Source Water Quality and the Cost of Nitrate Treatment in the Mississippi River Basin

A report published by The Northeast-Midwest Institute

For More Information

More information about the Northeast-Midwest Institute and additional context on this report is available at www.nemw.org.

Citation

Vedachalam, S., Mandelia, A.J., and Heath, E.A. 2018.
Source Water Quality and the Cost of Nitrate Treatment in the Mississippi River Basin,
Northeast-Midwest Institute Report, 44 pp., http://www.nemw.org/

Funding

This work was made possible by a grant from the Walton Family Foundation.

Cover: Aerial photo of the Des Moines Water Works Fleur Drive Treatment Plant, courtesy the Des Moines Water Works

Report Authors

Sridhar Vedachalam, Ph.D., Director, Safe Drinking Water Research and Policy Program
Ankita J. Mandelia, Policy Analyst, Toward Sustainable Water Information Program
Eric A. Heath, Senior Policy Counsel, Mississippi River Basin Program

Acknowledgements

The support and cooperation extended by the three water utilities and their staff are appreciated. Laura Sarcone of the Des Moines Water Works, Keith Alexander and Chaundra Smith of the City of Decatur, and Kevin Culver and David Cronk of Aqua Illinois Vermilion County answered numerous questions, and provided as much data as possible. Multiple organizations and individuals helped NEMWI reach out to water utilities in the Mississippi River Basin. Dale Robertson and David Saad of the USGS Wisconsin Water Science Center were extremely generous with their time and generated SPARROW results for the four study watersheds.

Table of Contents

Table of Figures

Table of Tables

Executive Summary

The Mississippi River Basin is the largest watershed in the United States, and agriculture is the dominant industry in the Basin, impacting land-use and water quality. Heavy use of fertilizers and manure on agricultural fields has contributed substantially to high levels of nitrate in the water, resulting in algal blooms, contaminated drinking water, and “dead zones” in open waters. The proliferation of harmful algal blooms and detection of toxins like microcystin in freshwater bodies such as the Raccoon River and Lake Erie have heightened the attention on limiting nutrient levels to protect drinking water sources.

This study analyzed water quality and treatment cost data over a 10-year period from January 2008 to December 2017 at three water utilities in the Mississippi River Basin – Des Moines Water Works, IA; the City of Decatur, IL; and Aqua Illinois Vermilion County, IL – and the watersheds of their associated four intake locations. In each of the four intake watersheds, farm fertilizer was the largest contributor of nitrogen loading, representing 51-62 percent of the total loading. Nitrogen reduction scenarios modeled after final and interim targets set by the Mississippi River/Gulf of Mexico Hypoxia Task Force suggested that cross-sector reductions would be most effective in reducing nitrogen loads in the source waters.

Nitrate concentrations generally increased over the study period, resulting in an increase in the daily exceedances of the nitrate Maximum Contaminant Level (MCL). In 2015, Des Moines’ two intake sources – the Raccoon River and the Des Moines River – recorded 272 and 192 exceedances, which meant that the influent water was above the USEPA’s regulatory and safety limit for more than half the year. In comparison, the intakes at Decatur and Vermilion County recorded lower rates of exceedances – 21 and 15 days, respectively, on average throughout the study period. If more effective conservation practices were to be implemented and the Mississippi River/Gulf of Mexico Hypoxia Task Force targets for reduced nitrate levels were to be achieved, it would dramatically bring down the daily exceedances above the MCL at all four intake locations. A 20 percent reduction in the intake nitrate concentrations would yield a 48-71 percent reduction in the daily exceedances, while a 45 percent reduction in the nitrate concentrations would virtually eliminate daily exceedances.

Capital expense is a significant component of the overall cost of nitrate treatment at the three utilities. Amortized capital cost of the treatment unit outweighed annual operations and maintenance (O&M) costs, except in Des Moines, which experienced heavy use of its treatment unit, especially in the latter half of the study period. A review of capital cost data from 10 other locations, in addition to the three study utilities, showed a scale effect: the cost per unit volume at the largest utility was orders of magnitude lower than that at much smaller ones. This suggests that smaller utilities face an undue burden of nitrate pollution in drinking water sources. A lack of robust data precluded any conclusions on O&M costs, but limited data from Des Moines and Decatur showed that in years when influent nitrate levels were the highest, the utilities spent 9 percent and 4 percent, respectively, of their overall operating budget on nitrate treatment.

Conservation programs have the potential to limit some of these costs to utilities, with the extent of their impact depending on a variety of factors specific to the watershed. Water utilities are increasing their engagement in watershed conservation practices in an effort to limit the need for specialized treatment units and reduce rate increases. The report discusses the role of the Farm Bill in promoting conservation programs, and makes additional recommendations to encourage cost reporting by utilities. With additional research, policymakers will have access to better data connecting conservation efforts to changes in water quality, and their associated costs.

Key Findings of Research

Based on data from three water utilities located in Des Moines, IA (two intakes); Decatur, IL; and Vermilion County, IL, the following are the key findings:

- Farm fertilizer was the largest contributor of nitrogen loading.
- Nitrogen reduction scenarios modeled after final and interim targets set by the Mississippi River/Gulf of Mexico Hypoxia Task Force suggested that cross-sector reductions would be most effective in reducing nitrogen loads in the source waters.
- Nitrate concentrations generally increased over the 10-year study period, resulting in an increase in the daily exceedances of the nitrate MCL.
- Daily exceedances were significantly higher during the second half of the study period. A 45 percent reduction in the intake nitrate concentrations would virtually eliminate exceedances, but even a modest 10 percent reduction would bring down exceedances by 20-33 percent.
- Capital expense is a significant component of the overall cost of nitrate treatment at the three utilities.
- Amortized capital cost of the treatment unit outweighed annual O&M costs, except in Des Moines.
- In years when influent nitrate levels were the highest, utilities spent 4-9 percent of their overall operating budget on nitrate treatment.
- Smaller utilities face an undue burden of nitrate pollution in drinking water sources.
- Conservation programs have the potential to limit some of these costs to utilities, although the extent of their impact will depend on a variety of factors specific to the watershed.

Introduction

The Mississippi River Basin is the largest watershed in the United States, draining approximately 40 percent of the land area in the lower 48 states. Agriculture is the dominant industry in the Basin, impacting land-use and water quality (National Park Service, 2017). Heavy use of fertilizers and manure on agricultural fields has substantially contributed to high levels of nitrate in the source water at intake locations of drinking water treatment plants across the Basin. The resulting increase in nitrate removal costs was the proximate cause of a lawsuit brought forth by Des Moines Water Works against drainage districts in three upstream Iowa counties (Walton, 2015). The lawsuit was eventually dismissed in federal court (Eller, 2017), but the underlying relationship between farming practices, especially the role of conservation, and the additional cost of water treatment, is worthy of exploration.

Detection of high levels of nitrate in source waters can result in a variety of costs for utilities. The health effects of high nitrate levels in drinking water are well examined (Van Grinsven et al., 2006; Manassaram et al., 2007). Utilities that exceed the United States Environmental Protection Agency (USEPA)-mandated maximum contaminant level (MCL) of 10 mg/L for nitrate (measured as Nitrogen) may have to pay a fine, give public notice to its customers, and list likely remedial measures to the state health agency and USEPA. Repeated violations may necessitate long-term measures, such as blending nitrate-rich water with other existing sources, drilling new wells or identifying alternative surface water sources, purchasing water from nearby utilities, or constructing nitrate treatment units (Fischenich, 2017).

Data from recently constructed treatment units in the Mississippi River Basin suggests that, depending on size and complexity, these units can cost anywhere from hundreds of thousands to a few millions of dollars (Naidenko et al., 2012). These costs are eventually passed on to the customers.

Construction of a new nitrate treatment unit is considered only after cheaper alternatives such as blending have been ruled out, although a combination of solutions may often be necessary. Data from recently constructed treatment units in the Mississippi River Basin suggest that, depending on size and complexity, these units can cost anywhere from hundreds of thousands to a few millions of dollars (Naidenko et al., 2012). These costs are eventually passed on to the customers.

Background

There is a global nitrogen crisis – not one of shortage, but that of an over-abundance. The world is using more nitrogen, mainly via fertilizers, than ever before, while simultaneously using it less efficiently than before (Pearce, 2018). The fallout is seen in the form of algal blooms, contaminated drinking water, and “dead zones” in open water. The Gulf of Mexico’s hypoxic zone has been a perennial cause for concern, but 2017 brought fresh worries as the dead zone expanded to its largest extent ever recorded (Smith, 2017). The proliferation of harmful algal blooms and the occurrence of toxins such as microcystin in Lake Erie in 2014, which caused the shutdown of Toledo, Ohio’s drinking water system, elevated the discussion on the impact of nutrients such as nitrate and phosphorus on freshwater sources. In the summer of 2016, Des Moines Water Works detected microcystin in Raccoon River, one of its primary water sources (Tang et al., 2018).

The first recorded instance of infants experiencing methemoglobinemia – a fatal condition in which red blood cells become incapable of binding to oxygen, causing hypoxia in tissues (commonly known as the “blue baby syndrome”) – was attributed to consuming well water contaminated with high levels of nitrate in Iowa City, IA (Comly, 1945).

Although the fate and transport of nitrate in water is well understood, the severity of nitrate pollution in drinking water has long been associated with groundwater sources. Nitrates can enter groundwater through direct seepage from farm fields where nitrate-rich fertilizers and manure are applied, or become absorbed by soils in the stream bed and eventually transport to an aquifer. A national study of private water wells by the United States Geological Survey (USGS) found nitrate concentrations above 10 mg/L in 4.4 percent of the sampled wells (DeSimone et al., 2009). The study noted the upper Midwest as one of the areas where concentrations were most commonly elevated. A recent study of trends in nitrate violations across the U.S. conducted by the USEPA concluded that even as surface water systems have improved during the past 20 years, the number of groundwater systems in violation and the average duration of violations are increasing, pointing to persistent nitrate pollution in drinking water (Pennino et al., 2017).

Since large public water systems primarily rely on surface water, which are highly sensitive to land use patterns, nitrate has been a cause for concern for water utilities relying on surface water in the agriculture-heavy Mississippi River Basin. Des Moines, IA was one of the first water utilities to construct a nitrate treatment unit in 1991; at the time of construction, it was the largest of its kind in the world (Elmer, 2017).

The current MCL for nitrate was set by the USEPA in 1991, based on a survey of epidemiological studies conducted between 1950 and 1970 of infant methemoglobinemia in populations exposed to water contaminated with nitrate (USEPA, 1987; Weir and Roberson, 2011). Since then, however, evidence has emerged pointing to the pervasive effect of nitrates on individuals of all ages, and the association of long-term exposure to nitrates in drinking water to chronic health outcomes, including bladder and gastric cancer, reproductive difficulties, health defects in newborns, childhood obesity, and thyroid problems (Van Grinsven et al., 2006; Manassaram et al., 2007). However, no conclusive evidence of a causal relationship has yet been established. It is conceivable that stronger evidence on the health impacts of elevated nitrate levels could prompt the USEPA to review the effectiveness of the current MCL, potentially leading to a lower limit. Such a change will make reduction of nitrate levels in water, both at the water utility intake and at the source, extremely critical. Lowering of the MCL would likely increase the cost of compliance at the water utility, making nitrate reductions at loadings sources an even more attractive option.

This study identifies connections between source water quality in the Mississippi River Basin and treatment costs at drinking water treatment facilities. Quantifying the impact of nutrient runoff from agriculture on downstream users can enable a better informed decision on the role and efficacy of the Conservation Title within the Farm Bill, which promotes and incentivizes land-based conservation practices to reduce nutrient runoff and improve water quality. Conservation programs comprised 5 percent of the total funding in the last Farm Bill approved in 2014, which is set to expire in September 2018 (National Sustainable Agriculture Coalition, 2017). In the past, conservations programs have been a target for spending reductions during Farm Bill negotiations among lawmakers. Lawmakers in Congress are currently debating a new Farm Bill, which will impact conservation policies for at least the next five years, making a study such as this critical for the upcoming decision-making. Linking watershed-scale monitoring to downstream impacts, will enable targeted solutions to keep water treatment costs low, promote sustainable agriculture, and maintain clean water in the Mississippi River and its tributaries.

Methods

Selection of Water Utilities

After consultation with water quality professionals affiliated with utility groups, policy organizations, and state officials working in or knowledgeable about the Upper Mississippi Basin region, a short list of candidate water utilities for inclusion in the study was created. This list of utilities covered a variety of nutrient loading and drinking water treatment service scenarios. Nutrient loading scenarios represented a range from heavy agricultural loading to a mix of agricultural, municipal, and industrial loading. Drinking water treatment variables included utility size, development type served (rural, urban, or suburban), and water source (surface water or groundwater). Inquiries were made to the utilities on this list via email, phone, and through referrals. Eventually, three utilities agreed to participate in this study: Des Moines Water Works, IA; the City of Decatur, IL; and Aqua Illinois Vermilion County, IL. Des Moines, IA primarily utilizes two intakes located in different waterbodies, the Raccoon River and the Des Moines River. Decatur, IL and Vermilion County, IL draw their water from dammed lakes located along their source water rivers (Figure 1). The Raccoon, Des Moines, and Sangamon Rivers are located in the Upper Mississippi River Basin, while the North Fork Vermilion River drains into the Wabash and then the Ohio River, eventually joining the Mississippi River at Cairo, IL.

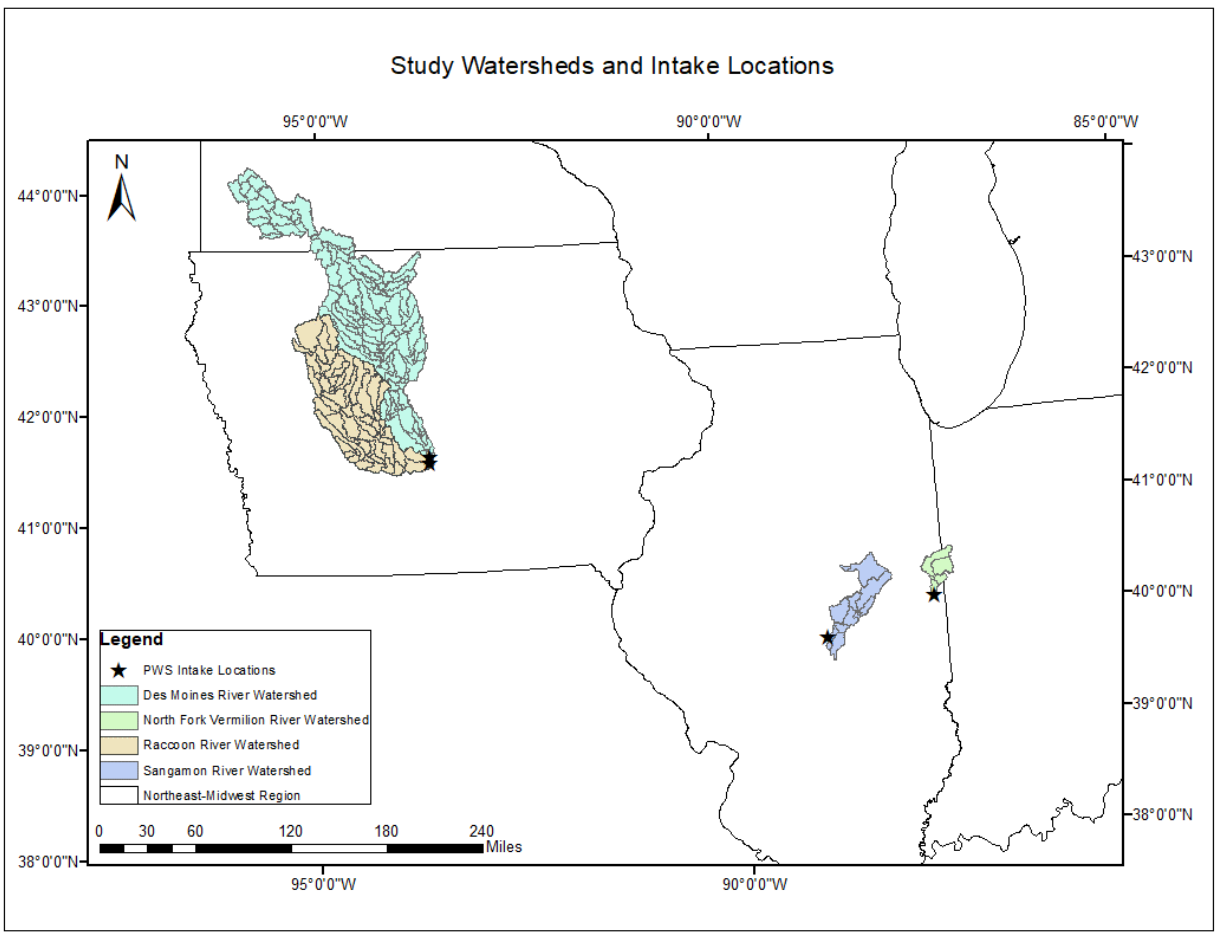

Figure 1: Study watersheds and the utility intake locations

Although varying in size, all four watersheds are predominantly agricultural, and the utilities serve a mix of urban, suburban, and rural customers. Information about the utilities' source watersheds are summarized in Table 1. The USEPA categorizes utilities based on the size of its service population. According to that classification, Des Moines is a "very large" utility (serving more than 100,000 residents), while Decatur and Vermilion County are "large" utilities (serving between 10,000 and 100,000 residents). Utility service information is summarized in Table 2.

Table 1: Utility source watershed information

Utility	State	Intake Source	Source Watershed	Watershed size (square miles)
Des Moines Water Works	IA	Raccoon River	Raccoon River	12,884
		Des Moines River	Des Moines River	3,625
City of Decatur	IL	Lake Decatur	Sangamon River	925
Aqua Illinois Vermilion County	IL	Lake Vermilion	North Fork Vermilion River	293

Table 2: Utility service information

Utility	State	Population Served	Capacity (MGD)	Average Production (MGD)
Des Moines Water Works	IA	233,020	100	47
City of Decatur	IL	76,122	36	20
Aqua Illinois Vermilion County	IL	46,560	14	8

SPARROW Modeling

After selection of the study utilities, the SPAtially Referenced Regressions On Watershed attributes (SPARROW) tool, developed by the U.S. Geological Survey (USGS), was utilized to model the watersheds, and identify the various contributors of nitrogen loading to the utilities' intake sources. As described by the USGS, SPARROW is

> *"…a watershed modeling technique for relating water-quality measurements made at a network of monitoring stations to attributes of the watersheds containing the stations…. The model predicts contaminant flux, concentration, and yield in streams…."* (Schwarz et al., 2006).

Results of the SPARROW model were then analyzed non-spatially and spatially, as described below.

Non-Spatial Analysis

The SPARROW modeling team at USGS, based at its Wisconsin Water Science Center, conducted the nitrogen loading calculations for each of the study watersheds. In the case of Des Moines, which utilizes two primary intakes, calculations were performed for each of the corresponding watersheds. The modeling results included a lot of relevant data, but for the purposes of this study, the non-spatial analysis focused on the following delivered incremental nitrogen loads:

- *Sewerage point sources;*
- *Atmospheric deposition;*
- *Confined manure;*
- *Farm fertilizer;*
- *Fixation and legume sources;* and
- *Urban land*

Loads from each of these sources were reported in kilograms (kg). In addition to these loads, the flow-weighted mean nitrogen concentration at the watershed outlet in milligrams/liter (mg/L) was reported. The SPARROW-generated concentration was later compared with the recorded nitrate-as- nitrogen[1] concentration at the drinking water utility intakes. Differences in the utility intake location and the SPARROW-generated watershed outlet are possible.

Next, scenarios simulating various levels of nitrogen reduction were developed to evaluate the impact of each type of loading. These scenarios were modeled after the Mississippi River/Gulf of Mexico Hypoxia Task Force's goals for nitrogen reduction in the Mississippi River, specifically a 20 percent reduction (interim target) and a 45 percent reduction (full target); as well a scenario in which one or more types of loading were completely eliminated (100 percent reduction). After each type of nitrogen loading source was evaluated individually, combinations of sources were evaluated to determine the impact of their simultaneous reduction on the overall nitrogen load of the watershed. These combinations and their components are listed in Table 3.

---

[1] In this study, concentrations of both nitrate and nitrogen are discussed. The SPARROW model output is reported as total nitrogen concentration, which includes nitrogen in all forms (ammonia, organic, reduced, and nitrate-nitrite). The concentrations of nitrate reported by the drinking water utilities are concentrations of nitrate as nitrogen, meaning only concentration of nitrogen in the nitrate is reported. For this reason, concentrations of nitrogen output by the SPARROW model and concentrations of nitrate reported by the drinking water utilities are comparable.

To form the source combinations, the six sources listed above were grouped together based on similarity in types of load or geographic origin. The first three combinations – *Point Sources, Runoff Loads, and Urban Sources* – are relatively self-explanatory. The category *Farm Field Loads* represents loads that are considered to impact surface water from fields and their crops. Loads that are less directly controlled by anthropogenic activity are grouped under *Background Sources*. The category *Farm Fertilizer + Background Sources* represents the complete impact of agricultural nitrogen loads.

Table 3: Various combinations of Nitrogen loading sources

Combination	Components
Point Sources	Sewerage Point Sources + Confined Manure
Runoff Loads	Urban Land Sources + Farm Fertilizer
Urban Sources	Sewerage Point Sources + Urban Land Sources
Farm Field Loads	Farm Fertilizer + Fixation and Legume Sources
Background Sources	Atmospheric Deposition + Fixation and Legume Sources
Farm Fertilizer + Background Sources	Farm Fertilizer + Fixation and Legume Sources + Atmospheric Deposition

Spatial Analysis

Spatial analysis was conducted on each of the four intake watersheds to identify the spatial origin of nitrogen loads reaching the intake point. ArcMap 10.6 (ESRI, 2018) was used to generate maps of each watershed, displaying each catchment[2] in the watershed, and their associated nitrogen load (normalized by the watershed nitrogen load) and yield (load per unit area).[3] The normalized load maps are useful for determining the spatial origin of the watershed's nitrogen loading, while the yield maps are useful for determining the relative concentration of nitrogen loading across the catchment areas in the watershed.

Utility Data: Nitrate Concentrations

Daily nitrate-as-nitrogen concentration data were obtained from each of the study utilities for a 10-year period beginning on January 1, 2008 and ending on December 31, 2017. Des Moines and Vermilion County operate their nitrate treatment units when the nitrate levels in the intake water exceed 9.5 mg/L, while Decatur uses 8.5 mg/L as a threshold for operating the nitrate unit.[4] The daily concentration data was utilized to identify seasonal and general trends, and the number of days in each calendar year that the water quality at the intake exceeded the USEPA's Maximum Contaminant Level (MCL) for nitrate-as-nitrogen (10 mg/L) as well as other thresholds set by the utilities. In addition, three scenarios – in which nitrate concentrations at the intake were reduced by 10, 20, and 45 percent – were developed and the resulting impact on the MCL exceedances observed.

[2] SPARROW divides each watershed into smaller catchment areas that do not necessarily correspond with any HUC boundaries.
[3] Load refers to the delivered incremental catchment total nitrogen load normalized by delivered watershed total nitrogen load. Yield refers to the delivered incremental catchment nitrogen yield.
[4] If the nitrate levels in the intake increase at a slow rate, Decatur uses 9.5 mg/L as a threshold for operating its nitrate treatment unit.

Utility Data: Cost of Nitrate Treatment

Cost data for nitrate treatment were obtained from each of the three utilities. The capital cost of each treatment unit at the time of construction was adjusted for inflation to 2018 values using the Price Trend Index for Iowa Highway Construction developed by IowaDOT (2018). Though designed for the transportation sector, the index's relevance to Iowa was taken into consideration. Capital cost was amortized over 30 years using a 3 percent rate of interest. Salvage value of the treatment plant at the end of the 30-year period was assumed to be zero. Des Moines provided the total annual operations and maintenance (O&M) cost for nitrate treatment for six years (2011-2016), without any breakdown. Decatur provided annual O&M cost for each year, with breakdown for chemical, labor, and parts. Electricity and brine disposal costs were not included. Vermilion County only provided the cost of chemicals for five years (2013-2017), hence annual O&M costs were estimated using the worksheet provided by Decatur. Cost per unit volume was calculated using the average daily water production during the study period, and expressed as $/kgal (or $/1000 gal) to ensure comparison with estimates from other utilities. In addition, published data on treatment cost (capital as well as O&M) were sought from peer-reviewed articles and grey literature.

Results

SPARROW: Non-Spatial Analysis

Among the four study watersheds, delivered total nitrogen load ranged from nearly 2 million kilograms (kg) in the North Fork Vermilion River watershed to over 30 million kg in the Des Moines River watershed, as displayed in Table 4. Flow-weighted mean concentrations ranged from 6.44 mg/L to 11.55 mg/L. Across the four watersheds, the SPARROW-modeled flow-weighted mean concentrations at the watershed outlets were 1.4 to 1.7 times greater than the ten-year measured mean nitrate concentration at the utility intakes, which ranged from 4.37 mg/L to 6.67 mg/L. This may be due to several different factors. The utility intakes are not necessarily located at the watershed outlets; in particular, the utility intakes for Decatur and Vermilion County are located upstream of the watershed outlets for the Sangamon River and the North Fork Vermilion River, respectively. Although estimates produced by the SPARROW model do not show any consistent regional biases (Robertson and Saad, 2014), it is unclear what is the cause of the overestimates in nitrogen concentrations produced by the SPARROW model in comparison to the measurements recorded at the intakes. In general, the modeled and measured mean concentrations were observed to be related to the size of the watershed; mean concentrations decreased with a reduction in the watershed size.

Table 4: Influent mean nitrogen concentrations calculated by SPARROW and as the 10-year mean of daily nitrate concentration at the intakes

Watershed	SPARROW-Modeled Flow-Weighted Mean concentration (mg/L)	10-Year Measured Mean Concentration (mg/L)	Total Nitrogen Load Delivered to River Outlet (kg)
Raccoon River (Des Moines, IA)	11.55	6.67	22,486,340
Des Moines River (Des Moines, IA)	9.12	6.02	30,237,999
Sangamon River (Decatur, IL)	6.47	4.52	3,832,495
North Fork Vermilion River (Vermilion County, IL)	6.44	4.37	1,833,558

Among all four intake source waterbodies, *Farm Fertilizer* is the largest source of nitrogen loading at approximately 51-62 percent, as shown in Figure 2. *Atmospheric Deposition*, and *Fixation and Legume Sources* are generally the next largest source at an average of approximately 15 percent contribution. Both of these sources are airborne – *Fixation and Legume Sources* represent nitrogen absorbed by plants from the air, indirectly reaching surface water; while *Atmospheric Deposition* represents nitrogen that reaches surface water directly from the air. *Fixation and Legume Sources* are noteworthy because they are an additional pathway for nitrogen to reach crops, which adds to the impact of agriculture on nitrogen loading.

Confined Manure is also a substantial source of nitrogen loading to the Raccoon and Des Moines Rivers at approximately 15 percent, but nearly negligent to the Sangamon and North Fork Vermilion Rivers at 1-2 percent. *Urban Land* is generally the second-to-least source of nitrogen at an average of approximately 4 percent contribution, and *Sewerage Point Sources* accounts for an average of approximately 1 percent of nitrogen loading to the intake source waterbodies.

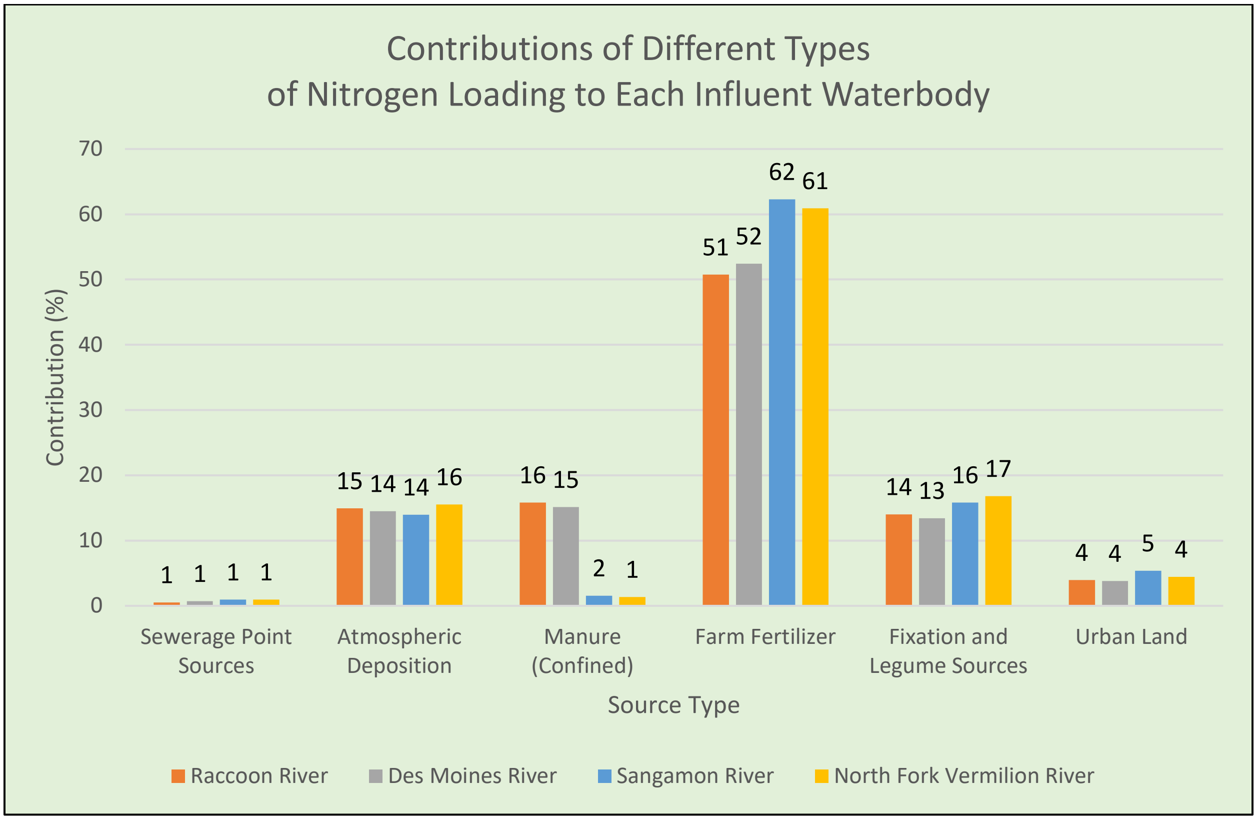

Figure 2: Contributions of different types of nitrogen loading to each influent waterbody

For each type of nitrogen loading, scenarios were designed to lower the loading from a particular source under consideration by a certain percentage to determine its impact on the overall nitrogen loading for the waterbody. The following scenarios were designed to reduce the source contributions:

- 100 percent reduction: This scenario models the impact of an individual loading source in comparison to the other loading sources.
- 20 percent reduction: This scenario represents the interim nutrient reduction goal for 2025 set out by the Mississippi River/Gulf of Mexico Hypoxia Task Force (USEPA, 2018). Some states in the Mississippi River Basin such as Illinois follow this interim nutrient reduction goal (Illinois Department of Agriculture/Illinois EPA, 2015).
- 45 percent reduction: This scenario represents the final nutrient reduction goal set out by the Mississippi River/Gulf of Mexico Hypoxia Task Force.

Additional scenarios were designed to reduce a combination of sources contributing to nitrogen loading. These combinations are described in the Methods section. The findings of the analysis are displayed in Table 5a-d.

Table 5a: Nitrogen reduction scenarios for the Raccoon River

<u>Raccoon River</u>			Percent of Original Sum Load	
	On/Off (100%)		***Nutrient Reduction Scenarios***	
Source Reduction Percentage			***20%***	***45%***
Individual Sources				
Sewerage Point Sources	99		100	100
Atmospheric Deposition	85		97	93
Confined Manure	84		97	93
Farm Fertilizer	49		90	77
Fixation and Legume Sources	86		97	94
Urban Land Runoff	96		99	98
Source Combinations				
Point Sources	84		97	93
Runoff Loads	45		89	75
Urban Sources	96		99	98
Farm Field Loads	35		87	71
Background Sources	71		94	87
Farm Fertilizer + Background Sources	20		84	64
Red-Yellow-Green Color Scale	Cells colored in shades of red indicate lower rates of nitrogen loading reduction, with the darkest cell representing the lowest reduction; cells colored in shades of green indicate a greater nitrogen loading reduction, with the darkest cell representing the greatest reduction; and cells colored in shades of yellow indicate intermediate reductions.			

Table 5b: Nitrogen reduction scenarios for the Des Moines River

<u>Des Moines River</u>			Percent of Original Sum Load	
	On/Off (100%)		***Nutrient Reduction Scenarios***	
Source Reduction Percentage			***20%***	***45%***
Individual Sources				
Sewerage Point Sources	99		100	100
Atmospheric Deposition	86		97	93
Confined Manure	85		97	93
Farm Fertilizer	48		90	76
Fixation and Legume Sources	87		97	94
Urban Land Runoff	96		99	98
Source Combinations				
Point Sources	84		97	93
Runoff Loads	44		89	75
Urban Sources	95		99	98
Farm Field Loads	34		87	70
Background Sources	72		94	87
Farm Fertilizer + Background Sources	20		84	64
Red-Yellow-Green Color Scale	Cells colored in shades of red indicate lower rates of nitrogen loading reduction, with the darkest cell representing the lowest reduction; cells colored in shades of green indicate a greater nitrogen loading reduction, with the darkest cell representing the greatest reduction; and cells colored in shades of yellow indicate intermediate reductions.			

Table 5c: Nitrogen reduction scenarios for the Sangamon River

Sangamon River			Percent of Original Sum Load	
	On/Off (100%)		***Nutrient Reduction Scenarios***	
Source Reduction Percentage			***20%***	***45%***
Individual Sources				
Sewerage Point Sources	99		100	100
Atmospheric Deposition	86		97	94
Confined Manure	98		100	99
Farm Fertilizer	38		88	72
Fixation and Legume Sources	84		97	93
Urban Land Runoff	95		99	98
Source Combinations				
Point Sources	97		99	99
Runoff Loads	32		86	70
Urban Sources	94		99	97
Farm Field Loads	22		84	65
Background Sources	70		94	87
Farm Fertilizer + Background Sources	8		82	59
Red-Yellow-Green Color Scale	Cells colored in shades of red indicate lower rates of nitrogen loading reduction, with the darkest cell representing the lowest reduction; cells colored in shades of green indicate a greater nitrogen loading reduction, with the darkest cell representing the greatest reduction; and cells colored in shades of yellow indicate intermediate reductions.			

Table 5d: Nitrogen reduction scenarios for the North Fork Vermilion River

North Fork Vermilion River			Percent of Original Sum Load	
	On/Off (100%)		***Nutrient Reduction Scenarios***	
Source Reduction Percentage			***20%***	***45%***
Individual Sources				
Sewerage Point Sources	99		100	100
Atmospheric Deposition	84		97	93
Confined Manure	99		100	99
Farm Fertilizer	39		88	73
Fixation and Legume Sources	83		97	92
Urban Land Runoff	96		99	98
Source Combinations				
Point Sources	98		100	99
Runoff Loads	35		87	71
Urban Sources	95		99	98
Farm Field Loads	22		84	65
Background Sources	68		94	85
Farm Fertilizer + Background Sources	7		81	58
Red-Yellow-Green Color Scale	Cells colored in shades of red indicate lower rates of nitrogen loading reduction, with the darkest cell representing the lowest reduction; cells colored in shades of green indicate a greater nitrogen loading reduction, with the darkest cell representing the greatest reduction; and cells colored in shades of yellow indicate intermediate reductions.			

Across all watersheds, eliminating *Sewerage Point Sources* (100 percent reduction), but maintaining all other sources at their SPARROW-modeled values, resulted in an average of approximately 1 percent reduction to the overall nitrogen loading to the waterbody, which is in line with the overall impact of *Sewerage Point Sources* on nitrogen loading to these source waters. The reduction of *Farm Fertilizer* in each scenario (100, 20, or 45 percent) causes the largest reduction in the overall watershed nitrogen load.

Even though *Farm Fertilizer* offers the largest scope of reduction due to its dominant effect on the overall nitrogen load, it is much more likely that reduction targets are spread across various sectors. Reducing *Farm Fertilizer* contributions, in combination with reductions of other related nitrogen sources caused substantial reductions in the overall watershed nitrogen load. An aggressive target of 45 percent reduction in *Farm Field Loads*, for example, reduces the overall nitrogen load to 65-71 percent of the original total, keeping all other contributions at the same level.

SPARROW: Spatial Analysis

Based on the SPARROW model output data provided by USGS, two specific outputs were mapped. Figure 3(a)-(d) displays incremental total nitrogen load delivered from the catchment to the outlet as a percent of the total nitrogen load in the watershed delivered to the outlet. Total nitrogen load, in this case, is the sum of the different types of nitrogen loading described earlier in this section. This was mapped to provide a geographical representation of the origin of the nitrogen load to the watershed outlet. Figure 4(a)-(d) displays incremental total nitrogen yield (=load/area) for each catchment. This was mapped to show locations of elevated nitrogen loading within each watershed.

The two data sets displayed in Figure 3 and Figure 4 provide varying interpretations of the impact of nitrogen to the source waters. The normalized load data set is useful to determine areas to focus nitrogen load reduction – for example, in the absence of specific data on load origin, catchments that release the most nitrogen into the waterway are potential targets for management efforts. The yield data set is useful for identifying locations of elevated nitrogen loading. Focusing best management practices (BMPs) in catchments with higher yields are likely to be more cost-effective, although the impact of those BMPs on the overall watershed nitrogen loading may be attenuated, depending on the size of the catchment. This difference is best encapsulated in the Des Moines River watershed, where the load is somewhat evenly spread across all catchment areas, with the highest concentration in the central part of the watershed (Figure 3(b)). However, the yield is highly concentrated in the lower section of the watershed (Figure 4 (b)).

According to the Raccoon River Watershed Water Quality Master Plan (2011), row crop production accounts for 85 percent of the land area in the North Raccoon River Watershed, but only accounts for 61 percent of the land area in the South Raccoon River Watershed. Looking at Figure 3(a) and Figure 4(a), these percentages of row crop production could explain why incremental total nitrogen load and incremental total nitrogen yield are heavier in the northern section of the watershed compared to the southern section.

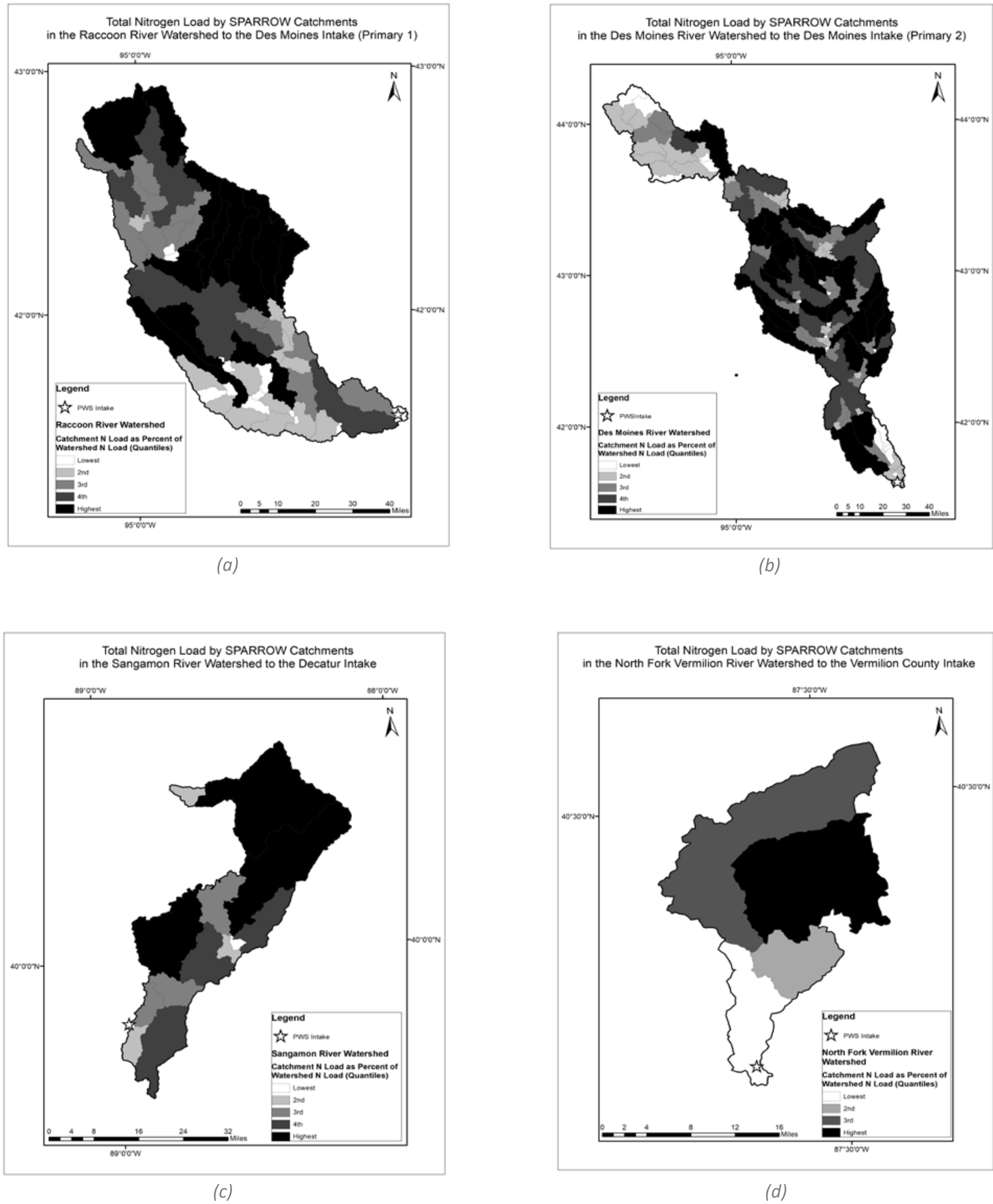

Figure 3: Total nitrogen load by SPARROW catchments in the (a) Raccoon River watershed to the Des Moines intake (primary 1), (b) Des Moines River watershed to the Des Moines intake (primary 2), (c) Sangamon River watershed to the Decatur intake, and (d) North Fork Vermilion River watershed to the Vermilion County intake

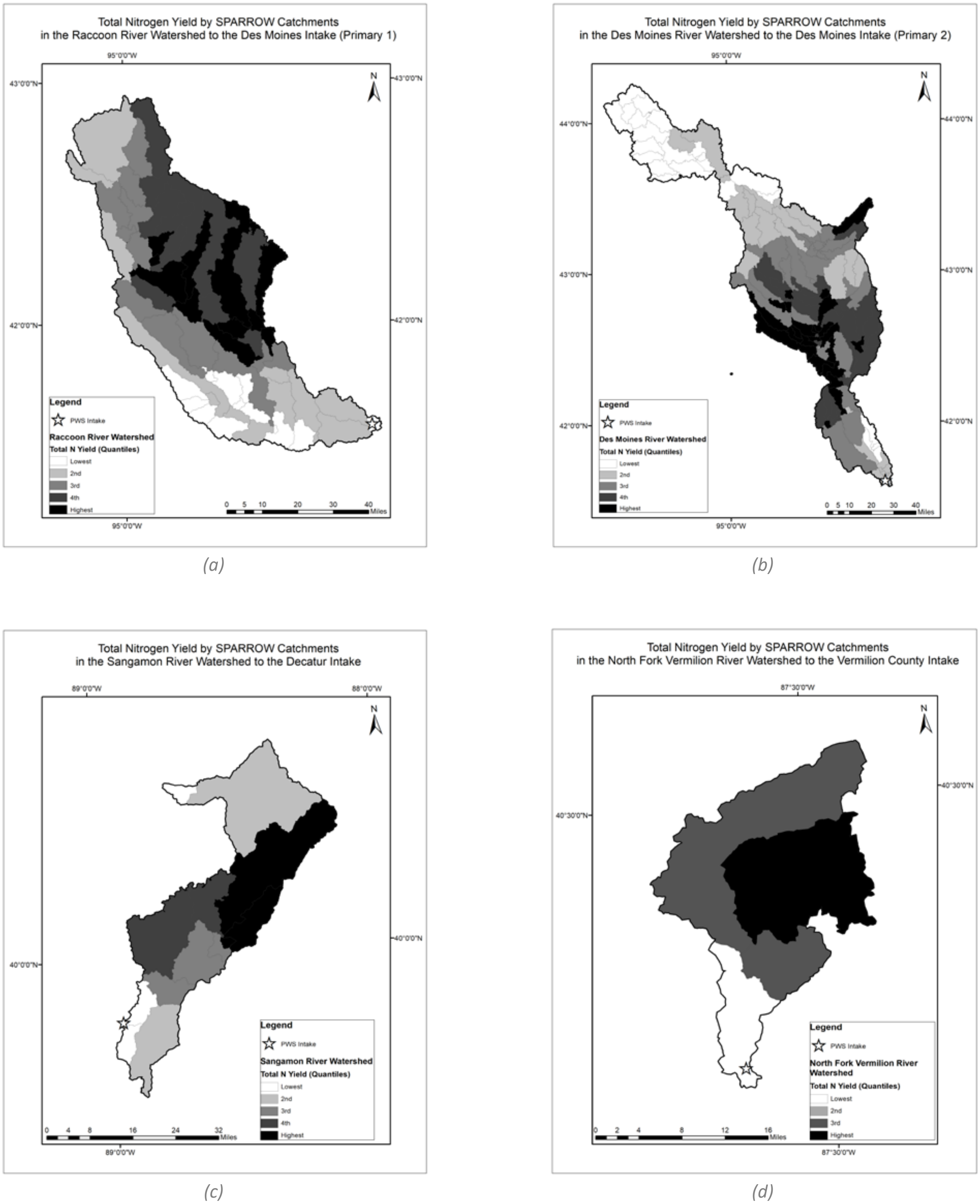

Figure 4: Total nitrogen yield by SPARROW catchments in the (a) Raccoon River watershed to the Des Moines intake (primary 1), (b) Des Moines River watershed to the Des Moines intake (primary 2), (c) Sangamon River watershed to the Decatur intake, and (d) North Fork Vermilion River

Utility Nitrate Concentrations

Daily influent nitrate concentration data were obtained from the three utilities for the time period 1/1/2008 – 12/31/2017. Since Des Moines utilizes two intake sources, separate data for each of the intake locations were provided by the utility. For this study, they were analyzed separately, although it is possible to combine them to produce a flow-weighted mean daily value. Figure (a)-(d) shows the daily influent nitrate concentration at the four intake locations over the 10-year study period.

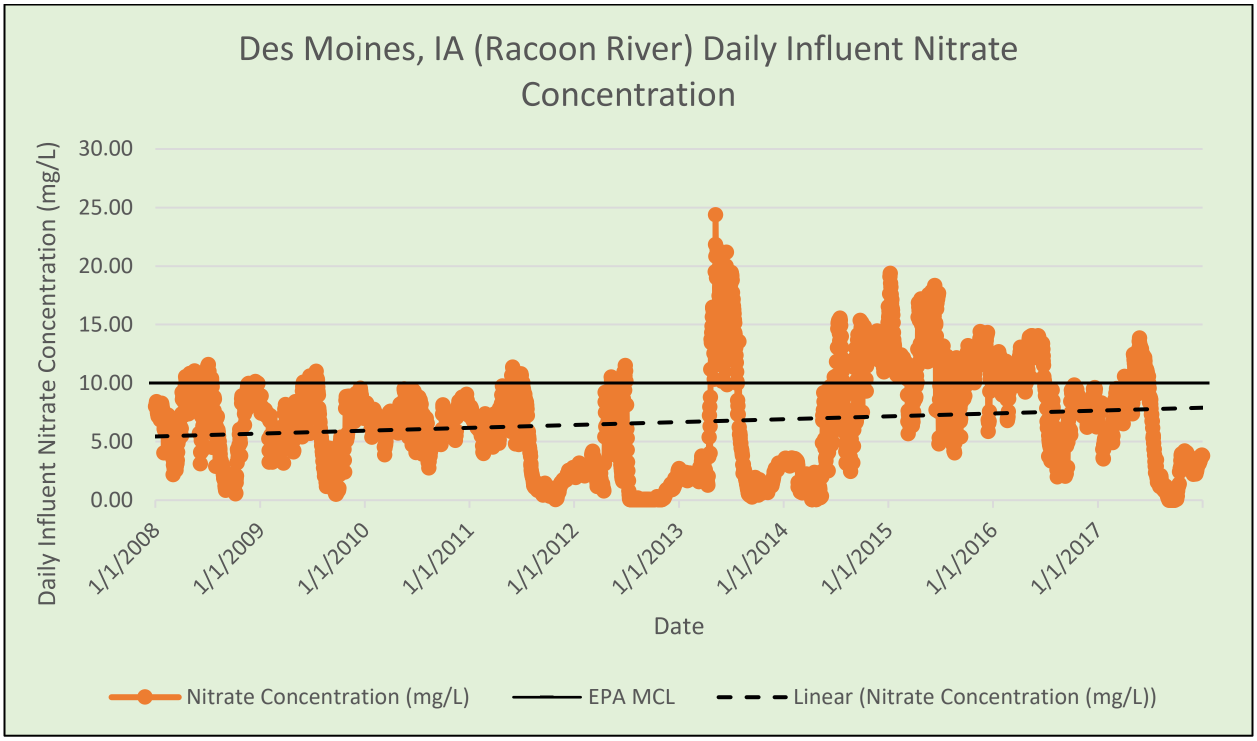

Figure 5(a): Daily influent nitrate concentration at Des Moines, IA (Raccoon River)

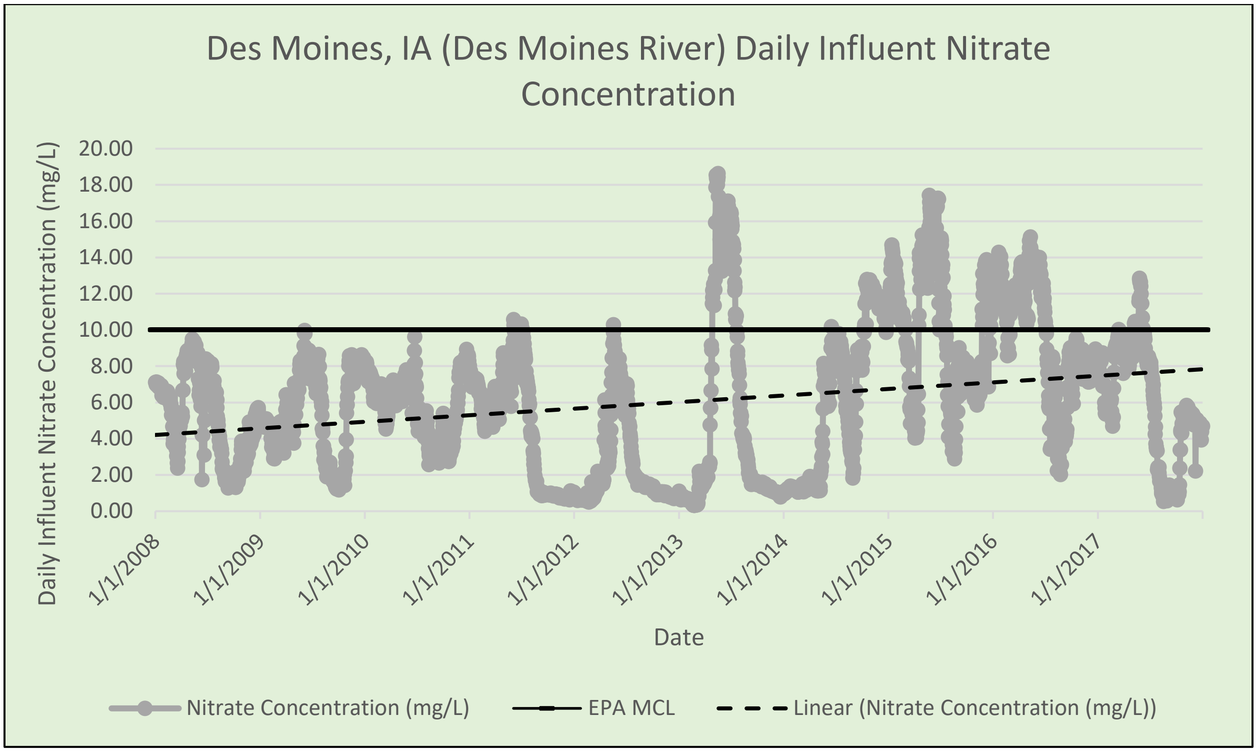

Figure 5(b): Daily influent nitrate concentration at Des Moines, IA (Des Moines River)

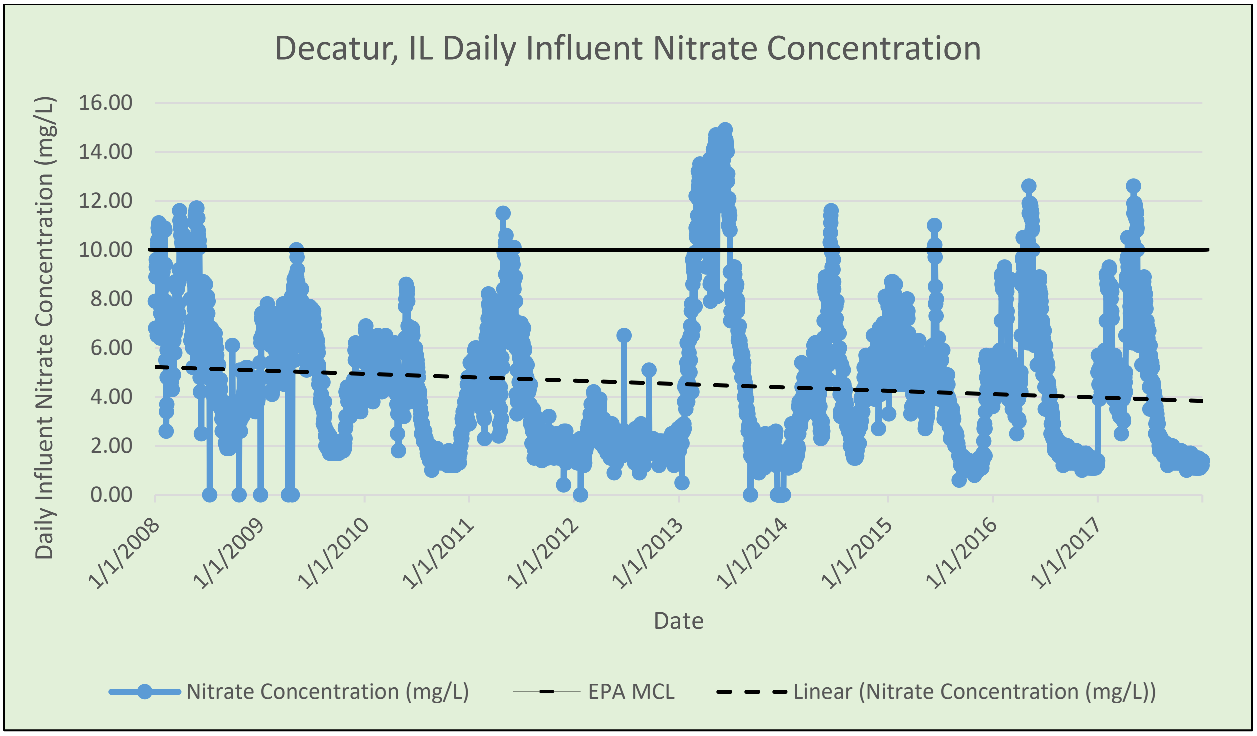

Figure 5(c): Daily influent nitrate concentration at Decatur, IL

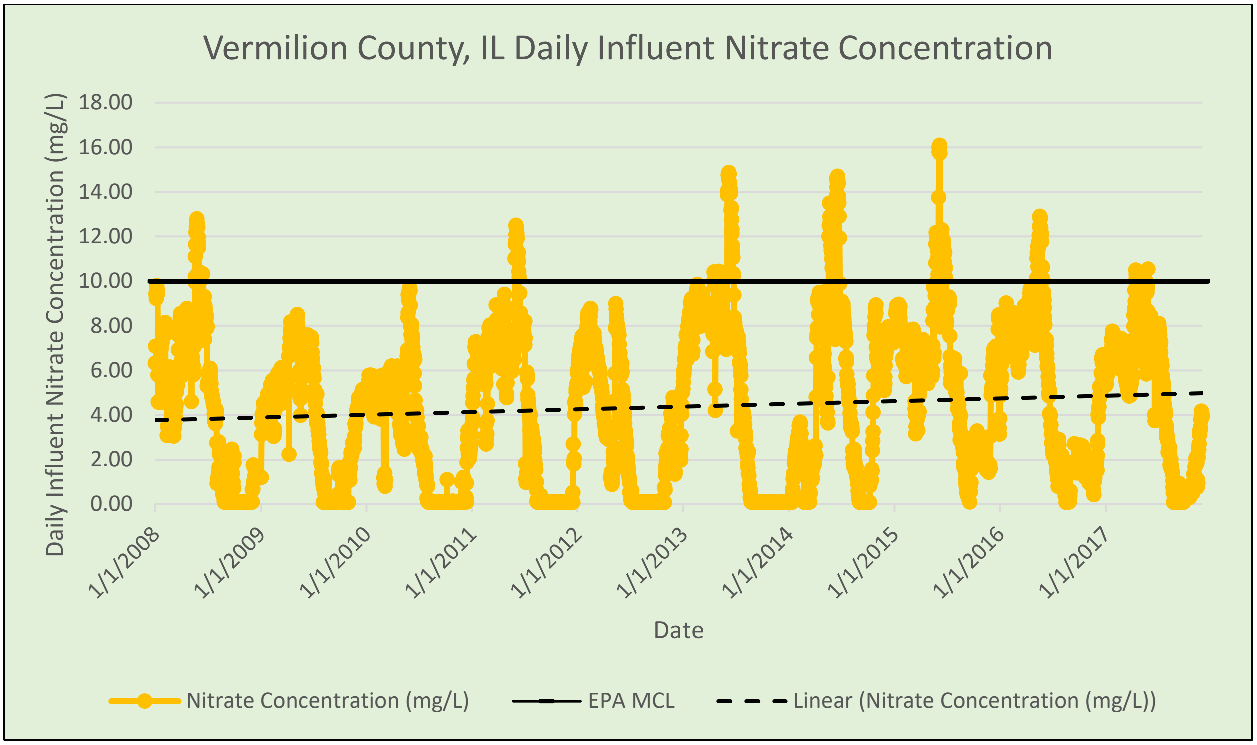

Figure 5(d): Daily influent nitrate concentration at Vermilion County, IL

There appears to be a general seasonal pattern in which nitrate concentration is high during the spring months and low during the winter months. This observation is likely caused by the increased runoff in spring months due to snowmelt, and freezing conditions during the winter. Vermilion County appears to experience a steady cycle of nitrogen loading, as compared to the other intake locations. In Decatur and Des Moines, IA (both the Raccoon and Des Moines Rivers), the influent nitrate is at a consistently low concentration for the winter seasons of 2012-2013 and 2014-2015. In the case of Des Moines, IA, nitrate concentrations are also consistently low for the winter season of 2013-2014. With the exception of Decatur, which exhibits a decreasing trend in influent nitrate concentration, all intakes exhibit a general increasing trend in influent nitrate concentration over 2008-2017.[5] This trend is especially rapid in the Raccoon and Des Moines Rivers, while being much more gradual in Vermilion County.

The intakes at Decatur, IL and Vermilion County, IL have lower mean and median influent nitrate concentrations compared to the intakes at the larger utility (Des Moines, IA), as shown in Table 4. The maximum influent concentrations range from 14.90-24.39 mg/L. Three out of the four intakes experienced their maximum influent nitrate concentration in the spring of 2013. Vermilion County was the exception having experienced its maximum in the spring of 2015, though high values were recorded in the spring of 2013. This observation may be related to regional precipitation, temperature, and possibly other relevant climate conditions at each of the utilities during 2008-2017.
The Des Moines intake locations at the Raccoon and the Des Moines Rivers experienced noticeably more days when the influent nitrate concentration exceeded the USEPA's Maximum Contaminant Level (MCL)

[5] Decatur's decreasing trend is highly influenced by the high nitrate levels in 2008. If observations from 2008 are excluded, Decatur displays no significant trend – neither increasing nor decreasing – during 2009-2017.

for nitrate, 10 mg/L, as compared to the Decatur and Vermilion County intakes, as shown in Figure 6. This observation may be related to specific land use characteristics of the Des Moines watersheds or due to the expected longer retention times experienced in relatively larger waterbodies. It is also worth noting here that *Confined Manure* is a significant source of nitrogen to both the Des Moines River and Raccoon River watersheds, according to the SPARROW model results. Examining the conversion of manure to readily available nitrate may help understand these high nitrate concentration rates in the Des Moines, IA watersheds. Overall, the number of days when the nitrate concentration exceeded the MCL has generally increased over time (Decatur being the only exception, displaying no significant trend), with most exceedances occurring during the latter half of the study period.

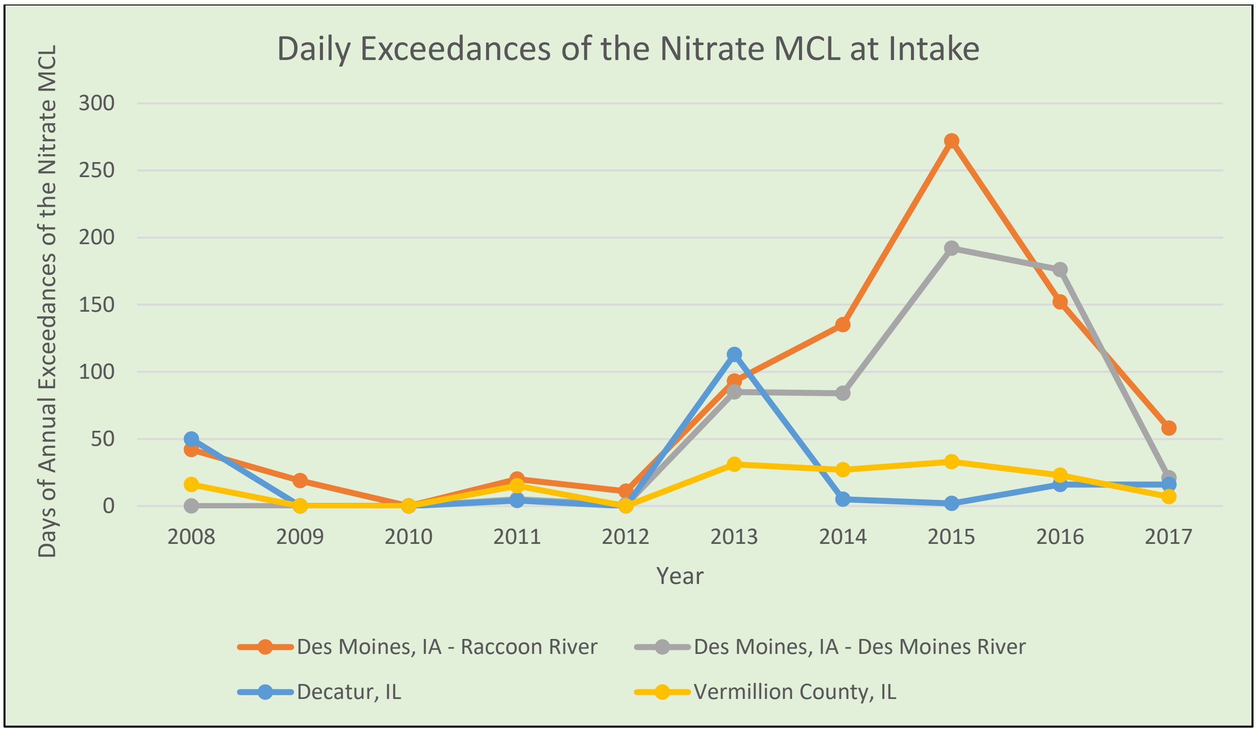

Figure 6: Daily exceedances of the nitrate MCL at intake

In 2015, the Raccoon and the Des Moines River intakes exceeded the nitrate MCL more than half the year – 272 and 192 days, respectively. On average, the number of annual exceedances across the four intakes ranged from 15 days in Vermilion County to 80 days in Des Moines (Raccoon River) (Table 6). As indicated earlier in the Methods section, Des Moines and Vermilion County operate their nitrate treatment units when the nitrate levels in the intake waters exceed 9.5 mg/L, while Decatur uses 8.5 mg/L as a threshold for operating the nitrate unit. Based on averages shown in Table 6 and the operating thresholds set by the utilities, Vermilion County and Decatur operated their nitrate treatment units for 19 and 37 days on average each year, respectively. Due to blending between the two primary water sources and several secondary sources in Des Moines, the exact number of days when the treatment unit was in operation is unclear. Many utilities run the treatment unit for a certain number of days every few months to wash the units (Jensen et al., 2012). This frequency may increase during the summer months, although an overlap with the operational days is often sought.
The ion-exchange technology employed for nitrate treatment is also beneficial in decreasing the precursors for disinfection byproducts and, therefore, the unit is often in operation for an additional

number of days (Chaundra Smith, City of Decatur, personal communication, May 9, 2018). Concentration exceedances for a more aggressive standard of 5 mg/L were also generated to highlight the impact of any potential changes in nitrate MCL, as discussed in Weir and Roberson (2011). Annual exceedances under a stricter limit of 5 mg/L are three to 11 times those under the current MCL, with the most impact on Vermilion County.

Table 6: Average annual influent concentration exceedances (2008-2017)

Utility	Annual Influent Concentration Exceedances (in Days)			
	10 mg/L	9.5 mg/L	8.5 mg/L	5 mg/L
Des Moines, IA (Raccoon River)	80	91	119	228
Des Moines, IA (Des Moines River)	56	63	90	212
Decatur, IL	21	25	37	134
Vermilion County, IL	15	19	39	167

Additionally, three intake concentration reduction scenarios were modeled to determine changes in the number of daily MCL exceedances if the overall watershed nitrogen loading were reduced by a modest target of 10 percent, the Hypoxia Task Force interim target of 20 percent, and the Hypoxia Task Force final target of 45 percent. The results of these scenarios are presented in Figure 7.

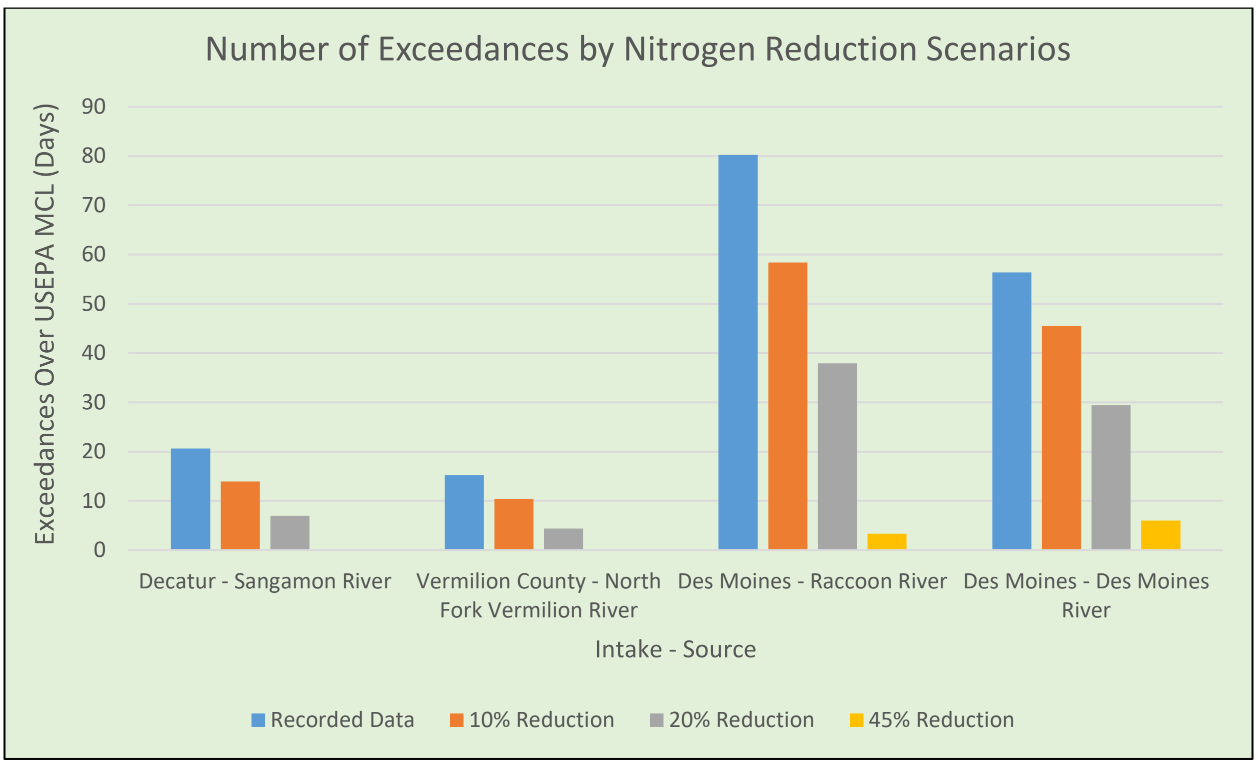

Figure 7: Daily exceedances of the nitrate MCL at intake during various nitrogen reduction scenarios

A 10 percent reduction in the intake nitrate concentrations yields a 20-33 percent reduction in the daily exceedances. A 20 percent reduction in the intake nitrate concentrations yields an even greater 48-71 percent reduction in the daily exceedances, while a 45 percent reduction in the nitrate concentrations virtually eliminates daily exceedances.

Nitrate Treatment Cost

Based on the data provided by the utilities, capital expense is a significant component of the nitrate treatment unit. The plants cost $10-$15 million to construct (inflation-adjusted 2018 dollars). The capital cost amortized over 30 years at a 3 percent interest rate ranged from $207,429 to $384,503 (Table 7). Normalizing the amortized annual capital cost per 1000 gallons of water production reveals the role of scale. Larger utilities like Des Moines incur lower capital cost than mid-sized utilities like Decatur and Vermilion County.

Table 7: Capital, operations and maintenance (O&M), and total cost of the nitrate treatment at study locations

Utility	Year of constru ction	Product -ion (MGD)	Inflation-adjusted capital cost ($ million)	Amortized annual capital cost ($)	Average annual O&M cost ($)	Average annual cost per unit volume ($/kgal)		
						Capital	O&M	Total
Des Moines	1991	47	10.3	207,429	513,286	0.01	0.03	0.04
Decatur	2002	20	14.6	384,503	67,598	0.05	0.01	0.06
Vermilion County	2001	8	12.3	318,733	25,193	0.11	0.01	0.12

The annual O&M cost varied throughout the study period, and was positively correlated with measures of nitrate contamination such as annual number of exceedance days and annual average concentration. On average, Des Moines spent more than $500,000 per year during the six years for which data were made available by the utility. The largest expense – more than $1.4 million – occurred in 2015, the same year which recorded the highest annual average nitrate concentration and the highest number of days when the influent water exceeded the MCL for nitrates at both its primary intake locations. The same pattern was observed in Decatur and Vermilion County as well. On average, Des Moines and Decatur spent 3.4 percent and 1.3 percent of their total O&M budget on nitrate treatment, respectively. However, that number went up to 8.6 percent and 3.8 percent, respectively, during years when nitrate levels were the highest, highlighting the significant effect of high nitrate levels on the utilities' cost of water production. Average annual O&M costs (normalized by volume) were lower than capital costs in case of Decatur and Vermilion County, but comparatively higher in Des Moines, whose intake water sources experienced significantly higher levels of nitrate and exceeded the MCL on more days as compared to the other utilities.

Data on the cost of nitrate treatment at other comparable utilities were sought in peer-reviewed and trade publications, but very few were publically available. Table 8 presents the cost of nitrate treatment in other utilities that were found in published literature. Capital and O&M costs were available in the case of Bloomington, IL and Hastings, MN. However, for eight other utilities in the Mississippi Basin, only capital costs were available, and thus, their data were combined and the averages presented under 'Other MRB utilities.' A breakdown of data available for these eight utilities in presented in the Appendix (Table S1). The most comprehensive dataset regarding the cost of nitrate treatment comes from Jensen et al. (2012), who published data from 26 utilities in central California.

Table 8: Capital, operations and maintenance (O&M), and total cost of the nitrate treatment units in other locations

Utility	Year of construction	Inflation-adjusted capital cost ($ million)	Capacity (MGD)	Amortized annual capital cost ($)	Average annual O&M cost ($)	Average annual cost per unit volume ($/kgal)		
						Capital	O&M	Total
Bloomington, IL	2005	2.83	12.1	86,007	349,284	0.02	0.08	0.10
Hastings, MN	2007	4.74	3.0	177,074	63,500	0.16	0.06	0.22
Other MRB* cities	2003	1.84	0.61	64,505		0.29		
<u>*Reported averages*</u>								
Very small			0.002 – 0.05			0.92	1.49	2.40
Small			0.05 – 0.39			0.18	1.06	1.28
Medium			0.39 – 1.30			0.23	1.02	1.29
Large			1.30 – 15.51			0.32	0.81	1.18

Notes: Data for Bloomington, IL and Hastings, MN were obtained from The Nature Conservancy (2012) and Dakota County (2018). An estimate of labor cost was added to the Hastings, MN data originally obtained from Dakota County. Other MRB cities refer to eight locations in the Mississippi River Basin that use an ion-exchange (IX) process for nitrate treatment, and whose data were recorded in Naidenko et al. (2012) and Minnesota Department of Health & Minnesota Department of Agriculture (2004). Data presented for 'other UMB cities' are averages of the eight locations; O&M costs were not available for these cities. Reported averages refer to data for IX nitrate treatment units in central California, which were initially recorded in Jensen et al. (2012). Estimates from Jensen et al. (2012) were inflation-adjusted to reflect 2018 values.

A plot of the annual capital cost (per unit volume) against the average production highlights the impact of scale economies (Figure 8). The capital cost of construction decreases with an increase in production. Des Moines, the largest utility in the sample, recorded the lowest capital cost.[6] Since capital cost constitutes a much larger proportion of the total cost, this suggests that rising nitrate levels in source waters that necessitate the construction of new nitrate treatment units will disproportionately affect smaller municipalities. The recent coverage of nitrate mitigation in Pretty Prairie, KS is instructive here (Walton, 2017).

[6] In addition to size, an alternative explanation for the lower cost at Des Moines could be the year of construction. Des Moines' treatment facility is the oldest in the sample, built in 1991, during an economic recession, and perhaps benefited from lower cost at the time.

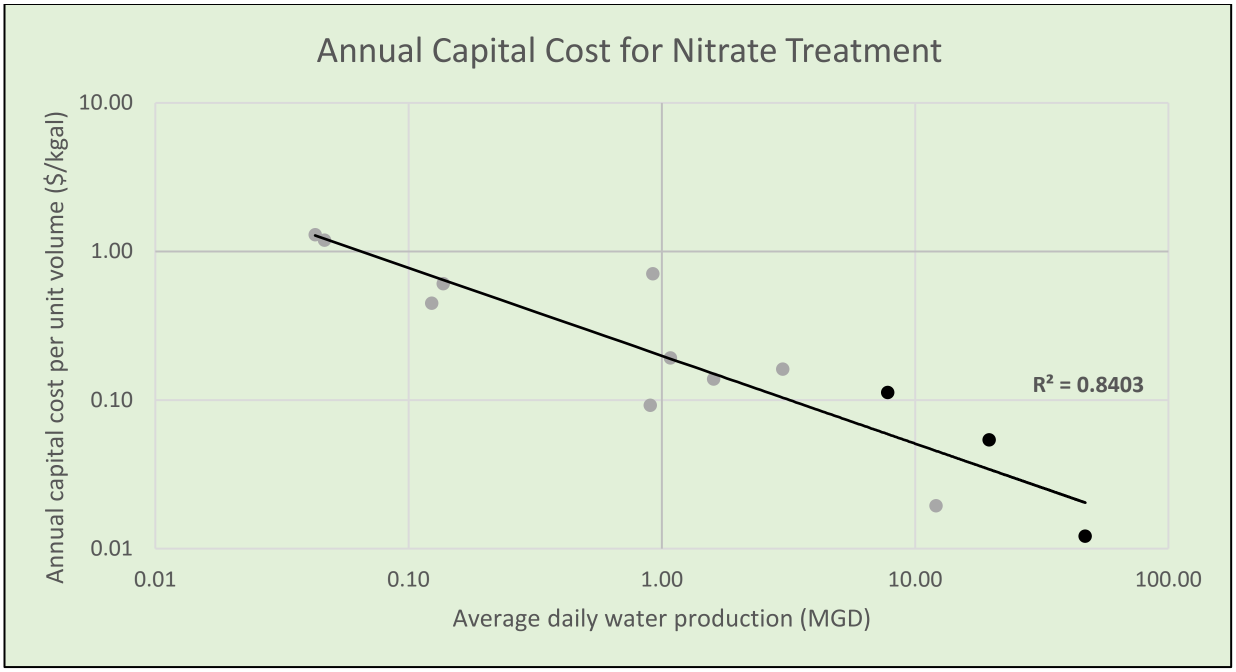

Figure 8: Annual capital cost per unit volume plotted against average annual water production. Both axes are log-transformed. Data from the study locations are highlighted in black.

A similar plot of annual O&M cost (per unit volume) against the average production is shown in Figure 9. The strong relationship between production volume and unit cost observed in Figure 8 is not as evident in the case of O&M cost. For one, there are fewer observations, since O&M costs were not available for the eight utilities in the Mississippi River Basin (Table S1). Second, even as O&M costs are subject to scale economies in general, other factors such as average nutrient levels, exceedance days, and the maintenance schedule at the treatment plant, to name a few, could play a critical role in determining the O&M cost.

Data from Jensen et al. (2012) were not shown in Figure 8 and Figure 9, since the utility size and cost were presented as ranges. The capital and O&M costs reported in Jensen et al. (2012) were, in general, higher than those found either in the study utilities or those presented in Table S1. They may be reflective of the higher cost of labor and other goods and services in California, or the comprehensive reporting of their costs. Additionally, the O&M costs at these utilities were consistently higher than the capital costs, contrary to the observations made earlier based on the data from utilities in the Mississippi River Basin.

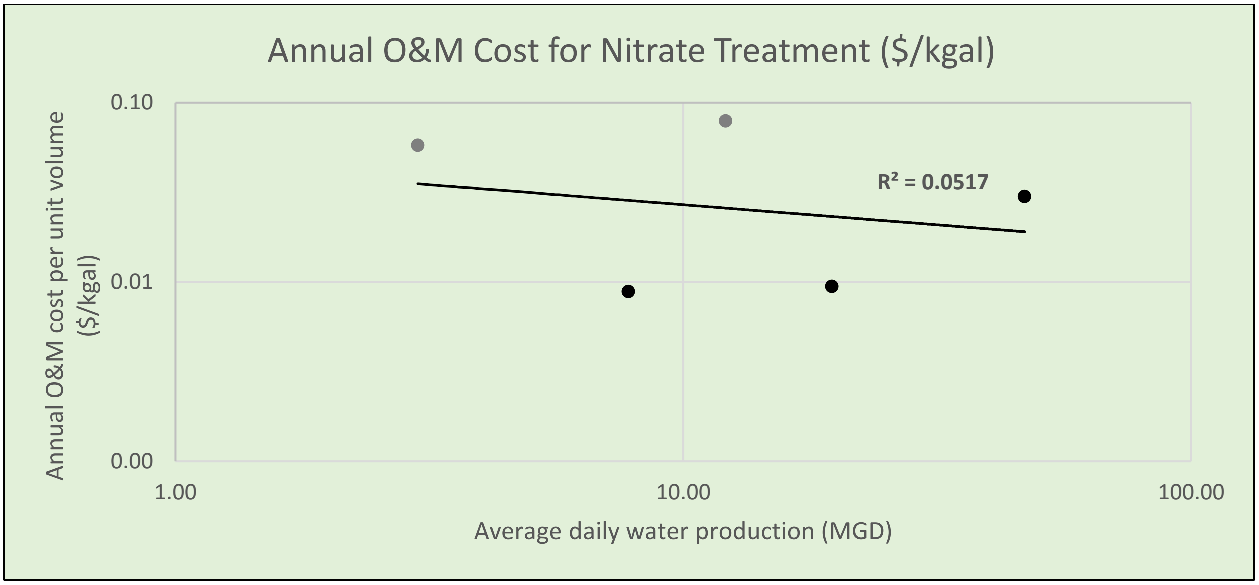

Figure 9: Average annual O&M cost per unit volume plotted against average annual water production. Both axes are log-transformed. Data from the study locations are highlighted in black.

Discussion

Agricultural activities have been identified as the primary contributor of nitrogen across the Mississippi River Basin (Robertson et al., 2014) and other watersheds such as the western Lake Erie (Betanzo et al., 2016; Robertson et al., 2011). The same was true across the four study watersheds, where *Farm Fields* and *Confined Manure* contributed a majority of the nitrogen runoff in the source waters.[7] A second critical driver of increasing nitrate concentrations is changes in land use patterns. Between 1999 and 2007, the Sangamon River watershed experienced an increase in land under corn cultivation (7 percent) and urban development (9 percent), while undergoing a decrease in land under soybean cultivation (11 percent) and grassland cover (6 percent) (Keefer et al., 2008). Similar concerns abound in the North Fork Vermilion River watershed, which has experienced an increase in impervious surface run off and outflows from septic systems and municipal wastewater treatment plants (Johnston and Peverly, 2008). Discounting year-to-year variations, the long-term trend for nitrate concentrations at intake locations of the four study watersheds is on an upward trajectory.

An examination of the intake concentration data shows that the number of times the intake nitrate concentrations have exceeded the MCL has generally increased in the latter half of the study period. This appears to coincide with a general increasing trend in eutrophication on a national and global scale (WRI, 2018), suggesting the need for a closer look to analyze the indirect causes and impacts of climate change and their connection to eutrophication. Additionally, the role of agricultural conservation practices and their associated policy needs to be well defined in this larger discussion. Increasing fertilizer consumption and the use of tile drainage, coupled with outcomes related to climate change such as a longer growing season, and a higher occurrence of intense precipitation events, cumulatively have the potential to increase nutrient runoff, unless remedial measures are undertaken.

---

[7] Nitrogen fertilizer consumption in the U.S. has continued to increase, though the rate of increase has slowed down considerably in the last 20 years (USDA, 2014).

Although the exact relationship between the influent nitrate concentration and the unit cost of treatment for drinking water is unclear, indications are that the two are linearly related. A study of nitrate removal in wastewater treatment plants in the UK found a positive linear relationship between nitrate load removed and the equivalent annual (capital and O&M) cost (Oxera, 2006).

Des Moines' exception, however, may not last much longer, as it is expected to spend $15 million to double its existing nitrate removal capacity to handle the high levels of nitrate in its influent waters (Elmer, 2016). The utility's planned expansion would result in an amortized payment of approximately $760,000, which would be more than three times its current annual capital cost, and more than double its current annual total cost.

Comparing the cost of capital and O&M at all utilities for which data were available, a pattern is noticeable. Except in the case of Des Moines, the capital cost of constructing a nitrate treatment unit (paid out in an amortized schedule) is a much larger expense than that of operating the same unit. Des Moines' exception, however, may not last much longer, as it is expected to spend $15 million to double its existing nitrate removal capacity, as seen in Figure 10, to handle the high levels of nitrate in its influent waters (Elmer, 2016). The utility's planned expansion would result in an amortized payment of approximately $760,000, which would be more than three times its current annual capital cost, and more than double its current annual total cost.

Figure 10: Inside photo of the Des Moines Water Works Nitrate Removal Facility (Source: Des Moines Water Works)

The average annual capital, O&M, and total costs of the three study utilities are comparable to those in Bloomington, IL and Hastings, MN, but much lower than the California utilities surveyed in Jensen et al. (2012). Overall, the lack of reliable cost data from other utilities in the Mississippi River Basin precludes a stronger assessment of the impact of nitrate on water treatment costs. The difficulty in obtaining cost information is shared by other researchers as well (Jensen et al., 2012; p140):

Costs can be difficult to assess due to inconsistencies in how cost information is reported. Comparison of costs across different systems is not always valid due to differences in influent water quality parameters, system size, waste management options, and system configuration. Published costs do not always include comparable information. […] A thorough cost analysis of design parameters for specific locations would be required for accurate cost estimation.

Although watershed conservation initiatives to contain the flow of nutrients into rivers and estuaries have a long history, the rising levels and their impact on drinking water sources have allowed water utilities to be an active stakeholder in the conservation process. The American Water Works Association (AWWA) – a trade group representing the interests of water utilities – has been heavily engaged in watershed conservation efforts to protect source waters, advocating for these programs in the Farm Bill (AWWA, 2018). All three utilities included in this study work with upstream watershed stakeholders to identify low-cost nutrient reduction strategies. However, it is unclear if these conservation strategies can be directly linked to any associated reductions (or containment in the increase) in the nutrient levels. For this reason, it is important to ensure adequate monitoring, both edge-of-field and in-stream, is in place to better connect agricultural conservation practices to river water quality. Conservation practices should be focused in watershed areas that contribute the greatest nitrogen load. And finally, stakeholder involvement in watershed-wide conservation planning should be increased, perhaps through a mix of appropriate incentives and the right policies.

Policy Implications

There is a range of important policy implications resulting from this study, spanning from immediate to the general and to the aspirational. This section will explore each of these in turn. Because the study is based on data from specific water utilities, additional policy implications may be developed as new data are collected and more information becomes available.

Immediate Policy Implications

The Farm Bill

A fundamental conclusion of the study is that the levels of nitrates in the source waters of the Mississippi River Basin water utilities are rising, with nitrate-based fertilizers identified as the major contributor. The most recent version of the 2018 Farm Bill developed in the U.S. House of Representatives that failed to pass on May 18, 2018, was seriously deficient in addressing these increasing nutrient levels. In fact, the House version of the Bill curtailed key programs that have been central to conservation efforts and continually reauthorized through past farm bills.

The most damaging modification in terms of conservation included in the House Farm Bill was the proposed repeal of the Conservation Stewardship Program, which provides funding to farmers for holistic, more long-term conservation projects that are critical to reducing nutrient pollution. While the proposed version would fold current contracts into the Environmental Quality Incentives Program (EQIP), it would ultimately cut funding from these more advanced measures, curbing projects which are critical to the reduction of nutrient pollution.

Though these projects include a number of different measures, one of the most notable types of conservation projects is crop rotation. By cycling soybeans into their crops of corn, farmers can reduce the amount of nitrates left in the soil from corn cultivation. Studies have shown that soybean residue absorbs the nitrates from the soil, ultimately reducing the nitrate concentration in the runoff that ends up in streams and rivers (Jones et al., 2016). Removing funding from programs that limit this runoff will only exacerbate the problems highlighted by this study.

There were provisions of the House's proposed Farm Bill that were beneficial to maintaining drinking water quality, however. Most notably, the bill would have ensured that at least 10 percent of conservation funding is targeted at protecting drinking water. The proposed bill also would have bolstered benefits under programs –

Farm Bill

It is the U.S. federal government's primary instrument for advancing agricultural and food policy, enacted every five years or so.

2018 Developments

January-April: Negotiations in the House and Senate.

May: Legislation failed to advance in the House on May 18.

June-August: Negotiations likely to continue. Legislation expected to be brought to vote again in the House. Senate version expected soon after that.

September: Current Farm Bill expires on September 30. In the absence of an agreement, a 1-year continuing resolution expected to be voted on.

Farm Bill Authorizations

2008: $288 billion

2014: $956 billion

2018 (proposed): $867 billion

Additional Context

In 2012, the Farm Bill failed to pass the House, resulting in a one-year extension till September 2013. The Bill failed to pass the House a second time in 2013 and had to receive a second short-term extension, before passing both houses of Congress in February 2014.

like the Regional Conservation Partnership Program – that are provided to farmers who make use of conservation practices that support the quality of water downstream.

As the House and the Senate continue working on the Farm Bill, they should preserve the existing conservation measures that support nitrate-reduction practices and maintain existing conservation funding levels. If the 115th Congress enacts a one-year extension instead of passing a new Farm Bill this year, it is paramount that the next Congress work to strengthen and expand a future Farm Bill's conservation programs during the next round of negotiations. Additionally, Congress should maintain the aforementioned provisions that support clean drinking water in any future iteration of the Farm Bill.

Waters of the U.S. Rule Change

In 2017, the USEPA proposed overhauling the Obama Administration's Clean Water Rule or "Waters of the United States." The rule essentially determines what bodies of water and wetlands fall under the Clean Water Act's protections. These safeguards include requirements for federal discharge and dredge-and-fill permits, state water quality certifications, and a number of other protective measures. By removing these safeguards, fewer polluters will be held responsible for their actions, resulting in worsening water quality and further increases in drinking water treatment costs.

While the USEPA initially was aiming to roll back the current rule by the end of this year, it now plans to implement changes no sooner than September of 2019. Language that would have a similar effect has appeared in various appropriation markups and as an amendment to the House version of the Farm Bill.

Trade Relations with China

Trade policy, likewise, has serious implications for agriculture, water quality, and the environment, and the findings of this study highlight the impact of trade on conservation.

Trade tensions between the U.S. and China have escalated during the Trump presidency in the wake of a number of public disputes between the two countries over various trade actions. These tensions have led to numerous economic threats by both the U.S. and China, most notably including steep tariffs on imports from the other country. Both sides have targeted goods produced by key industries to exert maximum political pressure. One of those imports against which China has proposed retaliation is U.S. soybeans.

Soybeans are the number one U.S. agricultural export, with China accounting for a majority of the sales. Even before implementation of the tariffs, Chinese buyers of U.S. soybeans have already begun to move on to sellers from countries like Brazil, Russia, and Canada.[8]. This shift in the market could devastate the U.S. soybean industry.

By risking the trade relationship with the biggest importer of U.S. soybeans, these trade tensions could effectively removing a major incentive for U.S. farmers to grow soybeans: the ability to sell them for a profit. Without interest from their main buyer and other countries ramping up production to meet Chinese demand, soybean farmers are likely to turn away from conservation practices like rotating soybeans into corn crops to limit nitrate runoff. This market shift will likely result in increased nitrate runoff and even higher water treatment costs for utilities.

---

[8] A translation of the list of goods covered by the proposed tariffs is available here: https://www.cnbc.com/2018/04/04/the-full-list-of-us-products-that-china-is-planning-to-hit-with-tariffs.html

General Policy Implications

Certain conservation programs that lower nitrate levels can save taxpayer money

A major finding of this study is that lowering nitrate intake levels, in turn, lowers the costs of drinking water treatment for water utilities. Even a modest reduction of 10 percent in the intake nitrate levels results in a 20-33 percent reduction in the number of daily nitrate MCL exceedances. A 20 percent reduction in the intake nitrate levels would result in an average reduction of 60 percent in the number of nitrate MCL exceedances. Going even further, a 45 percent reduction in the intake nitrate levels would bring the exceedance days to nearly zero.

Across all the intake watersheds included in this study, farm fertilizer represented the biggest contribution to nitrate pollution. Acknowledging the intersection between agricultural policy and nitrate pollution in source waters is vital to addressing the growing problem of rising water treatment costs.

In light of this interaction, conservation programs that work to reduce nitrate runoff from farms should be considered in the drafting of relevant legislation like the Farm Bill. Specifically, programs like the Conservation Stewardship Program that encourage long term, holistic conservation practices like crop cycling should be preserved and strengthened. Additionally, appropriators in the House and Senate should prioritize these conservation programs and even consider bolstering them with funding targeted specifically at nitrate reduction.

Changes in regulations can further increase the cost of drinking water treatment

By weakening regulations that protect source waters from pollution, Congress and the Executive Branch risk compounding the growing costs associated with providing clean drinking water. As the study has clearly shown, these costs are readily increasing.

As nitrate pollution increases, more and more communities throughout the U.S. will have to invest heavily in building treatment plants to remove nitrates from source waters. This study has highlighted the high costs associated with these plants, and many smaller communities are simply incapable of financing the necessary treatment plants without additional support.

Smaller, rural communities are the most heavily impacted by rising nitrate pollution

Until overall nitrate runoff is reduced to levels where exceedances no longer occur, Congress should consider policies that alleviate the undue burden placed on these smaller, rural communities. By providing various methods of capital support – grants, zero-interest loans, or debt forgiveness, to name a few – to smaller communities struggling with nitrate pollution, Congress can alleviate a significant financial concern associated with drinking water provision in rural parts of the U.S.

More data are necessary to fully address the problem of nitrate pollution

This study highlighted the rising costs associated with removing nitrate from source waters. However, there are still not enough data available to make definitive conclusions on matters like specific operation and maintenance costs for nitrate treatment by water utilities.

As the cost of providing safe drinking water continues to increase, it becomes even more important to address nitrate pollution at its source. Developing ways to collect and disseminate the necessary information between stakeholders is a necessary next step in combating the issue.

Policy Recommendations

Congress could make use of a number of legislative solutions to address the problems highlighted by this study. This section will explore some of the most promising options.

Provide capital support to small communities

Since capital expense of constructing a nitrate treatment plant, as compared to O&M, is the larger expense, support in the form of special grants, zero-interest loans, and debt forgiveness, should be considered by USEPA and state agencies, especially in the case of small utilities that have a small customer base and thus face a choice between poor water quality and high utility bills.

Facilitate nitrate removal cost reporting

Congress could implement various measures to encourage water utilities to better track the economic costs of nutrient loading. This could be achieved by providing utilities with the necessary equipment and training to track the costs associated with nitrate removal and then to report the data.

An alternate approach would be to tie the reporting of nitrate treatment costs to receiving State Revolving Fund (SRF) support. SRF is a critical financing mechanism that is employed by most public water utilities to finance large infrastructure upgrades, including nitrate mitigation strategies such as drilling of new wells and construction of new treatment plants. Such a requirement could be done at the federal level through legislation or report language in the appropriations process in Congress, or a guidance issuance by USEPA, or at the state level in selected states through similar means.

Increasing the amount of available information would allow utilities, farmers, and other stakeholders to better understand the impact of nitrate runoff on triggering an exceedance and the resulting treatment process. This also would facilitate methods of nitrate pollution management, like nutrient trading.

Regulating agricultural discharges as point sources

Ever since the creation of the Clean Water Act, non-point sources such as agriculture, septic systems, and stormwater systems have been exempt from the law's regulations. More recently, stormwater systems are being regulated as point sources under the Municipal Separate Storm Sewer Systems (MS4) permit program. The growing use of tile drainage presents a similar situation for agricultural discharges. Congress and USEPA should explore the possibility of regulating agricultural discharges as point sources, at least in watersheds with high levels of nitrate pollution.

Nutrient trading

Congress could explore the development of regional or national nutrient trading systems based on more refined data from improved monitoring by the utilities. Nutrient trading – a market-based solution that gives monetary value to management practices that reduce nutrients like nitrates – is a possible method of curtailing the increasing nitrate pollution in source water.

While a number of systems are already in place throughout the U.S., availability of further data such as edge-of-field and in-stream monitoring of nutrients and the cost of comparable treatment options, would help develop new trading systems in parts of the country where they currently do not exist. Additionally, it would help existing trading systems ensure that they are effective in lowering nitrate levels.

Further research is necessary before proceeding, but the prospect of nutrient trading is promising for addressing this problem, given its scale and severity.

Increase support for existing technical assistance programs and related research

A further option for a legislative solution to the increasing costs of nitrate removal from drinking water is to facilitate best practices within the agricultural community for fertilizer application. EQIP already provides technical assistance for various environmental protection measures.

Strengthening and further developing the technical assistance component of EQIP could ensure further dissemination of best practices for fertilizer application. Furthermore, providing research into new distribution methods and techniques that decrease the amount of residual nitrates left in the soil could also prove beneficial.

Appropriations

Finally, the study's findings regarding increasing nutrient levels, the cost of removing nutrients from drinking water, and the resulting increases in consumer water bills also have implications for federal spending and the appropriations process. In particular, several annual appropriations bills relate to possible remedies or responses to the problems identified in the study.

The House and Senate Agriculture Appropriations bills are two of the most significant sources of conservation appropriations, funding vital programs like the Natural Resources Conservation Service. Prioritizing the conservation components of these bills in future appropriation deliberations will help address the increasing costs associated with nitrate removal. Additionally, Congress could use the report language associated with these bills to help facilitate or implement some of the previously discussed legislative solutions.

Another key pair of appropriations bills is the House and Senate Interior Appropriations bills. Interior appropriations are relevant to both forms of agricultural conservation funding and some of the agencies best situated to address nitrate pollution – the USEPA, the U.S. Fish and Wildlife Service, and the USGS. Insuring robust funding for these agencies is instrumental in keeping drinking water safe. If funded appropriately, agencies like the USGS could additionally play a key role in addressing some of the open questions identified by this study and filling the relevant data gaps.

A final pair of appropriations bills that are relevant to the policy implications of the study is the House and Senate Energy and Water Appropriations bills. Energy and Water appropriations support environmental cleanup measures, key scientific research, and the Army Corps of Engineers. The Army Corps of Engineers plays a key role in conjunction with the USEPA in implementing the Clean Water Rule that specifies which waterways are covered by the Clean Water Act.

Open Questions

This study and its conclusions have led to a number of open questions and major avenues for further research. First, as stated earlier in the Discussion, reporting of O&M costs for nitrate treatment by water utilities is not comprehensive. Given the rising costs of water supply and the increasing contribution of nitrate treatment to the overall water rates, a comprehensive assessment of nitrate treatment costs in a large sample of utilities is needed to understand the impact of nitrates on water rates, identify cost-effective mitigation strategies, and bring stakeholders on-board.

Second, although conservation practices are heavily promoted by federal and state programs, their impact on measurable changes in water quality is not fully understood. Variation in the length and intensity of implementing conservation measures in the various watersheds in the Upper Mississippi River Basin can be utilized to identify the impact of these conservation measures on surface water quality by evaluating nitrate concentrations in the tributaries of Mississippi River. Comparing the relative costs of various conservation practices with the cost of treatment at a water utility can help identify the most cost-effective way to remove nitrates from drinking water.

Third, although numerous studies describe the need to collect additional data, few precisely pinpoint data gaps and propose how to fill them. Identification of the available data and gaps therein can address questions listed above, and help make decisions regarding water quality (both source and drinking water) in the Mississippi River Basin. This effort would complement the water quality data collection by USGS and support programs under Title II of the Farm Bill such as the Conservation Effects Assessment Program (CEAP) and the Mississippi River Basin Healthy Watersheds Initiative under the Regional Conservation Partnership Program (RCPP).

Conclusions

The 2015 lawsuit by Des Moines, IA against upstream communities in the Raccoon River watershed was a national demonstration of the economic impact of excess nutrient loading, not only on the Gulf of Mexico ecosystem, but on human health further upstream in the Mississippi River Basin. An analysis of water quality and the cost of nitrate treatment at three water utilities and their associated intakes in the Mississippi River Basin revealed that nitrate concentrations have been steadily increasing, resulting in an increase in the number of daily exceedances. An analysis of the source watersheds identified farm fertilizers as the largest contributor of nitrogen loading. Nitrogen reduction scenarios modeled after final and interim targets set by the Mississippi River/Gulf of Mexico Hypoxia Task Force suggested that cross-sector reductions would be most effective to bring down nitrogen concentrations in the source waters. If the Task Force targets were to be achieved, it would dramatically reduce the number of daily exceedances above the MCL at all four intake locations. Even a modest reduction of 10 percent in the intake nitrate levels results in a 20-33 percent reduction in the daily exceedances.

An analysis of the cost of nitrate treatment at the three water utilities revealed that the amortized capital cost of a treatment plant typically outweighs annual O&M costs. Furthermore, a review of capital cost of constructing a nitrate treatment unit at 13 water utilities in the Mississippi River Basin showed a scale effect: the cost per unit volume at the largest utility was orders of magnitude lower than that at much smaller ones. This presents a double bind for smaller communities: not only is the prospect of spending millions of dollars on an advanced treatment unit daunting, it would also be much more expensive for ratepayers given the smaller volume of treated water.

Conservation programs have the potential to limit some of these costs to utilities, although the extent of their impact will depend on a variety of factors specific to the watershed. Water utilities are increasing their engagement in watershed conservation practices in an effort to limit the need for specialized treatment units and reduce rate increases. The Farm Bill is an effective vehicle for undertaking these critical conservation efforts that have multiple benefits across sectors. While some proposed changes to the Farm Bill such as the emphasis on source water protection are positive steps, other changes will undermine years of stakeholder engagement and cooperation between farmers, utilities, and other watershed groups. As more research is conducted to understand the linkages between conservation efforts and changes in water quality as well their impact on water treatment costs, policymakers will have the benefit of seeing the full impact of conservation programs and funding efforts.

References

AWWA. (2018). AWWA animation video supports drinking water protection goals in Farm Bill. January 3. American Water Works Association. Accessed at: https://www.awwa.org/publications/connections/connections-story/articleid/4867/awwa-animation-video-supports-drinking-water-protection-goals-in-farm-bill.aspx

Betanzo, E. A., Hagen, E. R., Wilson, J. T., Reckhow, K. H., Hayes, L., Argue, D. M., & Cangelosi, A. A. (2016). *Water data to answer urgent water policy questions: Monitoring design, available data and filling data gaps for determining whether shale gas development activities contaminate surface water or groundwater in the Susquehanna River Basin*, Northeast-Midwest Institute Report, 238 p.

Comly, H. H. (1945). Cyanosis in infants caused by nitrates in well water. *Journal of the American Medical Association*, *129*(2), 112-116.

Dakota County. 2018. *Support Funding to Reimburse the Cost of Treatment Systems for Owners of Wells with Contaminated Drinking Water*. Accessed on April 24, 2018 at https://www.co.dakota.mn.us/Government/Board/Documents/SupportFundingReimburseCostWaterTreatmentSystems.pdf

DeSimone, L. A., & Hamilton, P. A. (2009). *Quality of water from domestic wells in principal aquifers of the United States, 1991-2004* (p. 139). US Department of the Interior, US Geological Survey.

Eller, D. (2017). With Water Works' lawsuit dismissed, water quality is the legislature's problem. *Des Moines Register*. March 17. Accessed on September 21, 2017 at: http://www.desmoinesregister.com/story/money/agriculture/2017/03/17/judge-dismisses-water-works-nitrates-lawsuit/99327928/

Elmer, M. (2017). Water Works plans $15 million for expanded nitrate facility. *Des Moines Register*. May 24. Accessed on April 13, 2018 at https://www.desmoinesregister.com/story/news/2017/05/25/water-works-plans-15-million-expanded-nitrate-facility/336648001/

ESRI. 2018. ArcMap 10.6. Redlands, California: Environmental Systems Research Institute, Inc.

Fischenich, M. 2017. Nitrates rising in Mankato's drinking wells. *The Free Press*. May 28. Accessed on April 25, 2018 at http://www.mankatofreepress.com/news/nitrates-rising-in-mankato-s-drinking-wells/article_b3baed98-4253-11e7-9e89-43e32f6b8ca8.html.

Illinois Department of Agriculture/Illinois EPA. (2015*). Illinois Nutrient Loss Reduction Strategy*. Author.

IowaDOT. 2018. Price trend index for Iowa highway construction. Accessed on April 9, 2018 at https://www.iowadot.gov/contracts/lettings/PriceTrendIndex.pdf

Jany, L. 2014. High levels of nitrates turning up in Hastings drinking water. *Star Tribune*. June 3. Accessed on April 24, 2018 at http://www.startribune.com/high-levels-of-nitrates-turning-up-in-hastings-drinking-water/261711101/

Jensen, V. B., Darby, J. L., Seidel, C., and Gorman, C. 2012. *Drinking Water Treatment for Nitrate. Technical Report 6 in: Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater.* Report for the State Water Resources Control Board Report to the Legislature. University of California, Davis: Center for Watershed Sciences.

Johnston, C., and Peverly, J. (2008). *Watershed Implementation Plan for Lake Vermilion and North Fork Vermilion River*. Vermilion County, IL.

Jones, C. S., Seeman, A., Kyveryga, P. M., Schilling, K. E., Kiel, A., Chan, K. S., & Wolter, C. F. (2016). Crop rotation and Raccoon River nitrate. *Journal of Soil and Water Conservation*, 71(3), 206-219.

Keefer, L., Bauer, E., & Markus, M. (2008). *Hydrologic and Nutrient Monitoring of the Lake Decatur Watershed*. Champaign, IL: Illinois State Water Survey.

Manassaram, D. M., Backer, L. C., & Moll, D. M. (2006). A Review of Nitrates in Drinking Water: Maternal Exposure and Adverse Reproductive and Developmental Outcomes. *Environmental Health Perspectives*, *114*(3), 320-327.

Minnesota Department of Health & Minnesota Department of Agriculture. 2004. Nitrate Contamination – What is the Cost? Accessed at http://www.mda.state.mn.us/protecting/waterprotection/drinkingwater.aspx

Naidenko, O. V., Cox, C., & Bruzelius, N. (2012). *Troubled Waters*. Washington, D.C.: Environmental Working Group.

National Sustainable Agriculture Coalition. (2017). Path to the 2018 Farm Bill: Conservation. March 14. Available at: http://sustainableagriculture.net/blog/path-to-2018-farm-bill-conservation/

National Park Service. (2017). Mississippi River Facts. Mississippi National River and Recreation Area Minnesota. Accessed on September 21 at https://www.nps.gov/miss/riverfacts.htm

Oxera Consulting. 2006. Accessed on April 24, 2018 at https://www.ofwat.gov.uk/wp-content/uploads/2015/11/rpt_com_oxera080107.pdf

Pearce, F. (2018). Can the World Find Solutions to the Nitrogen Pollution Crisis? *YaleEnvironment360*. February 6. Accessed on May 16, 2018 at https://e360.yale.edu/features/can-the-world-find-solutions-to-the-nitrogen-pollution-crisis

Pennino, M. J., Compton, J. E., & Leibowitz, S. G. (2017). Trends in Drinking Water Nitrate Violations across the United States. *Environmental Science & Technology*, *51*(22), 13450-13460.

Raccoon River Watershed Water Quality Master Plan. (2011). Author.

Robertson, D. M., & Saad, D. A. (2011). Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models. *JAWRA Journal of the American Water Resources Association*, 47(5), 1011-1033.

Robertson, D. M., & Saad, D. A. (2013). SPARROW models used to understand nutrient sources in the Mississippi/Atchafalaya River Basin. *Journal of Environmental Quality*, *42*(5), 1422-1440.

Robertson, D. M., Saad, D. A., & Schwarz, G. E. (2014). Spatial variability in nutrient transport by HUC8, state, and subbasin based on Mississippi/Atchafalaya River Basin SPARROW models. *JAWRA Journal of the American Water Resources Association*, 50(4), 988-1009.

Schwarz, G.E., Hoos, A.B., Alexander, R.B., and Smith, R.A., 2006, The SPARROW Surface Water-Quality Model—Theory, Applications and User Documentation: U.S. Geological Survey, Techniques and Methods 6–B3, 248 p. and CD –ROM.

Smith, C. (2017). New Jersey-Size 'Dead Zone' Is Largest Ever in Gulf of Mexico. *National Geographic*. August 2. Accessed on May 16, 2018 at https://news.nationalgeographic.com/2017/08/gulf-mexico-hypoxia-water-quality-dead-zone/

Tang, C., Lade, G. E., Keiser, D., Kling, C., Ji, Y., & Shr, Y. H. (2018). *Economic Benefits of Nitrogen Reductions in Iowa*. Iowa State University.

The Nature Conservancy. (2012). Economic Analysis of Nitrogen Removal Using Wetlands Versus Ion Exchange. June 18. Available at: https://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_287797.pdf

USDA (2014). Fertilizer use and price: Summary of findings. U.S. Department of Agriculture, Economic Research Service. Accessed on April 16, 2018 at https://www.ers.usda.gov/data-products/fertilizer-use-and-price/summary-of-findings/

USEPA. (1987). "Integrated Risk Information System (IRIS) -- Chemical Assessment Summary (Nitrate)." U.S. Environmental Protection Agency. https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=76

USEPA. (2018). Mississippi River/Gulf of Mexico Hypoxia Task Force. U.S. Environmental Protection Agency. Accessed on March 21 at https://www.epa.gov/ms-htf

Walton, B. (2015). Des Moines water utility to file nitrate pollution lawsuit. *Circle of Blue*. March 9. Accessed on September 15, 2017 at: http://www.circleofblue.org/2015/world/des-moines-water-utility-file-nitrate-pollution-lawsuit/

Walton, B. (2017). Kansas town faces big bill to clean drinking water. *Circle of Blue*. January 9. Accessed on May 17, 2018 at: http://www.circleofblue.org/2017/water-quality/kansas-town-faces-big-bill-clean-drinking-water/

Van Grinsven, H. J., Ward, M. H., Benjamin, N., & De Kok, T. M. (2006). Does the evidence about health risks associated with nitrate ingestion warrant an increase of the nitrate standard for drinking water? *Environmental Health*, *5*(1), 26.

Weir, L., & Roberson, J. A. (2011). National compliance costs from a potential revision to the nitrate regulation. *American Water Works Association. Journal*, *103*(3), 44.

World Resources Institute. (2018). What drives the increasing eutrophication trends? Accessed on May 17 at http://www.wri.org/our-work/project/eutrophication-and-hypoxia/what-drives-increasing-eutrophication-trends

Appendix

Table S1: Capital cost of the nitrate treatment units in eight locations in the Mississippi River Basin.

Utility	Year of construction	Inflation-adjusted capital cost ($ million)	Capacity (MGD)	Amortized annual capital cost ($)	Average annual O&M cost ($)	Average annual cost per unit volume ($/kgal)		
						Capital	O&M	Total
Adrian, MN	1998	1.33	0.14	30,355		0.61		
Amherst, WI	2011	1.68	1.08	75,889		0.19		
Clear Lake, MN	1995	0.93	0.04	20,237		1.30		
Edgerton, MN	2003	0.78	0.12	20,237		0.45		
Ellsworth, MN	1994	0.94	0.05	20,237		1.19		
Epworth, IA	2011	0.67	0.9	30,355		0.09		
Manchester, IA	2011	5.28	0.92	237,785		0.71		
Streator, IL	2002	3.07	1.6	80,948		0.14		