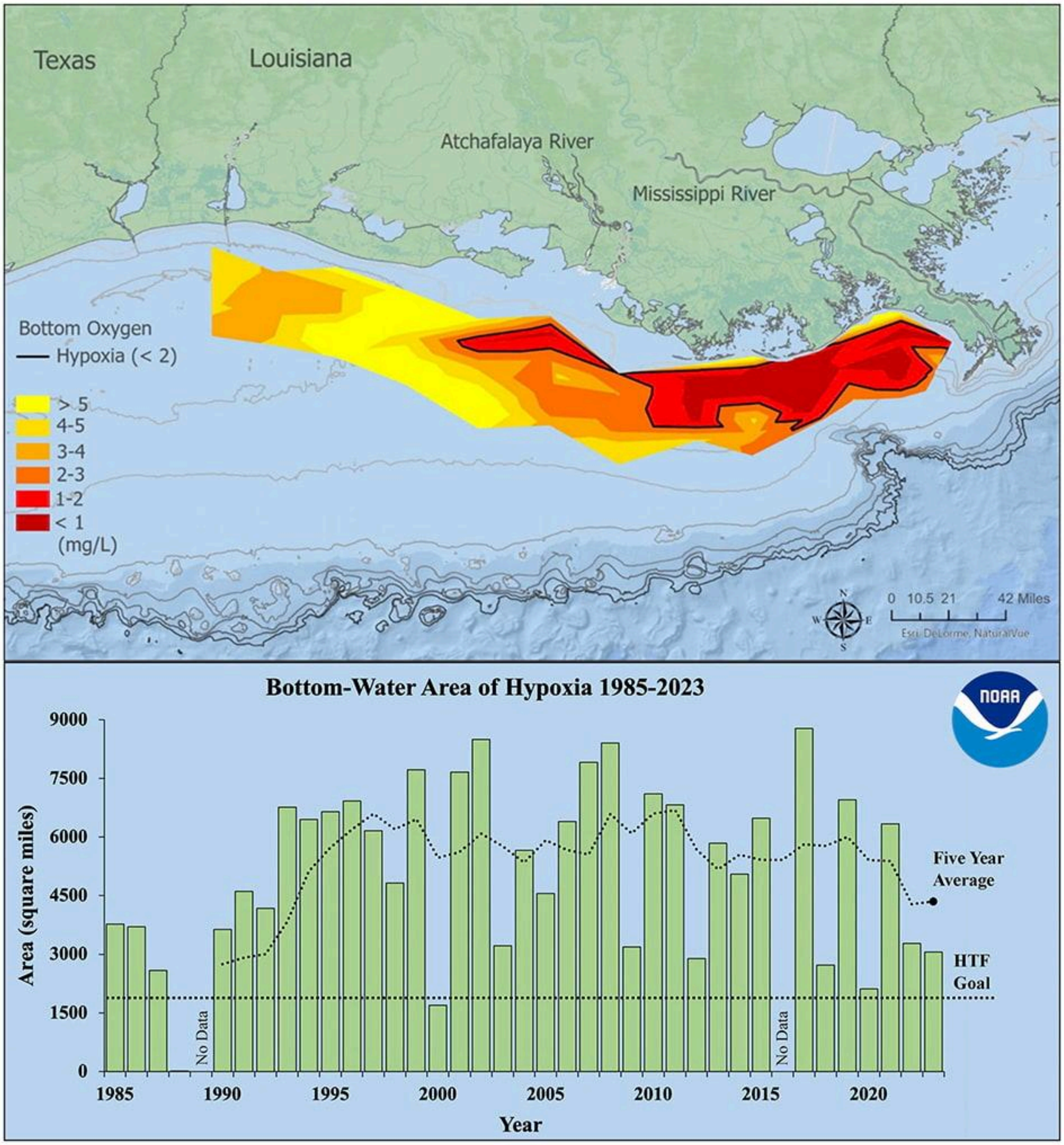

Figure 2. *The National Ocean Service tracks the size of the Gulf hypoxic zone through levels of oxygen and area of the zone. (Top panel) Red area denotes 2 mg/L of oxygen or lower, the level which is considered hypoxic, at the bottom of the seafloor. (Bottom panel) Long-term measured size of the hypoxic zone (green bars) measured during the ship surveys since 1985, including the target goal established by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (Hypoxia Task Force) and the 5-year average measured size (black dashed lines). Graphic credit: Louisiana Universities Marine Consortium, 2023.*

Nutrients in the water, such as nitrates, come from plants. Nitrates are necessary components of sustaining life, especially essential for farming practices including crops and livestock. Nitrates are so important to farming practices that they are commonly found in fertilizers (Osterberg and Wallinga, 2004; Xie and Ringler, 2017). The majority of nitrates in the MR are from agricultural production, primarily corn and soybean cultivation (Alexander et al., 2008). Other sources of nitrates include runoff or leakage from wastewater, landfills, animal feedlots, septic systems, or urban drainage (Bock and Easton, 2020; Minnesota Department of Health, 2023). Since there are so many possibilities for sources of contamination, as well as a geographically broad potential for contamination, it is often challenging to identify and regulate sources of nitrate in drinking water. This is why regulations are paired with farming techniques that mitigate nutrient flow, so that non-point source contamination, such as crop runoff into streams and rivers, can be limited.

Nitrates are not new to the environment. The compound is found naturally in plants; it is the scale at which farming uses it that causes excess nutrient loading. As agricultural techniques increased the application of fertilizers to their crops to facilitate mass-production, nutrients gradually overloaded the environmental system (Smith, 2003; Xie and Ringler, 2017). A global review of current nitrate uptake and use found that only 47% of the reactive nitrogen added to cropland is converted into harvested products, which means that less than half of the nitrogen used for crop fertilization is absorbed by plants, while the rest is lost to the environment (Lassaletta, 2014). In the U.S., the average nitrogen absorption was between 40 and 70%, but the amount of uptake depended on the crop (Lassaletta, 2014). This low percentage of nitrogen uptake is combined with a rising use of nitrogen in fertilizer, which research indicates began creating hypoxic conditions in the Gulf of Mexico appear around the turn of the last century, becoming more severe since the 1950's as the nitrate flux from the MR to the Gulf tripled (Rabalais et al., 2002). The factor of nutrient loading has itself grown over the years, both as a result of annual primary production—the modern method of over-applying nitrates on fields so that the soil is oversaturated, in case of heavy rain washing away the nutrients—and from compounded historical farming practices (Rabalais et al., 2002; US EPA, 2023; Stackpoole et al., 2021). Due to these historical, "legacy" nutrients, the current-year nitrate contributions of states do not fully explain the size of the hypoxic zone, which makes evaluating the level of policy effectiveness difficult. Policies are therefore often far-sighted in terms of measuring outcomes of implemented policies on the size of the dead zone. Individual waterways may carry better estimations of current-year contributions, making it easier to see the effect of regulations.

Waterways and ground waters within states become loaded with nutrients especially after rain and ice melt; the size of the hypoxic zone fluctuates according to the amount of precipitation in that year as well as the season (Mitsch et al., 2001; US EPA, 2023; Goolsby et al., 2001). Spring through late summer is prone to the large hypoxic zone, and wet years correspond to a larger hypoxia area than dry years, which poses significant concerns for a warming climate, where algal blooms are more likely (Mitsch et al., 2001; Montefiore et al., 2023). This is why research detailing the size of the hypoxic zone often refers to the "average size within the last five years" to identify long-term trends of policy on pollution. The problem only becomes more severe every year due to the warming climate, so updated evaluations concerning the success of nutrient reduction strategies are imperative to the field.

Because of the nature of the hypoxic zone—the physical structure of its water column, its fluctuating size, and the myriad sources of nitrates—it is difficult to attribute changes in size to just one policy change. Rather, it is many policy changes and mitigation efforts that will lead to any significant difference in the size of the dead zone. Water quality tests which look at the amount of nitrates (in mg/L, or ppm) in state waterways are sufficient as a proxy of the long-term size of the dead zone because of its prevalence as a major source of nitrates, even with historical effects obscuring the data. This makes it easier to track progress on reducing eutrophication. Furthermore, although regulations are aimed at the levels of nitrates found in water, large amounts of nitrates seep into waterways from non-point sources like widespread agricultural runoff, instead of point-sources like a specific waste facility. Regulation and enforcement can only be targeted toward point-sources because there is an entity that can take legal responsibility. Assigning responsibility and enforcing punitive measures to specific sources is a large part of the process of stopping further pollution. For non-point sources, there may be other ways of promoting pollution reduction, such as giving subsidies to farms that install riparian buffers. While there exists research that looks into the trends of regulation violations by state (Pennino et al., 2017), there has been limited research on the effectiveness of enforcement measures in relation to water quality.

From Federal to State Regulation

The problem for government regulation is this: they must allow farmers to apply some nitrates to meet the demand for crops and livestock, which by natural processes like precipitation, run into surface and ground waters, and collect in the Gulf. The degree of regulation is determined by the priorities of those in policy making positions. Concerns about regulation and enforcement measures are especially salient in areas that rely on drinking water collected from nitrate-high sources, because high levels of nitrates also affect human life, especially evident in infants; nitrates are the leading cause of a condition called “blue baby syndrome,” a result of hypoxia in the blood (Ward et al., 2018; Wisconsin Department of Health Services, 2020). Although nitrates are produced naturally in the human body, infant bodies process nitrate differently and so are at higher risk of being poisoned by nitrates than adults. Additionally, nitrate contamination in drinking water has been associated with more human health risks, including colorectal cancer, thyroid disease, pancreatic cancer, and neural tube defects, as studies have shown (Brender et al., 2013; Ward et al., 2010; Coss et al., 2004; Arbuckle et al., 1988; Ward et al., 2005). Nitrate contamination has become a matter of environmental justice, as some water treatment facilities do not have the technology to filter out nitrates from drinking water, and risk harming human health.

The threat of nitrate pollution, not just to ecosystems, but also to livelihoods and health, cannot be overstated. Many policies rely on mitigation strategies to limit the amount of nitrates that get into the water. However, there is the issue of the number of sources that pose a risk of nitrate contamination. Sometimes farms cannot mitigate the risk—either through buffer zones, bioreactors, or other mitigation strategies—because the underlying system of agriculture, laid upon tiles that drain directly into waterways, perpetuates water flow from farms into the MR (McEachran et al., 2020; Mahony et al., 2011). Mitigation of nitrate contamination only goes so far; it rests upon the regulations dictated by the federal government through institutions like the EPA and state environmental departments. However, in many cases these regulations are out of date. The Clean Water Act, originally ratified in 1972, was last revised in 1981 with further amendments made in 1987 and 2014. The Safe Drinking Water Act, ratified in 1974, was last updated in 1996, an amendment which served to limit the regulating power of the EPA (CDC, 2022; Snider, 2017). It is a slow, lengthy process to revise regulation standards; combined with barriers such as the temporary discontinuation of research under former President Trump, the EPA has been delayed in updating regulatory standards. It is as important to limit the flow of nutrients into surface- and groundwater through regulation as it is through mitigation done at the producer-level.

Regulations for Maximum Contaminant Level (MCLs) in the U.S. are decided by federal agencies like the EPA. With the exception of Wyoming, the District of Columbia, and most Native American communities, enforcement measures are left to state governments—known as "primacy agents" or primacy states (ECHO | EPA). Primacy agents have the power to decide how to enforce regulations, as long as they ultimately achieve compliance. They may also involve the EPA, though they are not required to. States compile quarterly reports to submit to the EPA, including number of reported violations and actions taken against violators, although there is a certain measure of discretion allowed in the reports. For example, a state may report a violation of the MCL for nitrates, but they are not required to report what the level was. Additionally, states with less-developed reporting methods may underreport the number of violations.

In terms of water policies and environmental quality, governors appoint the commissioner of each state's respective environmental department. These commissioners execute regulations on behalf of the state environmental agency. The policies favored by commissioners are likely to reflect that of the state government that appoints them, which supports the idea that political ideology influences environmental policies. Policies, in turn, determine the environmental quality of communities (Chang et al., 2018). Many studies focusing on the relationship between politics and environmental quality are conducted on either the national or the municipal level; generally, municipal governments focus on specific local environments and issues, while national governments focus on establishing a standard of environmental quality and regulating cross-regional problems. In the US, state governments fall in the middle—the environmental agencies specific to each state are in charge of enforcement within the state, based on standards established at the national level. They act as the "primacy agents."

While the federal government holds jurisdiction over national water affairs, states are the primary agents of carrying out water quality control. This includes enforcing regulations. States may, but are not required to, ask for assistance from the EPA. The EPA sets MCLs based on Acts passed by Congress, which take many years to amend. States track the number of violation reports and submit it on a quarterly basis to the EPA for review.

Political Ideology and Environmental Quality

A review of literature related to political ideology and environmental quality suggests that left-leaning parties are generally more willing to prioritize environmental protection, while right-leaning parties tend to overlook environmental issues (Neumayer, 2004; Vachan and Menz, 2006; Chang et al., 2018; Fowler and Kettler, 2021). In the United States, a key determinant to vote for environmental policy measures is the political ideology of a senator (Nelson, 2002; Fowler and Kettler, 2021). There is a political divide among elected representatives along partisan lines with regard to environmental issues, including senators and governors of states (Meyer, 2019; Nelson, 2002; Fowler and Kettler, 2021). The relationship between government ideology and environmental pollutants and quality has been verified by an increasing collection of empirical studies (King and Borchardt, 1994; Crepaz, 1995; Jahn, 1998; Scruggs, 1999; Neumayer 2003; Neumayer, 2004; Gassebner et al., 2011, Chang et al., 2018). Many studies are able to establish a relationship between right-leaning parties that occupy governorships or control Congress and degraded environmental quality (Meyer, 2019; Fowler and Kettler, 2021). Chang et al., Neumayer, King and Borchardt provide evidence for a relationship between left-leaning and improved environmental quality in OECD countries (Chang et al., 2018; Neumayer, 2003; Neumayer 2004; King and Borchardt, 1994).

However, with the exception of the study by Gassebner et al. that finds evidence for a relationship between water pollution and income per capita, most of these studies look at the relationship between governmental ideology and carbon emissions—measures which use air quality as the standard of environmental quality. Carbon emissions are a valuable source of information for environmental policy because they are the primary concern of many governments due to their status as the main source of global climate change (Schmalensee et al., 1998; Barassi et al., 2011). Additionally, climate change affects water quality, especially in cases of hypoxic zones where temperature and weather events may destabilize the system—so policies on carbon emissions likely have indirect effects on marine systems. Because most studies of environmental policies focus on carbon emissions due to its role in climate change, there is a dearth of literature that focus on water quality as a direct outcome of political ideology.

Information regarding water quality as a result of political ideologies of the state requires further exploration (Rusca et al., 2017). Nevertheless, studies of water policies find that the variation in voting and policy adoption can be correlated with political affiliation and political ideology (Gilligan et al., 2018; Gibson et al., 2021). In sum, political ideology determines the water policies that get passed, but there is a gap in knowledge in the relationship between water policies and water quality. The majority of the literature suggests that political ideology of states impacts the formation of environmental policies. This paper investigates the relationship between water policies and water quality, based on the literature that indicates water policies are influenced by political ideology. This is the reason that Minnesota, Wisconsin, and Iowa are a suitable comparison for environmental regulations: as primacy states, they are in charge of compliance within their respective jurisdictions. Furthermore, the differing political ideologies of the leaders in each state influences their chosen water policies, and likely their water quality. Investigating the causes behind differences in environmental policies is beyond the scope of this paper.

Conclusion

An overview of the literature indicates a need to investigate (i) nitrate levels in states that flow to the MR, and eventually to the Gulf, and (ii) water quality as an outcome of political ideology, through the mechanism of policy tools utilized by each majority party. These two points are crucial to determining whether state policies targeting nitrates are effective in reducing eutrophication in the Gulf. Nitrate contributions from land runoff are contributing to the formation of the dead zone by causing eutrophication. Policies focusing on regulation are limited because they must target point-sources, like a specific facility, rather than where the bulk of nitrates come from, non-point sources like farm fields and tile runoff. States partner with the EPA to enforce compliance, though for the most part states, as primacy agents, are in charge of their own enforcement measures. One relationship that this paper explores rests upon tangential evidence that environmental quality is influenced by the political ideology of the state. While there are no studies that research *water quality* as an outcome of political ideology, there is evidence that *water policies* are correlated with political affiliation and ideology of a state. This is important because the link between water policies and water quality measures the functionality of the system; if a policy is ineffective in protecting water quality it should be revised. Whether these policies are effective in achieving the desired water quality outcome is unclear as of yet. This paper seeks to answer part of this question by investigating the association between effective regulations and state or local water quality.

IV. Methods and Study Design

The main question I investigate is whether a stricter policy on nitrate contamination will reflect in the volume of nitrates contaminating state groundwater. To this end, data was collected from the U.S. EPA, which tracks nitrate levels and regulations, and state laws. The main variables of interest are the area of nitrate contamination and the regulations dictated by the EPA and state government agencies. I compare each state based on: budget as a state total, budget of DNR, budget given to water protection; strictness of enforcement using the length of maximum jail time and the amount in fines; each state's most severe enforcement measures; and the number of nitrate content violations for each state in the last year. Then I compare those metrics to the average levels of nitrates for each available site in 2023. Together, these metrics give an idea of how effective recent enforcement is, and points to where further efforts may be made.

As discussed in the background and context section, a comparative study between Minnesota, Wisconsin, and Iowa is appropriate because they all sit on the Upper Mississippi River region, and therefore are geographically and culturally similar. Even so, they differ in the political leanings of their state governments, which provides the basis for comparison. A limitation of the comparison is that results are not generalizable, because they are particular to those three states' histories and current positions on environmental policies, and the study provides a snapshot of the current context rather than a long-term comparison. Still, the model is valuable and can be implemented for other clusters of states.

Regulation standards are created by the EPA on a national level, while states may implement stricter, but not more lax, regulations. The maximum contaminant level for nitrates, as regulated by the EPA in 1992, is 10 mg/L, which is set at this level to protect against blue baby syndrome. However, the EPA notes that concentrations greater than 3 mg/L generally indicate contamination, while concentrations over 1 mg/L nitrate may indicate human activity (Madison and Brunett, 1985; Dubrovsky et al. 2010; US EPA, 2013). For this reason, a volume of nitrates greater than 10 mg/L counts as a violation and should be subject to enforcement. States must report to the EPA this information, which is available as public data after reports are filed.

In order to examine nitrate contamination, I use data from the U.S. EPA estimation of nitrate groundwater contamination, which details the area of groundwater that is in excess of the 10 mg/L limit, by state. Nitrate data are collected using grab samples, water quality monitors, and well testing at site locations throughout the state, then aggregated into a table along with the estimated percentage of the population affected by the maximum contaminant level. Nitrate concentrations were predicted by a U.S. Geological Survey (USGS) study titled, Machine Learning Predictions of Nitrate in Groundwater Used for Drinking Supply in the Conterminous United States, which used calibration data collected from 1988-2018 (Ransom et al., 2022). Drinking water source data is from USGS' Estimated Use of Water in the United States in 2005 and 2015, which informs the population statistics that were not used in this paper.

Minnesota, in Region 5 of the EPA's jurisdiction, has an agency for environmental oversight, which is the Minnesota Pollution Control Agency (MPCA). Wisconsin, also in Region 5, has the Environmental Management (EM) Division within their Department of Natural Resources. Iowa, which is in Region 7, has the Environmental Protection Commission (EPC) as the agency responsible for environmental oversight. Each of these agencies have websites with publicly available information regarding regulations and state enforcement measures. Each agency receives funding from state policymakers. Budgets are proposed by the governor and are released to the public soon after they are confirmed, at the beginning of the fiscal year.

To compare state environmental policies, I gathered information from the relevant regulations as specified in state environmental protection agencies and by the EPA. These policies are long-standing legislation and current up to this year. Iowa DNR, for example, lists the specific chapter in the Iowa Administrative Code, the environmental protection law that contains water quality specifications (Water Quality Standards IA). Minnesota and Wisconsin both have their respective regulations listed as publicly available information on the MPCA and EMD websites, respectively (Water quality standards MN; Water Quality Criteria WI). These were originally outlined by the Clean Water Act and the Safe Drinking Water Act, with regulations specified by the EPA. Further regulations by the state were compared to the standard of the strictest regulation, since all regulations must at least follow EPA-mandated standards. Enforcement measures, by state, were compared to the strictest punitive measure (the measure that is likely to have the greatest deterrent effect on violations). These were used to compare the levels of regulation between the states throughout the year 2023; a larger fine was categorized as "more strict" enforcement.

First, in terms of enforcement, the number of reports that agencies receive indicate the functionality of a state's system. In 2017, Pennino et al. identified trends in water quality violations across states, with data gathered from the EPA's national Safe Drinking Water Information System (SDWIS), which gets reports from U.S. public water suppliers, and showed that Wisconsin had more reports than either Minnesota or Iowa. I replicated their steps and found the number of reports for 2023. Public water suppliers have reported to SDWIS since 1978, and as of writing this, the records are complete up through the first quarter of 2024.

An important metric to evaluate regulation and water protection is the budget. Comparing budgets for state departments that deal with water quality can measure the state government's prioritization of water protection. This is because having more funds directed toward water protection indicates that environmental agencies have more power to enforce regulations and to monitor water quality, and therefore indicate a prioritization of water protection. For the federal EPA, budgeting is decided by Congress. In state governments, it is state policymakers who allocate the budget; this is why political ideology likely impacts environmental quality, as suggested in the overview of the literature. A smaller budget indicates a lower prioritization of environmental quality, because it leads to a limited ability to enforce regulations. In the analysis, fiscal year 2021 (FY21) was chosen for the budget metrics because it was the most recent year with complete census data. Additionally, budget data from 2021 is appropriate because it gives the budget time to take effect for later years.

A limitation of this methodological approach is that it does not establish causation; the association between regulation and nitrate contamination is not subjected to statistical analysis. However, causation in this case is difficult to establish because of the number of variables involved in the pollution problem. Each farm employs different management practices and contributes differently to the amount of nitrate in waterways, and it is extremely difficult to attribute pollution to just one, or a few, variables. A statistical analysis would either have to evaluate so many variables that it becomes difficult to establish causation based on the number of confounding factors, or bucket variables into broad categories that would make it hard to find significant results. For this reason, a direct comparison of the underlying policies—budget, enforcement, and reported violations—is the most appropriate methodological approach because it establishes the foundation for these other variables. For example, it is difficult to measure the nitrates that one farm contributes, but examining the budget reveals that states allocate funds toward incentivizing farms to mitigate nitrates themselves. Examining the enforcement indicates the state's willingness to pursue water quality violations and has an effect in deterring businesses and individuals from polluting. The number of reported violations shows whether public water systems are generally healthy. Additionally, since any nitrate concentration over a certain amount poses a danger to human health, the area of nitrate contamination is an important metric in evaluating the health of state waters. Even though this is a comparative study between only three U.S. states and the findings may not necessarily be generalized, the method will shed light on current enforcement practices and pave the way for future research on how state policies affect water quality.

V. Data Results and Analysis

Analysis found that there is a difference in the regulation of nitrates in each state that is reflected in the amount of nitrate contamination. Stricter enforcement was found to correspond with a smaller area of nitrate contamination. First, it was found that a larger budget allotted to water protection is associated with a smaller area of groundwater that has nitrate contaminations over 10 mg/L. Minnesota had the most capital to dedicate to water protection, with the biggest state budget and subsequent allocation to DNR. However, if looking at water protection as a percentage of DNR budget, Minnesota fell below both Iowa and Minnesota—contributing more on the whole, but proportionally less. Based on this result, it is likely that the size of Minnesota's state budget, which comes from a number of different sources, allowed them to spend more on water protection and achieve a better outcome. Each state also has different levels of agriculture including the intensity of farming (for example, Iowa with corn and Wisconsin with dairy), and the amount of land dedicated to production. These differences likely led to varied attitudes toward farming methods and views of violations, so that Wisconsin had more reported violations than Minnesota or Iowa. Enforcement measures followed the budget trend, with the strictest punishment for violators being $20,000 one-time payment or up to $10,000 per day per violation for Minnesota, $5,000 per day for Wisconsin, and $10,000 one-time payment for Iowa. The results section first examines the state budget allocations of each state, followed by the estimated groundwater nitrate contamination areas. Then it investigates reported violations, and lastly, enforcement measures manifested as punishment for violations.

In order to make the data accessible, all tables will be referencing a single larger table in Appendix A. Table 1 in Appendix A holds all cited sources contained in footnotes, while the tables in the body of this paper do not for ease of reference.

State Budget Allocations

For FY21	Minnesota	Wisconsin	Iowa
Total state expenditure	$59.8 billion	$50.5 billion	$28.7 billion
DNR total budget	$1.2 billion	$562 million	$425.8 million
Budget allocated to quality water protection	$18.6 million (0.016% of DNR)	$6.5 million (1.1% of DNR)	$6.4 million* (1.5% of DNR)

Table 1a: *Budget allocations per state, including total state expenditures in 2021, total budget allocated to the state's DNR, and budget given to water protection specifically, as raw number and as percentage of total DNR budget.*

Minnesota had the largest state budget in 2021 at $59.8 billion, over twice that of Iowa. Wisconsin's state budget was not far behind with $50.5 billion, of which $562 million was allocated to the Department of Natural Resources (DNR). The budget allocated to the Minnesota DNR was $1.2 billion, which was more than either Wisconsin's or Iowa's, at $425.8 million. This larger DNR budget allowed Minnesota to allocate a larger amount to water quality protection than Wisconsin or Iowa. The amount dedicated to water protection was only 0.016% of the total DNR budget in Minnesota, while it was a larger percentage in Wisconsin and Iowa, at

1.1% and 1.5% of the DNR budget, respectively. The size of the state budget allowed Minnesota to allocate more to water protection comparatively, however, it seems that water protection takes up less space in the budget overall. This may be a result of looking at the raw numbers—$18 million is a bigger budget than $6 million—instead of the water protection budget as a percentage of available funds.

A feature of the data that makes it hard to compare budgets is that there is no standardized budget form across states. Since each state calls the departments in the DNR different things—such as "water protection" in Minnesota, "water quality protection" in Iowa, and "targeted runoff management" in Wisconsin—there is no standardized way to compare directly. For example, the number used in these calculations for Iowa's water quality protection is an amalgamation of several water quality protection services. The actual allocation for the titled "Water Quality Protection" was $500,000, but including other metrics that are meant to assist with this goal, like "Water Quality Monitoring" and "GIS Information for Watershed" that works toward gathering "data that will be used by local groups to determine the most effective strategies for addressing non point source pollution problems" increases the budget a substantial amount (Iowa Budget Report, 2021). Other than creating a rather frustrating experience for gathering the data necessary for comparison, it means that state budgets largely do not have one standardized goal for water quality protection. The solutions of each state, and therefore their budget allocations, are different. Different solutions impact the degree to which water is being protected. It is evident that state budgets, proposed by the state leadership, have an impact on water quality, though the extent to which they are influenced by the solutions proposed in the budget remains unclear. There is reason for further research into specific methods.

EPA's Estimated Area of Nitrate Contamination

	Minnesota	**Wisconsin**	**Iowa**
Total land area (mi^2)	79,605	54,153	55,839
Estimated area of groundwater nitrate contamination (mi^2)	21	386	463
Area of agricultural land (million acres / mi^2)	25.4 / 39,688	14.2 / 22,188	30.5 / 47,656

Table 1b: *Total land area per state, including total land area in square miles, estimated area of nitrate contamination in the state's groundwater in square miles, and the area of agriculture of each state, in million acres and square miles.*

An analysis of the state size and nitrate levels finds that there is a difference in the estimated groundwater nitrate contamination of each state. The data shows EPA estimates of the area of each state that has groundwater nitrate concentrations over 10 mg/L (EPA 2024). The percentage of Minnesota that is estimated to have groundwater nitrate concentrations over 10 mg/L is 0.026%, as a percentage of groundwater area to land area. The EPA estimates Wisconsin to have 0.713% of their land to have groundwater nitrate concentrations over 10 mg/L. Iowa has an estimated 0.829% of total land with groundwater nitrate contamination over 10 mg/L. Of the three states, Iowa has the greatest area of groundwater nitrate contamination at 463 mi^2, which is associated with the highest percentage of agricultural land. Minnesota, the largest of the three states, has the smallest area of estimated groundwater nitrate contamination at 21 mi^2, and over half its land is agricultural. Wisconsin, of comparable size to Iowa, has a smaller estimated groundwater nitrate contamination, which corresponds to a smaller area of farmland.

A pattern is revealed from the data. Iowa, with the most amount of farmland that largely produces corn and soybeans, has a greater estimated contamination of groundwater sources. Meanwhile, Minnesota has a large land area and a small amount of estimated nitrate contamination in its groundwater. However, the pattern cannot be attributed solely to political leadership; Iowa has many more sources for contamination than Wisconsin and Minnesota, with about 85% of its land devoted to nitrate-producing agriculture. While these numbers indicate each state's production from the land, and therefore relative nitrate use, the data merely provides a more holistic overview of the agricultural system in each state. These agricultural systems may, in turn, influence the type of political ideologies that are prevalent in the state, but it is more likely that the politics are a result of land use rather than land use resulting from policies. Iowa has always boasted fertile fields, even before its politics became solidly red.

Reported Violations

	Minnesota	**Wisconsin**	**Iowa**
Number of reported water quality violations in 2023	11,533	82,047	27,341
Number of reported nitrate violations in 2023	752	15,123	8,011

Table 1c: *The number of reported Safe Drinking Water water quality violations by state. Top row shows the number of total water quality violations, and bottom row shows the number of nitrate violations in 2023.*

Analysis of Public Water Systems (PWS) shows that in 2023 there were more reported violations of safe drinking water regulations in Wisconsin than in Minnesota or Iowa. This is supported by evidence from Pennino et al. (2017) which found the same pattern in mean nitrate violations across the three states. Information reported to the EPA's Safe Drinking Water Information Systems reveals that in 2023, Minnesota reported 11,533 total water quality violations in 6,581 PWS, with 752 of them being nitrate contaminations. The greatest number of violations for a single PWS was 101. Iowa reported 27,341 violations in 1,817 PWS, of which 8,011 were nitrate violations, and the greatest number of violations for a single PWS was 220. Wisconsin reported 82,047 violations in 11,010 PWS, with 15,123 of them being nitrate contaminations. The greatest number of violations for a single PWS was 402.

Wisconsin, with 15,123 nitrate violations, has far more reported nitrate violations than either Minnesota (752) or Iowa (8,011). These findings are consistent with past research on nitrate contamination, which reveal that Wisconsin's outstanding number of reported violations is not a new phenomenon. Additionally, the greatest number of violations for a single public water system was 402, which is greater than either Minnesota or Iowa. This shows that violations are common in the same places—the same water systems are being reported for bad quality. Minnesota had the least number of overall water quality and nitrate violations in 2023, and there were fewer reported violations for the same PWS than for Iowa or Wisconsin. This is consistent with the findings that left-leaning states tend to have better environmental quality as a result of more progressive environmental policies.

While the violation data supports the pattern discovered in the preliminary findings, it is important to keep in mind a few caveats about violations as a metric of water quality. Reported violations are a good supplement for other metrics, such as budget and enforcement levels, but are difficult to evaluate on their own because they are endogenous variables. The level of violations could lead to several conclusions. If there are many violations, it could be an indication of the compliance agency's inability to enforce water pollution standards—violators continue to violate. On the other hand, if violations are uncommon, it may be a case of underreporting. Still, the consistent pattern of Wisconsin's high number of safe drinking water violations is an important value, considering that it follows a trend seen in past literature.

Enforcement of Regulations

	Minnesota	**Wisconsin**	**Iowa**
Maximum punitive threat for violating water quality regulations	$20,000 fine (APO) or $10,000 fine per day per violation (STIP) Consent decrees / Prosecution	$5,000 fine per violation per day Prosecution / Citation	$10,000 fine (APO) Prosecution
Maximum enforcement of water quality regulation taken in 2023	$20,000 fine	$100,000 settlement after prosecution	$10,000 fine + SEPs

Table 1d: *The maximum punishment for violating clean water regulations and the maximum enforcement measures actually taken in each state in 2023.*

According to the EPA, there are three types of enforcement actions: (1) Civil Administrative Action, which are actions that do not involve a judicial court process, and can include a notice of violation or an order to direct an individual, business, or other entity to come into compliance or clean up a site; (2) Civil Judicial Actions, or formal lawsuits, which are filed in court by the U.S. Department of Justice on behalf of the EPA against individuals or entities that have failed to comply with regulations, an administrative order, or have not committed to doing cleanup work; (3) Criminal Actions, which are reserved for the most serious violations, those that are willful, or knowingly committed. A court conviction of a criminal action can result in fines or incarceration. In a civil enforcement case, outcomes can include settlements, civil penalties that take the form of monetary compensation, and injunctive relief, which requires the regulated entity to perform a designated action and bring them into compliance. Additional actions can be assigned to the entity, called Supplemental Environmental Projects (SEPs), which are intended to mitigate harm and provide environmental and public health benefits. Civil cases are more common than criminal ones, and criminal cases warrant more serious penalties. Under the Clean Water Act, which is enforced by primacy agents (in this case, states) and the EPA, a first offense of criminal negligence has a minimum fine of $2,500 and a maximum fine of $25,000 per day of violation. A violator may also receive up to a year in jail. For a second offense, a maximum fine of $50,000 per day may be issued. For a knowing endangerment violation, such as placing another person in imminent danger of death or serious bodily injury, a fine may be issued up to $250,000 and/or imprisonment of up to 15 years for an individual. For an organization, there may be a fine of up to $1,000,000 (US EPA, 2013). The most serious violations are therefore criminal actions, which can lead to incarceration for the violating party.

In Minnesota, the Minnesota Pollution Control Agency (MPCA) assigns a monetary penalty based on several factors. These include the potential impact on public health and the environment, the level of noncompliance, whether the violation was intentional or accidental, promptness in correcting the problem, whether the violation was an isolated incident or a pattern, and whether a business gained an economic benefit from the violations (MPCA, 2023). In the event of compliance problems involving state or federal environmental laws, an Administrative Penalty Order (APO) is issued. The maximum penalty that can be assessed in an APO is $20,000. If a violation is serious enough to warrant a civil penalty greater than $20,000, or a longer time is required to complete corrective actions, there will be a negotiated settlement called a Stipulation Agreement (STIP)—there is no monetary minimum or maximum for a STIP, and SEPs can be part of a STIP. While the APO maximum for Minnesota is $20,000, the STIP can be up to $10,000 per day per violation, which is a stricter penalty that may be evaluated depending on the severity of the pollution. Consent decrees are the highest level of enforcement that the MPCA uses, which are overseen in court; this type of action is not commonly used. In 2023, the greatest penalty enacted on a water quality violation was a $20,000 fine, the maximum amount for an APO. In 2023, Minnesota did not experience a water quality violation event that required a consent decree, and so used the maximum APO penalty available for at least one violation that year.

In Wisconsin, the penalty for a civil case is $5,000 per violation, per day that the system is noncompliant. This seems forgiving, though fees can quickly rack up; in just four days of noncompliance, the offending entity would have to pay $20,000. In December 2023, Wisconsin District Attorney settled with a trucking company over water pollution violations; the company agreed to pay a total of $100,000 (Troutman Pepper, 2023). This was, essentially, a consent decree. Although this was one high-profile case out of many potential cases, it can be seen that the District Attorney takes water quality violations seriously and is willing to pursue criminal charges if necessary. In other words, the penalties are a credible threat.

Iowa is similar to Minnesota regarding the system it employs. Generally, APOs are the main method of enforcement, with the amount reaching up to $10,000 and often with supplementary actions, such as returning to compliance or cleaning up the scene. While the maximum penalty is half that of Minnesota's, the maximum penalty was utilized more often in 2023. Indeed, Iowa had more violations that required an APO than Minnesota in 2023.

Overall, Minnesota employs the strictest maximum punitive threat, followed by Iowa and Wisconsin, depending on the length of the noncompliance period. Each state has proved that they are willing to employ the full penalty if necessary. However, because Iowa's one-time penalty is half that of Minnesota, it poses less of a threat to potential violators. Thus, Minnesota's one-time penalty is a more extreme, more effective deterrent to potential violators. Wisconsin's system is, in the short-term, less effective than both, but it incentivizes getting systems in compliance with regulations quickly or risk compounding the fines. Minnesota also employs the per-day-per-violation system based on the severity of the assessed pollution at a greater rate ($10,000) than Wisconsin ($5,000), which shows it is stricter than Wisconsin on this metric as well. Based on this analysis, Minnesota has shown that it is willing to pursue greater enforcement measures than Iowa and Wisconsin, which is a direct result of legislative decisions. Here, again, there is the pattern that follows nitrate contamination and reported violations—Minnesota on one end, Iowa on the other, and Wisconsin somewhere in the middle.

Summary

The results of the data analysis support the original hypothesis that better regulation is associated with lower levels of nitrate contamination. First, the state budgets show that Minnesota spends the most of the three states on water protection due to its greater ability to pay. Iowa, on the other hand, has a far smaller state budget and dedicates many funds to water protection—although, as noted, it can be difficult to parse what falls under water quality protection. Second, the estimated area of nitrate contamination followed the pattern established in the bodies of literature. Iowa, the most right-leaning state, had the largest area of groundwater nitrate contamination, even as a percentage of total land area. This was expected, considering how much land is devoted to corn and soybean production. Minnesota, as the most left-leaning state, has the smallest area of nitrate contamination, especially when accounting for the size of the state. Wisconsin also followed the pattern, having a less estimated contaminated area than Iowa while being of comparable size. At the same time, it should be noted that these results have more to do with the geography of the land rather than the political context of the state. Third, the reported number of violations showed that Minnesota continued to have the lowest number of violations, even considering the total number of PWS and the highest number of nitrate violations per PWS. Wisconsin had the most nitrate contamination violations, showing consistency with past literature on the subject.

Iowa, comparatively, had lower numbers of violations, though also fewer PWS. The violation data supports the pattern that better regulation reflects on smaller contaminated areas, with caveats in mind reflecting the endogenous nature of reported violations as a metric. Finally, the enforcement measures reflect the same pattern seen in budgeting and violations—Minnesota with a more stringent penalty system than Iowa, and Wisconsin willing to pursue criminal actions in court. The analysis leads to the conclusion that stricter enforcement measures, which are directly decided upon by state legislatures and beholden to politics, do influence water quality to an extent.

VI. Policy Recommendations

There are several policy recommendations to be made for the health and protection of water systems. Updating water quality regulations is my first recommended policy. As emphasized in the literature review, current research that has studied the effects of nitrate on human health have established an association between the presence of nitrates in water sources and increased risk of cancer and birth defects, which means that the research that informed past regulations is now obsolete (Ward et al., 2018). These findings mean that updated regulations are necessary to continue to protect human health to the best of our knowledge. However, updating regulations is a slow and difficult process, which originates with the laws that establish standards for regulations. The last amendment to the Safe Drinking Water Act effectively limited the power that the EPA had for setting standards by requiring an extensive review process for any new standards (Snider, 2017). These processes to review and update regulations may also be delayed, set aside, or even overturned by presidential power (Snider, 2017). Limiting the power of the EPA to regulate chemicals limits their power to protect people; this should not be a political issue, but unfortunately it is. While updating regulations to fit the current standards of health should be a priority for Congress, amending the law to make establishing standards easier would go further to protecting water quality and human health. That should be the goal to strive for regardless of political affiliation. But in the absence of amending the law, updating nitrate regulations is the immediate priority for the EPA. Even further, states have the power to regulate at a tighter level than the EPA does now. While the EPA works to make amendments in the long-term, states can tighten regulations themselves and get a head start on constricting the amount of nitrates that are allowable by law. Doing so would push forward other solutions, since the increased number of fines incurred for violating the law is likely to push producers toward non-nitrate fertilizer options and incentivize other mitigation techniques.

One such technique that will be incentivized by evolving industry standards is precision agriculture. Precision agriculture is an advanced farming management method in which farmers provide optimized inputs such as water and fertilizer to enhance productivity, quality, and yield (Gebbers and Adamchuk, 2010, cited in Singh et al., 2020). It requires a huge amount of information about the crop condition, soil condition, and crop health in the growing season at high spatial resolution, and so is best implemented if farmers are educated on best management practices (Singh et al., 2020). Ultimately, precision agriculture will decrease the number of resources required to produce by optimizing based on actual crop requirement, and therefore it limits the amount of nutrient runoff.

While it is difficult to regulate the amount of nitrates that flow into the water due to the high contribution from non-point sources, there are ways to incentivize farmers to mitigate runoff in order to promote water quality. One policy that does this is regional water quality trading, which works across states. According to the EPA, water quality trading is “a market-based approach that states may pursue as means to attain water quality improvements,” and aims to control pollutants from multiple sources (2016). It works by allowing "one source of pollution to control a pollutant at levels greater than required" by regulatory standards and "sell 'credits' to another source, which uses the credits to supplement their level of treatment in order to comply with regulatory requirements" (US EPA, 2016). Currently, Minnesota has five water quality trading schemes, while Wisconsin has three and Iowa has two (Liu and Brouwer, 2022). Wisconsin also has a water quality trading policy and guidance in place, while regulations are under development in Minnesota and Iowa (Liu and Brouwer, 2022). The development of water quality trading programs in conjunction with guidance on participation is important in effectively managing water quality standards, especially in places where there are more stringent regulations planned.

An important aspect of making water quality a priority is to be transparent. Since there is not one standardized form, it is critical that states make their budgets and enforcement accessible to show their stance on water quality. It is difficult to do when there are many endeavors in the budget that require funds, but it is possible to make a separate report or summary on water quality, the money going toward protecting it, and recent steps in enforcing regulations. This would boost visibility of the issue and signifies a commitment toward water quality and public health.

VII. Conclusion

States with stricter regulations are associated with a smaller contaminated area, which confirms the original hypothesis of the paper. Stricter regulations are also associated with left-leaning political ideology more so than right and are a product of bigger budget allocations to enforcement or water protection. While these are not causative conclusions, having smaller contaminated areas coincide with left-leaning political ideologies indicates a relationship between the two and begs further research. These budgets are decided by political leaders of the state, and so there is therefore a basis to claim that political ideology impacts water quality. This paper finds that the left-leaning ideology of Minnesota corresponds more strongly to better water quality, while the mixed- and right-leaning ideologies of Wisconsin and Iowa have comparatively worse water quality. This is possibly a result of prioritization on the state level that allocates the budget and decides on the level of strictness of enforcement. My findings contribute to the literature on political ideology and environmental quality, reinforcing and building upon the evidence that found a relationship between right-leaning ideologies and degraded environmental quality, as well as between left-leaning ideologies and better environmental quality (Fowler and Kettler, 2021; Meyer, 2019; Chang at el., 2018; Neumayer, 2004; Neumayer, 2003; King and Borchardt, 1994). Furthermore, rather than carbon emissions, this paper focuses on water—an important resource often left out of the discussion about environmental health.

This paper focuses on three states on the Upper Mississippi River (MR) that are on different parts of the ideological spectrum when it comes to political leadership. A limitation is that it only focuses on three states during a particular year, rather than all the states that contribute to the MR over time, or even every state in the United States that contributes to hypoxic zones. Therefore, the generalizability of the findings are not very broad, and the methodology cannot claim causation between any one regulation and the quality of state water systems. Another barrier that comes with comparing across states is the lack of standardized information. However, this paper identifies several important metrics that every state can use as a model to evaluate their water policies' influence on water quality. These metrics may be applied in future research to evaluate the effectiveness of the state in regulating nitrate contamination and suggest ways to adjust in order to achieve compliance with EPA regulations. Whether it be adjusting the proportion of the budget that goes to water protection, or revising the punitive measures used against violators of water quality regulations, these metrics may be used both by policymakers and by the public to evaluate the state's commitment to reducing nutrient loading.

This paper also points out that major laws regarding water quality and water protection are out of date. Nitrate regulations must be updated to reflect the level at which we use them, and to incorporate more recent research that shows nitrates increase risk of certain types of cancers and birth defects (Ward et al., 2018). New major research into the human health implications of nitrate contamination has continued to come out since 2004 (Ward et al., 2018; Brender et al., 2013; Ward et al., 2010; Coss et al., 2004; Arbuckle et al., 1988; Ward et al., 2005), which was not factored into current regulation standards. For this reason, this paper introduces several policy recommendations that national- or state-level governments may implement, including amending water laws to make it easier for the EPA to regulate, updating regulations themselves, and incentivizing precision agriculture and water quality trading.

Further research is necessary to generalize the findings to other contexts and to determine the best enforcement measure to reduce nitrate pollution across geographical regions. The Gulf hypoxic zone is one of the biggest, but far from the only, dead zones that routinely form due to nutrient loading. While the United States provides a two-party, polarized political system that has politicians on the spectrum between liberal and conservative leanings, there are many countries around the world that do not subscribe to the same political ideologies. In addition, while nitrates are one important compound to study because of its human health impacts and its role in dead zone formation, there are other nutrients impacting water quality, which may or may not be regulated. Studying how different political systems impact environmental regulation is an important step in understanding political ideology and water policies, as well as their impact on water quality on a national, regional, and local level.

Many aspects of farming push toward profits at the expense of health and the environment. It is the duty of state leadership to protect their constituents and take steps to improve the environmental quality of their states. The Mississippi River has exemplified the struggle between public and private interests, but with greater public pressure, policies that aim to protect health and limit excess nutrients in the Gulf of Mexico can prevail. It is undoubtedly going to be a long road to clean waters, but peeling back regulations is not the solution. This paper presents an association between stronger regulations, owed to political leadership, and a smaller area of water that is contaminated with nitrates, which will hopefully open a door to further research regarding the association between policies and water quality. Regardless of political party, the aim of environmental protection should be to do the right thing: save the fish.

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Appendix

Table 1: A comparison between three states on select metrics

	Minnesota	**Wisconsin**	**Iowa**
Total state expenditure[1] in 2021	$59.8 billion	$50.5 billion	$28.7 billion
DNR total budget '21	$1.2 billion[2]	$562 million[3]	$425.8 million[4]
Budget for water quality protection '21	$18.6 million[5] (0.016% of DNR)	$6.5 million[6] (1.2% of DNR)	$6.4 million[7] (1.5% of DNR)[8]
Total land area (mi^2)[9]	79,605	54,153	55,839
Total surface water area - not groundwater (mi^2)[10]	7,312	11,327	419
Estimated area of groundwater nitrate contamination (mi^2)[11]	21	386	463

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[1] Source: US Census Bureau Annual Survey of State and Local Government Finances, 1977-2021 (compiled by the Urban Institute via State and Local Finance Data: Exploring the Census of Governments; https://state-local-finance-data.taxpolicycenter.org.

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[8] The budget listed for Iowa's DNR comes from multiple budget allocations. The actual budget for solely "water quality protection" was $500,000 in 2021. Using this number, Iowa used 0.12% of their DNR budget on water quality protection. However, for the purposes of data analysis I calculated the amount that was budgeted toward water quality protection in different ways, including, for example, "Groundwater Monitoring," "Waste Reduction and Assistance," and "Water Quality Monitoring" that did not fall under the title "Water Quality Protection."

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Area of agriculture (million acres / mi^2)	25.4[12] / 39,688	14.2[13] / 22,188	30.5[14] / 47,656
Number of reported water quality violations in 2023[15]	11,533	82,047	27,341
Number of reported **nitrate** violations in 2023[16]	752	15,123	8,011
Maximum punitive threat for violating water quality regulations	$20,000 fine (APO)[17] or $10,000 fine per day per violation (STIP)[18] Consent decrees / Prosecution	$5,000 fine per violation per day[19] Prosecution / Citation	$10,000 fine (APO)[20] Prosecution[21]
Maximum	$20,000 fine[22]	$100,000 settlement	$10,000 fine[24]

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