

Economic Benefits of Nitrogen Reductions in Iowa

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Extended Abstract

Iowa agriculture provides tremendous benefits to the state, national, and global economy. The intense nature of the state's agricultural activities is not without cost. Agricultural industry is a large contributor to water quality problems both within the state as well as in downstream rivers, streams, and the Gulf of Mexico. First released in November 2012, the Iowa Nutrient Reduction Strategy (NRS) lays out a technology-driven framework for reducing nutrient delivery to waterways in Iowa and, ultimately, the Gulf of Mexico. These efforts are part of a broader strategy that includes 11 other states to reduce the size, severity, and duration of hypoxia in the Gulf of Mexico.

While the Gulf Hypoxic Zone has received a lot of attention, meeting the NRS targets would also have large local benefits. Many water utilities and homes with private wells must treat their water due to high nitrate levels. In a recent court case, Des Moines Water Works (DMWW) unsuccessfully sued three Northwest Iowa drainage districts to compensate for its nitrate removal costs. According to DMWW, the utility spent over \$500,000 to remove nitrates in 2016 and plans to expand its nitrate removal capabilities in coming years at an estimated cost of \$15 million. Beyond the state capitol, water utilities across the state dedicate substantive resources to remove nitrates. Ensuring nitrates in drinking water remain low is imperative—high nitrate levels in drinking water are associated with adverse human health outcomes for susceptible populations. Beyond drinking water, nitrate pollution also contributes to the poor water quality of Iowa's rivers and lakes, diminishing the recreational value of these resources.

This report explores important costs of high nitrates to Iowans and summarizes benefits to the state of meeting its NRS targets.¹ In **Section 1**, we discuss important factors that determine nitrate levels in the state's streams, rivers, and lakes.² We also provide background on drinking water sources in the state and existing nitrate regulations in the United States.

Section 2 explores nitrate removal costs to public water supply (PWS) systems and private well owners. We first summarize nitrate removal technologies, and their associated operating costs, that are available to PWS systems. Because many Iowans living in rural areas rely on private wells for their home's drinking water, we also explore trends in nitrate levels in private wells and discuss treatment and avoidance costs to these households. We then provide three case studies of how towns in Iowa manage nitrates in their drinking water. We find that Iowa's PWSs have invested at least \$1.8 million in nitrate treatment equipment since 2000, that many small PWSs cannot afford to meet EPA safe drinking water standards for nitrates, and that many Iowans that rely on private wells are potentially exposed to unsafe nitrate concentrations in their drinking water.

Section 3 summarizes another cost of nitrates in the state—lost recreation benefits. We discuss the impacts of agricultural runoffs (mainly nitrogen and phosphorous) on Iowa's lakes. We focus on the contribution of these pollutants to the development of harmful algal blooms (HABs), a noxious form of algae that is harmful to human health. We document an increase in the prevalence of beach advisories and closures in the state from HABs. We then value some of the recreational benefits of meeting Iowa's NRS targets. Improving the quality of Iowa's lakes by meeting the NRS targets would increase recreational benefits to all Iowans by approximately \$30 million per year.

In **Section 4**, we discuss the current state of knowledge on adverse human health impacts from exposure to high nitrates in water. A substantial epidemiologic and public health literature documents associations between nitrate exposure and blue baby syndrome in infants. Other work suggests that long-term exposure to nitrates, even at low levels, may also be associated with other adverse health impacts. We conclude the section by discussing the need for more data and research exploring the causal relationships between nitrate exposure and human health.

Summary of Findings:

Economic Costs of Nitrates in Drinking Water

- Forty-nine public water suppliers serving over 10% of the state's citizens treat water for nitrates either by blending or using nitrate removal equipment.
- Health-based nitrate drinking water violations are concentrated among small public water supply systems and have decreased in recent years after a surge in violations from 1995 to 2010.
- Investing in nitrate removal equipment increases public water supply systems' costs of serving their customers. These costs can be especially high for small systems. We highlight five utilities that invested over \$1.65 million in nitrate removal equipment through the State Revolving Fund since 2000.
- Data from various sources suggest that as few as 7% and as many as 25% of Iowa's private wells may contain unhealthy nitrate levels.

Recreational Benefits of Reducing Nutrient Pollution

- Meeting the Iowa Nutrient Reduction Strategy targets for nitrates and phosphorous will increase recreation benefits from Iowa's lakes by about \$30 million per year.
- Harmful Algal Blooms due to excess nutrient pollution have become more problematic in recent years, further diminishing recreation values, and potentially threatening recreational users' health.

Health Effects of Nitrates in Drinking Water

- Infant exposure to excess nitrate levels in drinking water is widely believed to be a causal factor in babies developing 'blue baby syndrome,' a potentially deadly disease.
- Longer-term exposure to nitrates in drinking water has been associated with elevated risks of other chronic and short-term health effects, though more research is needed to understand these impacts and their costs better.

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1. Introduction

Nitrogen and phosphorus are essential nutrients for plant growth. Farmers around the world supplement naturally occurring nutrients in their soils with both chemical and animal fertilizer. In addition to technological advancements in plant genetics and crop production technologies, such as advanced methods to mitigate weeds and insects, much of the steady advances in historical yields in the United States and abroad are attributable to the increased use of fertilizers. Phosphorous and nitrogen enhance energy transfer, photosynthesis, and hasten plant maturity, but can cause water pollution when levels exceed plant uptake.

Iowa is a global leader in agricultural production, an achievement only possible because it is among the world's most highly altered and intensively managed ecosystems. Converting historic prairie and wetland to cropland in Iowa has dramatically increased nutrient impairment problems in the state's waterways. Much of Iowa's farmland is tile drained. Sub-surface drainage systems throughout the state remove excess water from land, lower water tables, and expose nutrient-rich soil. In addition to water, tile drains transport nitrogen (as nitrate) and dissolved phosphorous directly to the state's ditches, streams, and, eventually, large rivers and lakes. Surface runoff from fields also carries nutrient-rich sediment into waterways, particularly in springtime when vegetative cover and evapotranspiration are low, and fields have little vegetation. Nutrients also leach through permeable soil and rocks into the state's vast groundwater reserves.

The dominance of annual crops, loss of wetlands, lack of in-field conservation practices, and excess nutrient applications exacerbate these problems. Excess nutrients have undesirable impacts on both community water supplies and local ecosystems. The Environmental Protection Agency (EPA) sets strict limits on nitrates in drinking water because infants and other vulnerable populations experience adverse health impacts from drinking water with elevated nitrate levels. Both nitrogen and phosphorous also overstimulate algal growth in water. Algae blooms can deplete oxygen and harm aquatic life in Iowa lakes. Moreover, some algal overgrowths produce toxins that are harmful to humans and animals. Water system operators in high-nutrient prone regions of the state must, therefore, be vigilant in ensuring nitrate and other toxins remain below acceptable levels. Private households with private wells must also treat their water, as those that are unaware of nitrate levels in their wells may be unknowingly exposed to harmful levels.

This report studies costs of excess nitrates in Iowa's waterways, and quantifies benefits to meeting the state's Nutrient Reduction Strategy (NRS) targets. We focus on costs to both public water supply systems and private well owners due to excess nitrates in drinking water sources, recreation losses due to excess nutrients in Iowa's lakes, and potential health impacts of exposure to water containing nitrates. While phosphorus is a significant contributor to nutrient pollution in Iowa, phosphorous levels in drinking water are not a primary concern by regulators in the United States. However, phosphorus' contributions to toxic algal blooms in drinking water sources is an emerging issue, and phosphorus and sediment are significant contributors to pollution of Iowa lakes used for recreational purposes.

We begin this section with a summary of the determinants of nitrates in Iowa's surface and ground waters. We then discuss the source of Iowans' drinking water, basics of nitrate removal technologies, and relevant drinking water regulations. Last, we provide a background on Iowa's lakes and rivers, and their importance as a source of recreation for all citizens in the state.

1.1.Determinants of Nitrates in Surface and Ground Water

Nitrates are present in all of the world's fresh waterbodies, but humans contribute in many ways to nitrates in water. Wastewater treatment plants, city sewage systems, and industrial facilities discharge nitrate-rich by-products directly into rivers. Homeowners that apply lawn fertilizers or have leaky septic systems also contribute nitrates to both surface and groundwater. Nitrate levels are especially high in the intensive agricultural producing regions, mostly as a result of nitrogen fertilizer and manure applications for plant growth. Nitrogen flows as nitrates into surface water, leaches into groundwater from fields, and also comes from manure from livestock operations. This form of agricultural pollution is particularly acute in Iowa, where farmland accounts for over 90% of land use and producers lead the nation in row crop and livestock production.

Nitrate pollution from agriculture in any year depends on several factors, including the condition of the farm economy, weather, geology of the land, and land use. Fertilizer use for crop production varies depending on the type of crop planted (corn or soybeans), crop rotation, crop and input prices, and farmland characteristics such as slope, subsurface rock types, and soil nutrient levels. Farmers that follow a corn-soybean rotation typically use less fertilizer and pesticides relative to those that plant continuous corn.³ Since 2005, continuous corn rotations have become more common in the state as demand for corn as an input for ethanol production has increased exponentially with U.S. renewable fuel mandates.⁴ Fertilizer applications also vary with crop and fertilizer prices.⁵ Nutrient pollution from animal agriculture depends largely on the size of Iowa's livestock industry, which is driven by worldwide supply and demand. As Iowa continues to increase its reputation as a major supplier of quality meat worldwide, the intensity and size of its livestock industry will grow. At the same time, the land over which manure from these operations can be distributed remains fixed, increasing the importance of proper manure management practices.⁶ Beyond crop practices and manure management, nitrogen in water is also affected by soil texture, the underlying geology of land, temperature, and excessive precipitation.⁷

Nitrate contamination in surface water occurs through a relatively straightforward process—water runs off fields and other surfaces into drainage systems and ditches that eventually reach the state's many streams and rivers. In some regions of the state, groundwater also discharges into surface water.⁸

Nitrate movements into groundwater depend on local factors. Nitrogen moves as nitrate in water through soils and subsurface rock layers, eventually reaching the underlying water table. The amount and depth of water movements below plant roots depend on the porosity of the surface—a measure of the openings in the earth's materials. Much of water eventually reaches an aquifer—a geological formation, typically made of rock that contains and conducts groundwater. Five principal aquifers supply groundwater for public and private water sources in Iowa. Four are bedrock aquifers that consist of sedimentary rock layers such as limestone, shale, sandstone, and carbonate rock. The state also has many alluvial aquifers—aquifers that typically lie within shallow sand and gravel deposits along Iowa's large rivers.

Nitrate concentrations in the groundwater depend on the aquifers' depth, the porosity of rock above it, and the speed that water discharges from the aquifer. Iowa's aquifers vary in all of these dimensions. As a result, nitrate contamination in the state can vary even if the landscape looks the same from the surface. Current nitrate concentrations also depend not only on the amount of nitrogen pollution from the current year but also from all previous years. In some aquifers, if all nitrate pollution from human sources halted, it could still take many decades for the nitrate levels in an aquifer to return to its natural level due to slow recharge and discharge.⁹

1.2. Drinking Water Sources and Nitrate Regulation

Iowa households receive their drinking water from one of two sources: a public water supply system (PWS) or a private source such as a well. PWSs are defined as any water provider with at least 15 service connections or systems that provide regular service for at least 25 individuals.¹⁰ Over 2.8 million Iowans (90%) receive water from 1,874 PWS systems, while private water systems serve the remaining 230,000 Iowans. In 2016, nearly all PWS systems, 92%, relied on groundwater supplies, while the remaining systems relied on surface water or groundwater that is heavily influenced by surface water. While the vast majority of PWSs draw water from groundwater sources, many of the largest PWSs in the state use surface water. From a population perspective, around 55% of Iowans get water from PWSs that rely on groundwater while PWSs that rely on surface water serve the other 45%.

PWS systems are regulated by state and federal authorities who set and enforce drinking water standards. The principal law that guides these standards is the Safe Drinking Water Act (SDWA).¹¹ The law requires the EPA to set standards for a variety of water contaminants that all PWSs must meet. While the EPA sets national standards, state agencies typically oversee monitoring and enforcement. In Iowa, enforcement is handled by the Iowa Department of Natural Resources (IDNR). Many standards, including those for nitrate and nitrite, are set as maximum contaminant levels (MCLs)—the maximum limits on the concentration of contaminants in drinking water. If water tests below the MCL for all contaminants, it is determined to be safe for human consumption. The MCL for nitrate is 10 milligrams of nitrate per liter of water (mg/L).

The IDNR enforces the MCL standards for nitrates and other water contaminants by requiring every PWS to report contaminant concentrations of treated water periodically (e.g., every month, quarter, or year). The reporting frequency depends on whether a PWS has had previous violations as well as whether the system draws untreated water from a source known to contain higher nitrate or other contaminant concentrations. If a PWS reports contaminant levels above the MCL, the supplier receives a violation, and the IDNR will take enforcement actions to ensure that the PWS returns to compliance. This typically involves the PWS notifying its customers of the violation, testing their treated water more frequently, and if the problem is systemic, requires the PWS to take proper action to resolve the issue.

Iowa's PWSs consistently provide safe and reliable drinking water. Of the roughly 1,850 regulated PWS systems in Iowa, all but 84 had no health-based drinking water standard violations in 2015 and 2016. As previously discussed, PWS systems must meet several drinking water standards. Since 2007, the percent of PWSs in compliance with all drinking water standards has always exceeded 90%, and the number of health-based standards violations have declined steadily over this period. While there has been a steady reduction in violations for many MCL standards, the number of nitrate violations has remained mostly at the same level since 2010. In 2016, 11 PWSs violated nitrate MCL standards on 17 occasions.¹² These statistics do not include several utilities that failed to monitor nitrates. While compliance levels exceed 90%, nearly 20% of PWSs did not adequately monitor and report contaminant concentrations in 2016. As we discuss in greater detail in Section 2, the low number of nitrate violations also does not indicate that nitrates are not a problem for PWS systems—many of these systems have dedicated a large amount of resources to ensure their drinking water does not violate the MCL levels set by the EPA.

Unlike PWS systems, the roughly 230,000 Iowans that rely on private water supplies are not required to monitor the quality of their drinking water. Private wells fall outside the scope of the SDWA, so landowners with private wells are often on their own in ensuring that contaminants in their well drinking water are at safe levels. Some programs are available through the state government to test water quality. For example, the Iowa Department of Public Health (IDPH) offers free water quality tests for all of Iowa's private well owners through the Grants to County (G2C) program.¹³ Well owners can send water samples

to a certified laboratory that will test their water for the same contaminants that PWSs are required to monitor. Participation in the G2C program varies from county to county. While many counties use all available funds, other county programs are under-subscribed. Importantly, a large number of private wells in Iowa go either unmonitored or are infrequently monitored. This is problematic since many contaminants are undetectable to humans—even if water is colorless, odorless, and tasteless, it may still contain elevated nitrate levels or other pollutants that may adversely impact human health.

1.3.Treating Nitrates in Drinking Water

Treating elevated nitrate levels in water involves either blending water or removing and disposing of nitrates in water. For PWSs with access to multiple wells or untreated water sources, the easiest method to meet SDWA requirements are to either switch from a source with elevated levels to one with little or no nitrates, or to blend water from both sources so that the finished water contains nitrates below the MCL.

Many PWSs do not have a secondary water supply source to blend water to meet the MCL standards. In these cases, the suppliers must often invest in costly nitrate removal technologies. The EPA lists three approved removal technologies that PWSs can use to treat their water: (a) ion exchange (IX) systems; (b) reverse osmosis (RO) systems; and, (c) electrodialysis reversal (EDR) systems. While we provide greater detail on the first two of these technologies in Section 2, the selection of the ‘right’ system for any PWS depends on several factors including the number of homes it serves, the level of nitrates and other contaminants in its source water, and its disposal options. All of these technologies are costly. As we highlight in Section 2, their costs are especially high for small communities, leaving them with few options to decrease citizens’ nitrate exposure. One other common feature of these technologies is that none destroy or transform nitrates in the water. All remove nitrates from the water, and the PWSs must then dispose of them, typically by reintroducing them back into downstream waterways.

Of Iowa’s 1,850 PWSs, 12 blend water due to high nitrate levels, 32 use an IX system, and 9 use an RO system. In Section 2, we present case studies on three separate PWSs in Iowa that deal with elevated nitrate levels on a regular basis. We use these case studies as a platform to better understand the costs of elevated nitrate levels in the state. Importantly, while upstream industrial and agricultural sectors generate nitrates, we document how the costs of excess nitrates are borne by local consumers in Iowa through increased water utility expenditures.

Private well owners rarely have access to multiple water sources, and therefore are unable to blend water with elevated nitrate levels. Thus, owners with high nitrates in their wells must install nitrate removal systems. There are two types of nitrate removal devices available to homeowners: (a) point of entry (POE) devices; and, (b) point of use (POU) devices. POE devices treat all well water before it enters the home. In contrast, POU devices are typically smaller and need to be installed on every tap or water outlet that the home uses for drinking water. Both systems are costly and require regular maintenance and upkeep. As we document in Section 2, many Iowans draw water from areas in the state with elevated nitrate levels. However, little is known currently about the prevalence of POE or POU systems in the state.

1.4.Impacts on Iowa’s Rivers and Lakes

In addition to impacting drinking water supplies, nitrogen pollution contributes to the impairment of Iowa’s many lakes and river systems. According to a recent survey conducted by the Center for Agricultural and Rural Development (CARD) at Iowa State University, nearly 60% of survey respondents from a state-

wide survey reported traveling to at least one of Iowa's many lakes in 2014. Thousands of Iowan's enjoy canoeing, kayaking, and fishing along the more than 18,000 miles of navigable rivers and streams throughout the state.¹⁴ Nutrient pollution diminishes water quality in these lakes and streams, decreasing the recreation value of any Iowan visiting these sites. Worsening lake quality has also led to increases in beach advisories at state parks warning people to avoid the water.

Nitrogen, along with phosphorous, contributes to algae growth in lakes and streams. Large algae growths are unsightly, and have been shown to diminish recreational users' enjoyment, harm aquatic life, and decrease local housing values.¹⁵ While unsightly and at times foul-smelling, many algal growths are harmless to humans. They can, however, have detrimental impacts on aquatic life. Dense algal growths can deplete oxygen in water and eventually form hypoxic conditions, or dead zones. One of the largest and best known dead zones arises in the Gulf of Mexico, the area of which exceeded the size of New Jersey in 2017.

A particularly noxious type of algal growth, known as harmful algal blooms (HABs), produce toxins that are harmful to both humans, other mammals, and aquatic life. Among the most common toxins produced by HABs are microcystins that, if consumed, can cause liver and tissue damage. While HABs are an increasing problem for all U.S. states, they have become more common in Iowa in recent years. In the summer of 2016, Iowa DNR issued a record-breaking 37 beach advisories in state parks due to the presence of microcystin generating HABs. In the same summer, DMWW detected microcystins in the Raccoon River, one of its primary water supply sources.¹⁶ The increasing prevalence and intensity of HABs threaten the health of both recreational users in the state and, potentially, public water supply systems.

2. Economic Costs of Nitrates in Drinking Water

This section explores the presence of nitrates in drinking water in Iowa and discusses the costs to public water suppliers and homeowners of removing nitrates. We first compile the most comprehensive data to date on the presence of nitrates in Iowa's drinking water supplies. Using these data, we discuss trends in nitrate concentrations in both PWSs and private wells. Next, we summarize the characteristics and costs of several nitrate treatment options for both PWSs and private well owners. We discuss both technologies that actively remove nitrates from drinking water as well as other options available to PWSs and homeowners when these technologies are too costly.

We then discuss a prominent source of public funds for water treatment systems in the state. We present several recent examples of Iowa PWSs taking advantage of low-interest loans to address problems of excess nitrates in source water. These data provide valuable insights into the costs of nitrate removal equipment to PWSs. We conclude with case studies of three Iowa towns with high nitrate concentrations in their source water and discuss how each town has been able to address the issue.

2.1. Trends in Nitrate Concentrations

Many factors contribute to nitrates in drinking water. PWSs that rely on surface water can face circumstances in which nitrate concentrations can vary in near real time. In contrast, fluctuation in nitrates in groundwater depends on the aquifer depth, how quickly water flows into and out of the aquifer, and many other local factors. As such, PWSs that rely on groundwater and private well owners may face systemic high or low nitrate levels. Here, we compile the most comprehensive available data to date to study how nitrates concentrations and SDWA violations have evolved over the last two decades in Iowa.

2.1.1. Public Water Supply Systems (PWSs)

Background. A public water supply system is defined under the SDWA as one that serves at least 25 individuals daily for at least 60 days a year or has at least 15 service connections. The EPA further places PWSs into three categories based on how frequently the system operates. Community water systems (CWSs) include cities, municipalities, and towns that provide water to residents year round. Non-transient non-community systems or transient non-community systems provide water to customers on a less permanent basis, including to schools, hotels, and restaurants with independent water supply systems,

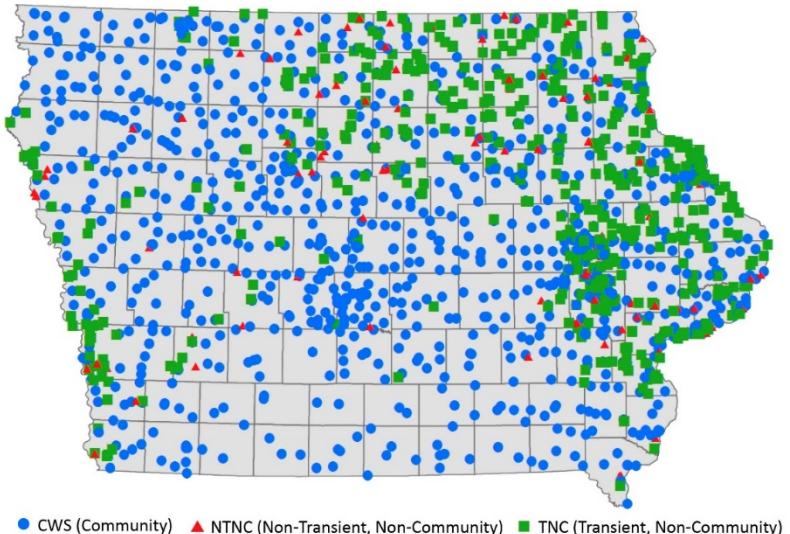


Figure 2.1: 2016 Public Water Supply Systems

Source: 2016 PWS Annual Compliance Report

and highway rest areas, bars, and golf courses. In 2016, of the 1,847 PWSs in Iowa, 1,094 were CWS, while the remaining were transient systems. Figure 2.1 graphs the location of Iowa's PWSs in 2016.

Every PWS in Iowa is required to periodically send treated water samples to certified state laboratories for nitrate testing. The state issues the PWS a violation if any sample has a nitrate concentration higher than the EPA-allowed MCL. The SDWA includes two relevant notification requirements when violations occur: the Public Notification Rule (PNR) and Consumer Confidence Reports (CCR). The PNR requires PWSs to alert consumers if: (a) there is risk to public health; (b) drinking water does not meet drinking water standards; (c) the water system fails to test its water; (d) the system has been granted a variance (allowance to use a less costly treatment technology due to a violation); or, (e) the system has been granted an exemption (more time to comply with a new regulation). The frequency of notice depends on the type of violation. Tier 1 violations involve acute risk to human health, and utilities must notify all affected customers within 24 hours. Tier 2 violations are health violations that do not pose any immediate health risks and must be reported within 30 days of the violation. Tier 3 violations are less dire SDWA violations and require an annual notice. In contrast, CCRs are yearly reports that every PWS must send to all customers. They contain basic information about the PWS water supply, violation records, and water quality summaries.

Historical Nitrate Violations. Figure 2.2(a) graphs MCL violations for all Iowa PWSs from 1980 to 2017.¹⁷ We separate violations by the three types of PWSs. A few features of the data are immediately apparent. First, in most years, violations are most common for CWSs that serve Iowans' year round. Second, the violation history can be divided into three periods: (a) 1980 to 1994—violations rarely exceeded 30 per year,¹⁸ and the majority of violations were for CWS systems; (b) 1995 to 2010—the state regularly had years with greater than 50 nitrate violations, and the state had more than 100 nitrate violations in 2003; and, (c) 2011 to present—nitrate violations have receded since 2011, and once again there are typically less than 30 violations in any given year. However, transient non-community systems share a higher proportion of reported violations compared to the early period.

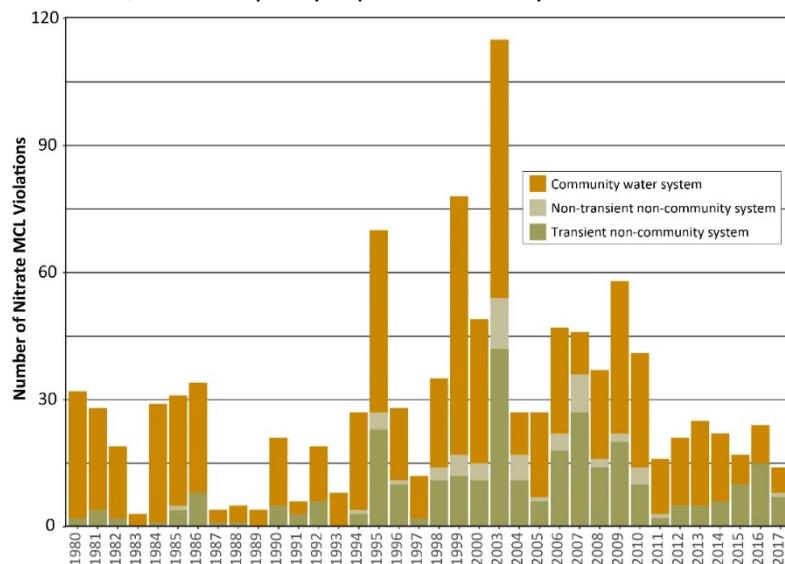


Figure 2.2(a): Nitrate Violations by System Type

Source: SDWIS Federal Reporting Services

Figure 2.2(b) presents the same data, but by PWS service population size: (a) very small (25–500); (b) small (501–3,300); (c) medium (3,301–10,000); (d) large (10,001–100,000); and, (e) very large (over 100,000). Most PWSs in Iowa are small—1,285 systems, 70% of PWSs in Iowa—serve less than 500 people. Many of these small PWSs are in rural areas and rely on shallow wells that are especially susceptible to nitrate pollution. This is evident in Figure 2.2(b)—the vast majority of violations in all periods are for small systems. As we will highlight in our case studies at the end of this section, small PWSs often lack the budget to invest in nitrate treatment technologies. As such, nitrates often remain a systemic problem for these utilities.

2.1.2. Private Wells

Background. The SDWA does not regulate drinking water from private wells. In Iowa, around 230,000 people, 7.6% of the population, rely on private well water. While the state offers water quality testing services for all homes with a private well, well owners are ultimately responsible for the safety of their water.

Early well water quality studies.

Iowa's DNR has monitored groundwater quality in the state since the early 1980s. Starting in 1982, the DNR, Iowa Geological Survey, the University of Iowa Hygienic Laboratory, and the U.S. Geological Survey (USGS) cooperatively launched the Iowa groundwater quality monitoring program (GWQM) to evaluate and assess the water quality of Iowa's major aquifers. The program monitors several groundwater contaminants including ammonia-nitrogen, arsenic, herbicides, and others. The latest program report in 2004 indicates that 31 of 469 samples (around 7%) collected throughout the state contained nitrate concentrations higher than the SDWA MCL for nitrate.¹⁹ However, these data are over a decade old and are likely not a representative sample because the survey targets areas that are susceptible to nitrate pollution.

Part of the GWQM effort was to develop groundwater vulnerability risk indicators for several contaminants.²⁰ In general, four types of aquifers and areas are susceptible to nitrate contaminants: (a) alluvial aquifers; (b) karst areas (terrain with many sinkholes or springs); (c) shallow bedrock aquifers; and, (d) shallow drift aquifers (aquifers less than 50 feet below permeable beds). All four are common in Iowa. Alluvial aquifers are found throughout all of the state's river valleys. Karst areas are found mostly in northeast Iowa. Shallow bedrock aquifers and drift aquifers are common in the eastern half of the state.²¹

Another source of groundwater quality monitoring data is the Statewide Rural Well Water Survey (SWRL). The program was established by the Groundwater Protection Act of 1987, a landmark policy aimed at addressing nitrate pollution problems in the state. The program sampled 686 wells in 1988 and 1989, covering all 99 counties. The survey found that 18.3% of tested private wells contained elevated nitrate concentrations, and around one-third of private wells in northwest, southwest, and southeast Iowa exceeded the nitrate drinking water standard.²² While dated, the survey provides evidence that nitrate problems in private wells in the state may be a systemic issue.

More recent water quality studies. Another rural water quality program, the Iowa Community Private Well Study (ICPWS), was conducted during the summer and fall of 2003 by the University of Iowa, Iowa DNR, and USGS.²³ The study included two samples. The first included tests from 103 private wells from 50 incorporated communities without public water supplies, mostly in the eastern portion of the state. Nitrate was detected in 57% of wells, and nitrates exceeded the MCL limits in nearly one-quarter of the

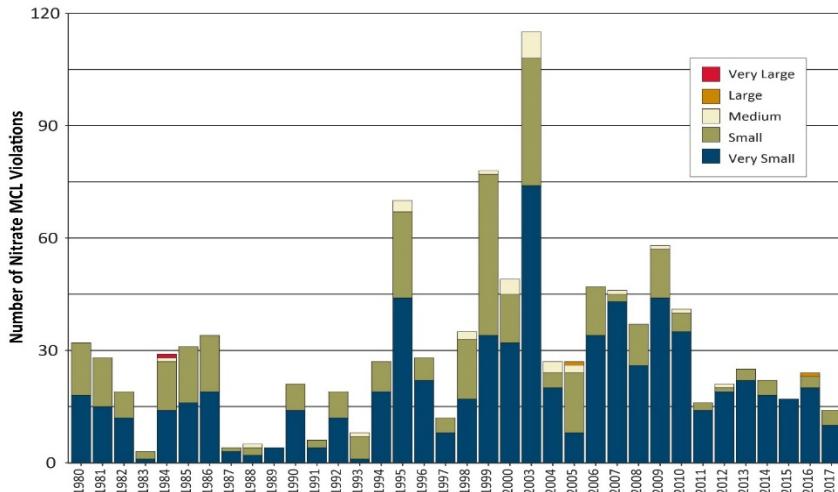


Figure 2.2(b): Nitrate Violations by System Size

Source: SDWIS Federal Reporting Services

wells. The second sample included 133 private wells from 15 incorporated communities, also without public water supplies. The communities in the second sample were selected based on the presence of potential contaminant sources including private septic systems, underground storage tanks, and landfills. Similarly, nitrate was detected in 55% of the sampled wells, with over 20% exceeding the EPA MCL standard. Compared with SWRL, ICPWS wells had a higher detection frequency of nitrate than SWRL wells.

The second phase of the Statewide Rural Well Water survey (SWRL2) was conducted from 2006 to 2008. In total, 473 private wells were sampled in 89 Iowa counties, including 116 wells from the original study. Overall, fewer wells had elevated nitrate concentration in Phase 2—only 12% exceeded the nitrate MCL standard, and average nitrate concentrations in the samples decreased. The findings suggest progress may have occurred over the preceding two decades; however, many samples contained nitrate levels far above MCL standards. It is also difficult to determine whether the improvements are due to differences in sampling, improved water quality, or improved well construction.

The Private Well Tracking System and Grants-to-Counties Program.

While informative, the previous studies suffer from small samples and lack of consistent sampling. The infrequent sampling also makes it difficult to determine whether rural residents' well water quality has improved or worsened over time. To try to address this question, we compiled data from the Iowa DNR and Department of Public Health (DPH). Water quality tests are required when new wells are constructed, or old wells are plugged. The state also allocates funding to counties to pay for regular well water quality testing. Financing for the tests, around \$300,000 each year, is administered through the state's G2C water well program.²⁴ The Iowa DNR compiles data from these tests in its Private Well Tracking System (PWTS). The PWTS database includes nitrate samples from more than 113,000

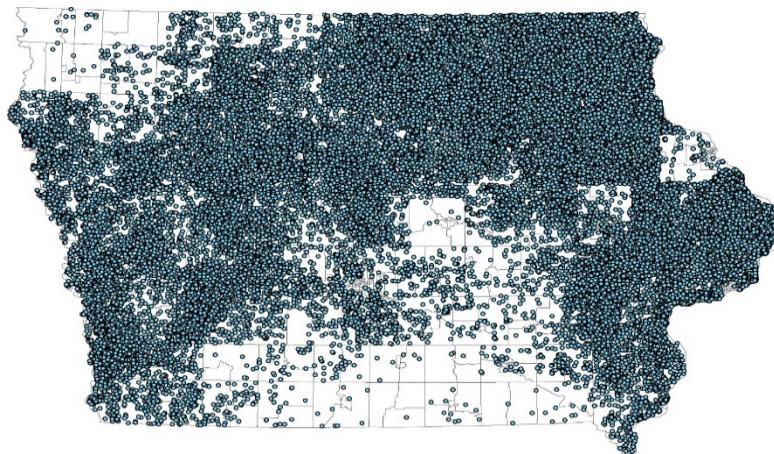


Figure 2.3(a): Private Wells with Nitrate Tests (2002-2017)

Source: Iowa DNR Private Well Tracking System

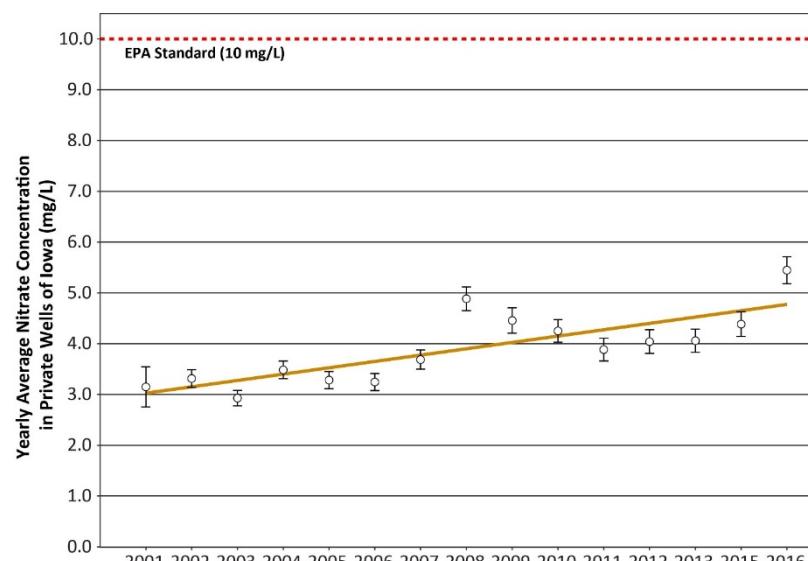


Figure 2.3(b): Box Plot of Yearly Nitrate Concentrations

Source: Iowa DNR Private Well Tracking System

tests from over 58,000 residential wells collected between 1989 and 2017. These data have been collected systematically since 2002; as such, we focus this report on data from these more recent tests.

Figure 2.3(a) graphs the location of wells in our sample from 2002 to 2017 in the PWTS database. Northwestern and southern Iowa have fewer test records than other parts of the state. In most cases, this is because many rural homes in those regions have access to water from PWSs, due to the unavailability of reliable aquifers. Figure 2.3(b) graphs the average yearly nitrate concentrations from all sampled wells.²⁵ There are two notable features of the data. First, on average, private wells in our sample contain nitrate levels far below the EPA MCL requirements. Second, average concentrations have been steadily increasing in the sample since 2001—in 2001 average nitrate concentrations were just over 3 mg/liter, but rose to 4 to 5 mg/liter in 2016 and 2017.

While average concentrations are below MCL standards for safe drinking water, many wells in our data contain nitrate concentrations above those levels deemed as safe under the SDWA. Figure 2.3(c) graphs the proportion of samples with concentrations exceeding the nitrate MCL. As with average concentrations, the number of nitrate readings exceeding the EPA's MCL from 2001 to 2016 has risen. From 2001 to 2007, 9% to 12% of sampled wells contained excess nitrate concentrations. In 2015 and 2016, the proportion increased to 13% and 18%, respectively.

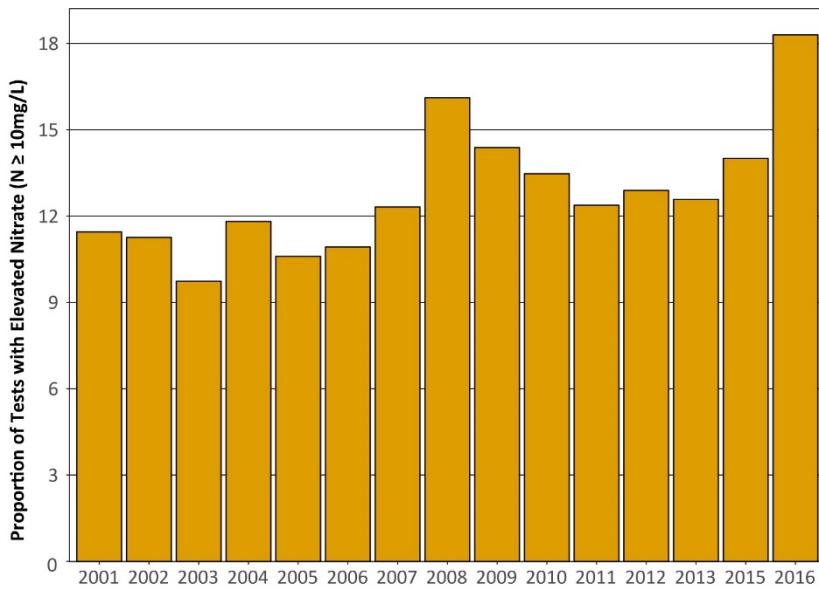


Figure 2.3(c): Proportion of Wells with Nitrate Concentrations Exceeding MCL

Source: Iowa DNR Private Well Tracking System

Depth is an important determinant of a well's vulnerability to nitrate pollution. Deep wells normally draw groundwater from an aquifer covered by a less permeable rock layer, providing a natural barrier to nitrate leaching from the surface into the aquifer. In contrast, shallow wells lack this natural advantage. Figure 2.4 highlights this problem. In the top-left panel, we graph nitrate concentrations for all tests in 2016. The graph highlights key 'hot spots'—areas of the state with systematically high nitrate concentrations in well water. Concentrations are highest in the western half and northeast portions of the state, though high concentrations arise in almost all areas.

In the three additional figures, we divide the test results into three categories based on well depth: (a) high vulnerability (less than 50 feet deep); (b) intermediate vulnerability (50–150 feet deep); and, (c) low vulnerability (greater than 150 feet deep). While all three samples have wells that exceed the nitrate MCL limits, highly vulnerable wells are much more likely to contain high nitrate concentrations. Using all data from 1989 to 2017, 25% of highly vulnerable wells have nitrate levels exceeding the MCL, compared to 12% and less

than 7% for the intermediate and low vulnerability groups, respectively. Most wells in the low vulnerability group that have high concentrations are located in northeast Iowa, which has a karst topography that allows nitrates to penetrate further into the earth. When we remove those samples from the data, a very low proportion of low vulnerability wells have nitrates exceeding the MCL standards.

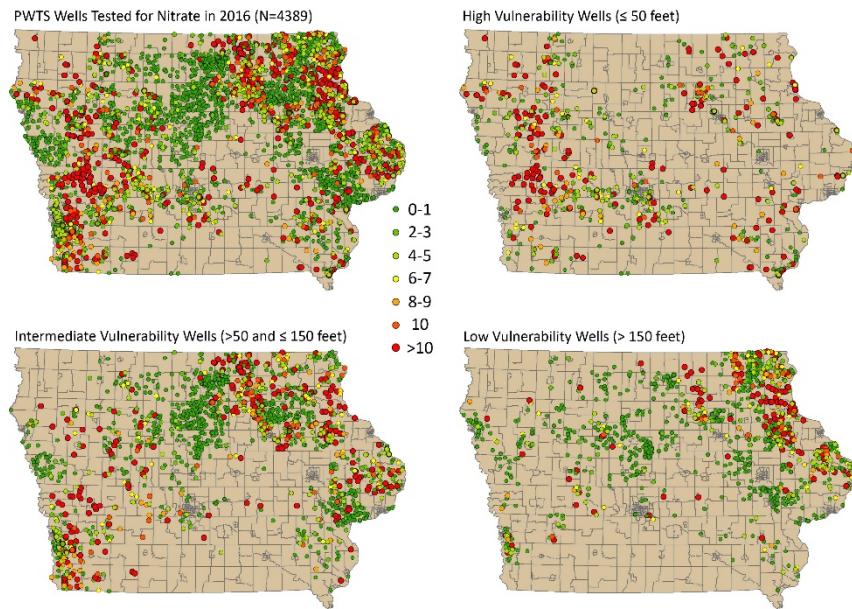


Figure 2.4: 2016 Nitrate Test Results by Well Depth

Source: Iowa DNR Private Well Tracking System

2.2. Nitrate Removal Technologies and Costs

2.2.1 Public Water Supply System Treatment Options

Background. Public water suppliers have several options to treat water with excess nitrate concentrations. However, treating nitrates can be costly. As a result, many PWSs do not invest in treatment systems unless they have systemic problems with their drinking water supply source. One common choice is to blend water from multiple sources. If a PWS draws water from multiple sources, it may mix high- and low-nitrate water. Alternatively, it may stop using certain water sources. If water quality conditions worsen over time, this strategy may require PWSs to construct new wells or seek to protect wellhead areas to prevent surface nitrogen from leaching into drinking water.

Alternatively, PWSs may invest in nitrate removal systems. The EPA has identified two acceptable nitrate treatment methods used by Iowa PWSs: (a) ion exchange (IX) systems; and, (b) reverse osmosis (RO) systems. Both technologies separate, concentrate, and remove nitrates in drinking water. PWSs that use these technologies must determine how to dispose of concentrated nitrates removed from their water, and many resort to releasing the nitrates back into surface water.²⁶

A last option for PWSs with excess nitrate problems is to treat water in customers' homes or provide alternative drinking water for customers such as bottled water or trucking potable water from other PWSs. Home treatment systems include point-of-entry (POE) and point-of-use (POU) equipment. POE systems treat water before it enters a home or building, while POU s are installed at a single tap or outlet and supposed to treat water coming from that outlet only. Most POE and POU systems use IX and RO technologies.²⁷

In 2016, 49 of Iowa's 1,847 PWSs serving over 310,000 Iowans reported either blending water or using a nitrate treatment system. Twelve reported blending water from multiple sources, 32 used an IX system, and nine used an RO system (some utilities use multiple strategies). Below, we briefly describe how IX and RO technologies work and their costs. Much of the cost data are from a 2010 study conducted by researchers at the University of California, Davis.²⁸

Costs and comparisons of nitrate treatment technologies. Ion exchange systems are the most commonly used nitrate removal systems in Iowa. IX systems are usually cheaper than other treatment alternatives and have the additional benefit of removing other water contaminants such as arsenic, perchlorate, selenium, chromium, and uranium. Put simply, an IX system works by passing water through a unit containing sodium chloride. Contaminants such as nitrates in the water are exchanged with chloride ions and “fixed” onto the unit, reducing contaminant levels in water leaving the unit. A key determinant of the IX system cost and efficiency is source water quality. Source water containing more nitrates requires operators to replace or regenerate chloride ions more often, an added expense. Regeneration requires “backwashing” the system using a highly concentrated brine solution. During the process, nitrates captured by the unit are removed in a backwashed brine, and the resulting stream must be properly disposed. The cost of handling the backwashed brine can be high. Furthermore, IX systems can increase chloride in treated water, increasing the water corrosiveness and creating an unpleasant taste.

RO systems remove even more contaminants than IX systems, including nitrates, arsenic, lead, fluoride, radium, uranium, copper, microbes, and more. However, the system has higher capital and operations, and management (O&M) costs. RO systems work by passing water through fine membranes, capturing contaminants such as nitrate ions, and passing cleaner water through the membrane. Similar to IX systems, RO needs an appropriate disposal management plan for wastewater.

Many factors go into choosing the best nitrate treatment system for a PWS system, including source water quality, system flow rate, and budget. Table 2.1 compares costs of the two systems using data from a study by the University of California, Davis for small, medium, and large PWSs. For example, a smaller PWS

Table 2.1: Operating Costs of Ion Exchange versus Reverse Osmosis Systems

(Adapted from Vivian B. Jensen et al. 2012)

Population Served	Design Flow (typical average flow) MGD	Treatment	Annualized Costs (\$/1000 gallons)		
			Capital Cost range (Avg.) \$/1000 gallons	O&M Cost Range (Avg.) \$/1000 gallons	Total Combined Cost Range (Avg.) \$/1000 gallons
Very Small (25 – 500) ^a	0.009 – 0.17 ^b (0.002 – 0.052) ^c	IX	0.05 – 1.53 ^d (0.75) ^e	0.28 – 3.81 (1.22)	0.62 – 4.60 (1.97)
		RO	0.47 – 4.40 (2.43)	0.22 – 16.16 (4.22)	0.69 – 19.16 (6.64)
Small (501 – 3,300)	0.17 – 1.09 (0.052 – 0.39)	IX	0.08 – 0.25 (0.15)	0.15 – 2.63 (0.87)	0.34 – 2.73 (1.05)
		RO	0.19 – 1.13 (0.47)	0.23 – 1.15 (0.57)	0.58 – 1.34 (0.93)
Medium (3,301 – 10,000)	1.09 – 3.21 (0.39 – 1.3)	IX	0.06 – 0.52 (0.19)	0.12 – 1.69 (0.84)	0.36 – 2.04 (1.06)
		RO	0.44 – 0.63 (0.53)	0.91 – 2.76 (1.89)	1.35 – 3.39 (2.59)
Large (10,001 – 100,000)	3.21 – 30.45 (1.3 – 15.51)	IX	0.09 – 0.41 (0.26)	0.13 – 1.39 (0.66)	0.22 – 1.81 (0.97)
		RO	0.33 – 1.46 (0.97)	0.40 – 2.21 (1.48)	0.73 – 3.67 (2.38)

Notes: All cost values are converted into 2010 dollars. a: Population size; b: Design flow; c: Average flow range; d: Capital cost range (corresponding to design flow); e: Average estimated capital cost.

serving 500 individuals (producing 0.17 million gallons per day) would face an annual total cost of \$280,000 with an IX system, while medium and large systems serving populations of 10,000 and 100,000, respectively, would have costs of \$2,400,000 and \$20,000,000 annually. For comparison, these annual costs for an RO system would be around \$1,200,000, \$4,000,000, and \$40,000,000, respectively. RO systems are especially cost high for small systems. Thus, the systems may be too costly for some PWSs even if it is the best treatment system from a technology perspective. As we will see in the following section, equipment cost for nitrate removal systems are not linearly scalable and vary depending on the specific needs of a PWS.

Alternative treatment options. Some PWSs cannot afford IX or RO systems. The most straightforward alternative is to mix water from multiple sources. If some water sources contain high nitrate levels while others contain low concentrations, a PWS can dilute the high-nitrate source water by blending. Water blending is particularly attractive because it avoids certification and disposal requirements that come with installing an IX or RO system. Although water blending is much cheaper than other treatment options, it is only possible when a PWS has a local, low-nitrate raw water source available. Also, the strategy may require PWSs to construct new wells or drill deeper to groundwater sources that are less susceptible to nitrate pollution. Both are potentially significant expenses and face tradeoffs, as deeper wells may contain higher concentrations of other contaminants such as arsenic and radium.

An alternative to treating or blending local water supplies is to connect to a nearby water system. This is an especially attractive option for smaller towns that are near large PWS systems. Similarly, several small communities can consolidate their resources and invest in a single, shared water treatment system. Often, the last resort for PWS suppliers that are unable to treat, blend, or supply water from other sources is to either provide bottled water or truck in potable water for their communities or to provide POU and POE devices to households directly. These are typically very short- to medium-term solutions, and, depending on the community size, can be very costly. Also, the Iowa DNR does not currently allow PWSs to comply with the SDWA using household POU systems.

Table 2.2 compares the costs of these alternatives for a single household and for a small PWS that serves 1,000 homes. For a small PWS, the least expensive option is to, if available, drill a new well, while supplying bottled water far exceeds all other costs. For an individual household, the least expensive

Table 2.2 Costs of Alternative Water Supply Options

(Adapted from Vivian B. Jensen et al. 2012)

	Estimated Annual Cost Range	
	Single Household	Small PWS (1,000 Households)
Water Blending	N/A	\$200,000 - \$365,000
Well Reconstruction	\$860 - \$ 3,300	\$80,000 - \$100,000
Drill New Well	\$2,100 - \$3,300	\$40,000 - \$290,000
Install POU, Reverse Osmosis Unit	\$250 - \$360	\$223,000
Pipeline Connection to Existing System	\$52,400 - \$185,500	\$59,700 - \$192,800
Trucked Water	\$950	\$2,850
Bottled Water	\$1,339	\$1.34 M

Note: All costs are discounted over a 20 year period at a 5% discount rate, except for the POU estimate and trucked and bottled water costs.

option is to install and maintain their own POU RO unit, while the most expensive option is to connect a pipeline to an existing water supply system.

Well-head and source water protection. While treatment, blending, and supplying bottled water to PWS customers all reduce nitrate exposure, all come at a potentially significant cost. An alternative to treating polluted source water is to protect source water from nitrate pollution. Because most nitrates in Iowa result from agricultural activities, this involves changes in land use. In Iowa, these activities are often coordinated through the Iowa DNR's Source Water Protection (SWP) program. The SWP program is a voluntary program available to targeted communities that have drinking water supplies susceptible to nitrate contamination. The program works with communities to determine the source of nitrate contamination, provides grant support to implement practices to reduce contamination, and assists in implementing any identified projects. These projects typically require communities to adopt new ordinances and zoning restrictions to require low impact developments in strategic locations or purchasing land easements to take local land out of agricultural production.

2.2.2. Household Treatment Options

The most common treatment options for individual or small groups of households are POE and POU devices. POU devices attach to faucets and treat water used for direct consumption (e.g., drinking, cooking). In contrast, POE devices treat all water as it enters a home. The SDWA allows small PWSs to install and maintain POU and POE devices to comply with certain MCLs, so long as the devices meet certain technical requirements. However, to date, no small communities are approved to use these devices to comply with nitrate standards.

POU and POE devices are often the most cost-effective treatment option available to households with private wells (Table 2.2). Before installing a POU system, a homeowner should test their water quality to determine the best device. Proper use and maintenance of POU systems requires community education programs, often provided by local communities.

2.3. Nitrate Treatment Capital Expenditures by Public Water Supply Systems

The SDWA established a revolving loan fund to support investments in water infrastructure projects. The program is typically administered through states and provides low-interest loans to community water systems to build and upgrade their water infrastructure. Nitrate removal investments are eligible to receive loans. In Iowa, the funds are distributed by the DNR and state Finance Authority through the State Revolving Fund (SRF) Loan. Because the program offers highly competitive loan terms, it is one of the most popular sources used by PWSs to fund drinking water treatment investments, and since 2000 the program has supported around 580 projects for a total value of \$1.15 billion.

We use data from the universe of applications to the SRF to gain a better sense of historical expenditures on nitrate removal equipment by Iowa utilities. As we highlight below, the capital costs can be substantial, particularly for small PWSs. While the SRF provides low-interest loans, the costs of these capital expenditures are ultimately borne by utility customers.

We identified seven funded or proposed projects since 2000 that requested funding for nitrate treatment technologies as part of their loan request. Of those, five included separate cost estimates for the capital costs of nitrate treatment equipment, totaling over \$1.8 million (2015 dollars). These costs do not include operations and maintenance expenditures and are, in that sense, a lower bound of the true costs of these

systems. We also know that 41 PWSs use an IX or RO system to treat their water. We, therefore, are capturing only a fraction of total statewide expenditures on IX and RO systems. However, as discussed previously, IX and RO equipment also remove other contaminants. Thus, the costs of these systems to other PWSs may not be wholly attributable to excess nitrates. Nonetheless, we believe the examples below provide important insight into the costs utilities face when deciding whether to treat nitrates.

Renwick, Iowa (SRF Funding Year: 2006, Status: Completed). The city of Renwick provides water to just over 250 people in north-central Iowa. The city draws water from two deepwater wells; and, in 2006, because its water supply infrastructure was aging, it commissioned a study comparing costs of upgrading its existing infrastructure or building a new plant. As part of this effort, the city invested in an IX system to treat nitrates and other contaminants in its source water. Bids for the IX system ranged between \$128,000 and \$136,000.

Emerson, Iowa (SRF Funding Year: 2007, Status: Completed). In 2007, the city of Emerson applied for funding to build a new water treatment plant. The city serves just over 400 customers and draws water from two nearby wells. As part of its new treatment plant, the city included two IX units and a salt storage tank for the brine. The total estimated cost of the IX system was around \$457,000.

Ellsworth, Iowa (SRF Funding Year: 2007, Status: Completed). Ellsworth has a small PWS system that provides water for around 500 people in central Iowa. The city draws water from the Mississippian aquifer, and the city has struggled for years to meet MCL requirements for multiple contaminants. The city's finished water regularly contained unsafe levels of arsenic, total organic carbon, and nitrite. As part of the city's decision to upgrade its water treatment system, it commissioned a report comparing the costs of installing new IX and RO treatment systems. The estimated capital costs of a new IX system was around \$136,000, while the cost of a new RO system was estimated to be around \$226,000. The city ultimately received \$2,500,000 for the entire project of improving its water treatment plant using an IX system in November 2007.

Manchester, Iowa (SRF Funding Year: 2010, Status: Funded). Manchester is a town in eastern Iowa that provides water to just over 5,000 people. It draws water from the Silurian aquifer, and in 2011 three of the city's five wells contained nitrate levels above the allowable MCL. Of the three contaminated wells, one was previously treated using an IX system, while the city did not use the other two. In 2010, the city applied to use SRF funds to pay for a combined IX system so that it could once again use the two contaminated wells and reduce nitrate levels in its treated water for at least the next 20 years. The total estimated capital cost of the nitrate reduction system was around \$480,000.

Van Meter, Iowa (SRF Funding Year: 2015, Status: Waiting for Bidding). Van Meter PWS provides water for around 1,100 people in central Iowa. The city draws water from two shallow wells near the Raccoon River that have proven susceptible to nitrate contamination. In conjunction with the city of De Soto, Van Meter commissioned a study of costs of installing either joint or separate nitrate treatment systems. The report identified two strategies for the cities: invest in a joint water treatment plant or build separate treatment plants. Cost estimates of both options included an RO system to remove excess nitrates in the city's source water. The estimated capital cost per plant for the RO equipment came in around \$450,000 per plant if the cities built separate plants and \$600,000 for the joint plant. The project is currently waiting for bidding.

2.4. PWS Case Studies

For our last examination of the costs of nitrates on drinking water supply systems, we present three case studies of how PWSs of various sizes deal with elevated nitrates in their utility. As in the previous section, the studies provide a limited analysis of the relevant costs to these operators of coping with excess nitrates in their drinking water supply. Nonetheless, they all provide valuable insights into the costs of high nitrates in PWSs drinking water sources.

2.4.1. Waterloo Water Treatment Plant

Waterloo Water Treatment Plant (WWTP) serves around 70,000 people in Waterloo, Iowa. WWTP sources its water from 14 strategically located wells throughout the city. While the city can provide 50 million gallons per day (MGD), its average demand is around 12 MGD. The city's wells draw from two primary sources, the Cedar Valley aquifer, and an alluvial aquifer. While the Cedar Valley aquifer is relatively protected from surface contaminants, those wells drawing from the alluvial aquifer are susceptible to nitrate contamination.

Nitrates concentrations in the wells that draw from the alluvial aquifer fluctuate continuously. As a result, the city regularly tests for nitrates in these wells, and at times must stop drawing water from them. Thus, the city benefits from its over-capacity and portfolio of wells to comply with relevant drinking water standards. It has done so successfully since at least 2012—nitrate concentration data provided by the utility show few treated water readings with nitrates exceeding 7 mg/L and average concentrations around 6 mg/L.

Given its flexibility and size, WWTP can meet nitrate health standards with little more cost than that of monitoring and switching the portfolio of wells that supply water on a given day. Both costs are minimal. If the water demand from the utility were to grow in the future, this option might not be available, and the utility would need to invest in nitrate treatment technologies. We can estimate these costs using data from Table 2.1. We estimate the treatment costs for an IX system designed to treat 15 MGD would come at a capital cost of over \$5 million, with yearly operating costs exceeding \$3.6 million. Because the utility would need only to treat a subset of its wells, these cost estimates are likely overstated. However, this case is emblematic of the costs of nitrates to medium and large PWSs. Those that are fortunate to have excess capacity and draw drinking water from multiple sources can blend at little cost. However, costs increase substantially if capacity becomes more constrained or the PWS does not have a reliable, low-nitrate drinking water supply.

2.4.2. Lewis Water Treatment Plant

Lewis Water Treatment Plant is a small treatment plant serving around 430 people in Lewis, IA. Unlike Waterloo, the plant draws water from a single source with nitrate concentrations regularly exceeding the nitrate MCL. To address this, the utility uses an IX unit to treat much of its 30,000 gallons per day demand. Because of the poor source water quality, the utility must backwash its two IX systems every 60,000 gallons, roughly every four days. The city disposes of the brine water into its municipal sewer system.

The PWS IX system is effective at reducing nitrates in the city's drinking water supply. Figure 2.5(a) graphs yearly average source and treated water nitrate levels from 2003 to 2017 based on data provided by the utility. In three years, average nitrate concentrations in Lewis' source water exceeded the nitrate MCL standards, and in many other years the levels are quite close to the MCL. Over this period, the utility used its IX system in all years, ensuring treated water concentrations were consistently far below the EPA standard.

We do not have estimates of the capital costs of Lewis' IX system. However, the utility was able to provide estimates of some of its operations and maintenance costs. The main O&M costs are electricity, for which we do not have data, and salt. Purchased salt is used to prepare the brine for backwashing the system, and the utility was able to provide us with data on its salt purchases back to 2005. In Figure 2.5(b), we graph our estimates of the average daily salt expenditures alongside the average daily nitrates removed for 2005 to 2016. The latter is equal to the difference of the total amount of nitrates between the untreated and treated water used per day. A clear pattern is apparent—salt expenditures increase in years with high nitrate levels and decreasing in years with lower nitrate levels. These costs range between \$6 and \$15 per day, or around \$4,000 per year. While the variable costs are modest, these do not include other costs such as staff time or electricity, as well as the initial capital costs of the equipment.

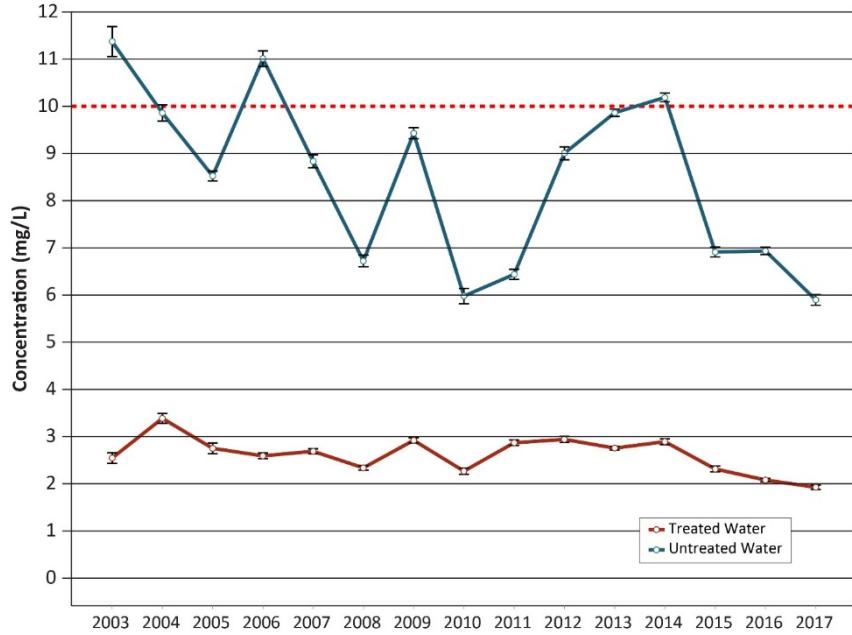


Figure 2.5(a): Lewis Drinking Water Treatment Plant Nitrate Concentrations (treated and untreated water)

Source: Lewis Drinking Water Plant

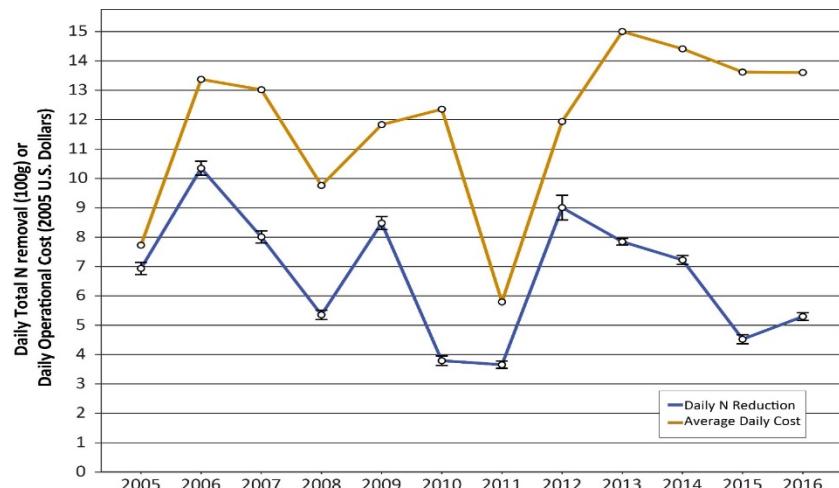


Figure 2.5(b): Lewis Drinking Water Plant Nitrates Removed and IX System Operating Costs

Source: Lewis Drinking Water Plant

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2.4.3. Bristow Municipal Water Supply

Bristow Municipal Water Supply serves around 150 people in and around Bristow, Iowa. The utility primarily draws water from one local well but has another well available as a backup emergency supply. Daily water production is around 15,000 gallons/day, and the utility uses a water tower that typically stores 25,000–30,000 gallons.

Like Waterloo, Bristow does not treat its water for nitrates and adds only disinfectants to its source water. The plant has struggled to meet MCL

standards for nitrates in recent years, and according to the Iowa DNR, has had four nitrate-related violations over the past five years. The utility also struggles with other contaminants. DNR data show five different violations related to excess coliform, chlorine, and lead in its treated water.

Figure 2.6 graphs average monthly nitrate concentrations in Bristow's water supply since 2012 using data provided by the plant operators. The graph shows an apparent upward trend in nitrate concentrations between 2012 and 2017 with sporadic, high-nitrate concentration events. This highlights a key challenge faced by small utilities like Bristow—the lack of multiple water supply sources or treatment systems leaves the PWS with few options when nitrates violate MCL standards. If the trend in nitrate concentrations continues, the utility will likely face a much higher incidence of excess nitrates going into the future, and average concentrations may soon systematically exceed the MCL.

As with many other utilities in Iowa, the source of Bristow's problems is relatively clear—Bristow's well lies within 50 feet of farmland. Absent changes in on-land practices, the utility is faced with a difficult decision of how to comply with SDWA standards going into the future. Investing in nitrate treatment technologies is cost-prohibitive given the utility's size. Other alternatives to meet SDWA standards include drilling a new deeper well, supplying households with POU systems, connection to a nearby water treatment plant that is free of nitrate pollution, supplying the community with bottled water, or investing in source-water protection efforts. While the city requires a more formal engineering analysis to understand the costs of treating its water, we can provide some rough cost estimates using data from the UC Davis nitrate study.

Using data from Section 2.2, we estimate that an IX system would cost between \$1.35 and \$1.46 million to build, and the city would need to pay for O&M costs as well. Conservatively, drilling a new well could cost around \$8,760, with an added operating cost of \$1.60/thousand gallons. The lower bound estimates of drilling a new deep well would be \$8,760. While relatively low cost, this option is viable for Bristow only

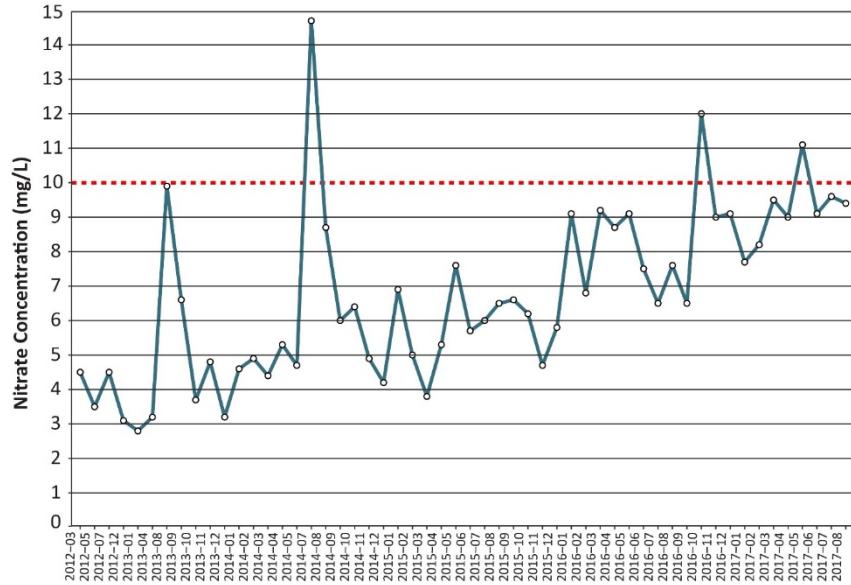


Figure 2.6: Bristow Drinking Water Plant Nitrate Concentrations (2012-2017)

Source: Iowa Department of Natural Resources

if deeper water sources are available and contain lower nitrate concentrations. While the utility could purchase POU systems for all homes in its service territory for less than \$100,000 per year, the Iowa DNR does not approve these devices for SDWA compliance. Alternatively, Bristow could provide bottled water to all household at an estimated cost of around \$75,000/year. The last option would be to connect to another water supply system. The nearest two viable suppliers are Dumont Water Supply (~3 miles) and Allison Water Supply (~6 miles). Using an estimated pipeline cost of \$61/foot and a connection fee per household of \$9,000, connecting to Dumont Water Supply would cost around \$1.6 million.

3. Recreational Benefits

In this section, we discuss the recreation value of water quality and its importance to Iowa communities and residents. Improving water quality supports increased biological diversity and increases water clarity, both of which enhance recreation benefits to Iowans. For many small towns, improved water quality can also mean more local business opportunities. CARD has conducted several studies quantifying these impacts. In this section, we use the information collected in these studies to generate estimates of the recreational water quality benefits to Iowans of fully implementing the conservation actions outlined in the Iowa NRS that are designed to achieve 45% reductions in nitrates and phosphorous. We then discuss an emerging problem due to excess nitrate pollution in Iowa—the increased prevalence of HABs and resulting beach closures.

3.1 Economic Value of Recreation

There is no market for water quality—Iowa's citizens cannot directly pay for improvements in water quality at a local lake. This does not mean that people do not value water quality—ample evidence supports the fact that people would be willing to pay for environmental improvements in general, and water quality in particular, if they were able to do so. The willingness to pay for improving water quality represents its economic value. The concept of willingness to pay as a measure of economic value applies to all goods and services, regardless of whether they are traded in markets or not. By estimating the economic value (willingness to pay) of water quality, it is possible to put the value of this resource on par with other goods and services valued by Iowans.

3.1.1 Measuring the Value of Environmental Quality

Economists have long studied how to estimate willingness to pay. There are two general approaches: (a) stated preferences; and, (b) revealed preferences. The stated preference approach relies on surveys that ask people to answer hypothetical questions. Essentially, researchers create a hypothetical market for environmental quality and directly ask interviewees about their willingness to pay for environmental improvements. Respondent's values, if credible, reveal both their use value—their perceived value of improved recreation benefits—as well as non-use values—the value they give to clean lakes in Iowa even if they do not use them for boating or fishing.

In contrast, revealed preference methods rely on observing peoples' actual behaviors to infer an implied economic value of certain activities. A simple example helps clarify this approach. A common revealed preference method uses the costs of traveling to visit lakes with different levels of water quality to estimate willingness to pay. Consider a family that is deciding to visit a lake in Iowa. They have access to a nearby lake that is impaired. Alternatively, the family can drive, at a cost, to a lake further away that has less pollution. The family's choice to either go travel to the high-quality lake or go to the nearby, impaired lake implicitly reveals their willingness to pay for water quality.

In this project, we follow a revealed preference approach using data from the Iowa Household Lake Survey conducted at CARD to estimate willingness to pay for achieving the nutrient reduction goals set in the Iowa NRS.²⁹ These goals are to reduce both total nitrogen and phosphorus loads leaving the state by 45%. Since our willingness to pay estimate is calculated using revealed preference methods, it captures only use values from water quality improvements in the state.

3.1.2. The Iowa Household Lake Survey

In 2014, CARD conducted a statewide, representative survey of households' recreational trips to more than 100 in-state lakes. The survey was mailed to nearly 7,000 Iowa households, about half of whom had responded to prior surveys conducted by CARD. The survey is part of a broader effort known as the Iowa Lakes Valuation Project that seeks to evaluate the economic value of water quality improvements in the state.³⁰ Around 50% of surveys were returned, with the majority of respondents between the ages of 35 and 75. Of the respondents, about 60% reported visiting at least one lake in 2014, and 20% reported at least one overnight trip.³¹ In addition to the household survey, water quality estimates for all lakes were collected from the Limnology Lab at Iowa State University. Every year, the lab takes water samples from more than 100 Iowa lakes that include measurements of total nitrogen (TN) and total phosphorous (TP).

The combined data on survey respondents' locations, the destination of their trip(s) and distance to various alternatives, and water quality at the lakes in Iowa allow us to estimate the 'revealed' value that households put on water quality in the state. More information about Iowan's use of these lakes including the activities they enjoy while visiting them, the average age, family size, education level, and income of visitors is available at <http://bit.ly/LakesReport2014>.

3.1.3 Quantifying the Economic Value of Water Quality Improvements

Here, we provide an intuitive description of our methodology. A more detailed description of the method is available from the authors upon request, and refer the reader in the endnotes to important references that further explain the methods.

The first part of our exercise requires determining how to characterize water quality improvements in our statistical model. Lake water quality can be subjective and may be difficult to quantify, but a commonly used metric is the 'Secchi' depth of a lake. The Secchi depth measures the depth that a black and white disk remains visible to the naked eye from the surface of the water. Greater levels of Secchi depth are associated with less eutrophication and less nutrients (particularly phosphorus). We use statistical methods to convert the 45% reductions in TN and TP that the conservation practices described by the NRS are designed to achieve into improvements in Secchi depth.

We model Iowan's lake recreation demand using a random utility model using standard best practices in the literature.³² Essentially, these models quantify, and statistically control for, the effect that various attributes of lakes have on the choice of which lake the household visits. These attributes include the lake size, distance from the home, water quality, boat ramps, and other relevant features. The model also controls for household characteristics such as family composition, income, and other observable traits.

Using our model, we estimate that Iowans would be willing to pay about \$30 million per year for recreational improvements from the better water quality associated with full implementation of the NRS. It is important to recognize that this estimate measures only the water quality improvements in the lakes included in this study. Thus, benefits associated with water quality improvements that might occur in rivers and streams of the state, wetlands, farm ponds, and other lakes are not included in this benefit. Further, the set of land use changes outlined in the Iowa NRS would likely generate other environmental improvements that are not captured in this estimate.

3.2 Beach Advisory – Harmful Algae Bloom (HABs)

The Iowa DNR routinely monitors the water quality at all state park beaches and many locally managed beaches in Iowa. Whenever the water quality is deemed unsafe, the DNR issues a beach advisory, discouraging citizens from visiting and swimming at those beaches.

Beach advisories are issued for many reasons. An increasingly common reason for beach advisories in the state is the development of Harmful Algal Blooms (HABs). HABs are algal overgrowths in water caused by excess nutrients like nitrates

and phosphates and are influenced by factors including temperature and rainfall. HABs contain toxins that are harmful to both aquatic life and human health. HABs have become more common throughout the United States, and have led to infamous problems in beaches and water supply systems in the Great Lakes regions. The most common toxin found in U.S. lakes are microcystins.³³

We collected beach advisory data for 39 Iowa state parks over the past 12 years to understand the growing importance of this problem. Figure 8 graphs the trend in beach advisories from 2006 to 2017. The data show a clear increase in the number of warnings due to elevated microcystin levels in the state. From 2012 to 2014 around 20 beach advisories due to microcystins were issued, and the number of warnings increased to over 30 in 2015 and 2016. The most recent data for 2017 shows a decrease in beach advisories, which may be due to low summertime rainfall in that year.

Reducing the prevalence of beach advisories due to HABs would have similar, and potentially much larger, benefits as those captured in the economic value estimates from section 3.1.3. Poor water quality does not prevent people from visiting lakes every year, while beach advisories may cause families to cancel planned trips altogether. Exposure to microcystins in water can also cause illness and in rare instances prove fatal.³⁴ Thus, more research is needed to understand the costs of this emerging problem.

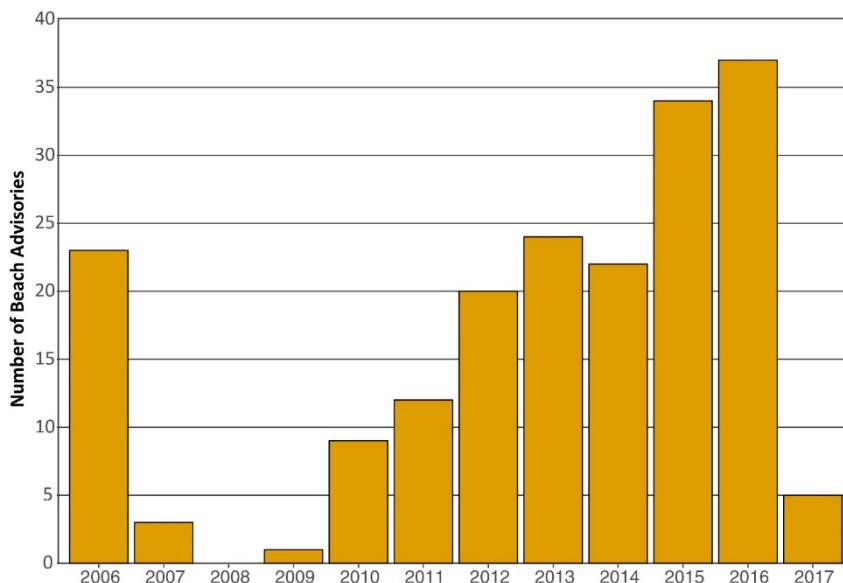


Figure 3.1. Number of beach advisories issued by IDNR 2006–2017

Source: Iowa Department of Natural Resources

4. Health Effects of Nitrate in Drinking Water

Our report focuses on the cost of removing nitrates from drinking water supplies and nutrient impacts on recreation values in Iowa. We conclude our report with a brief discussion of the available evidence on the health impacts of nitrates. As we highlight below, while there is an established public health literature documenting associations between nitrate exposure in drinking water and adverse health impacts, little causal evidence of these effects exists. Many studies also exclude costs to consumers from avoiding nitrates in drinking water. Consumers may respond to news of high nitrate concentrations by purchasing water filters, bottled water, or water from other sources. If this is the case, health costs may be low since exposure is limited. However, these ‘avoidance’ costs may be substantial.

We begin this section with a discussion of the most well-known impact of nitrate exposure—blue baby syndrome. We then discuss the process by which the EPA set an MCL for nitrates in drinking water. Next, we present the existing evidence on the impact of nitrate exposure and chronic health outcomes. We conclude with a discussion of the need and potential opportunities for new research.

4.1. Acute Health Impacts of Nitrate Exposure: Blue Baby Syndrome

In 1945, Hunter Comly, a physician in Iowa City, reported that two infants became ill after consuming baby food prepared with water from local, shallow wells.³⁵ Tests revealed that nitrate concentrations in the two wells were 90 and 150 mg/L. Comly described another four infants that drank well water from other wells with elevated nitrate concentrations that showed skin discoloration, while a fifth reported difficulty in breathing. All reported symptoms were suggestive of the babies having methemoglobinemia—a fatal condition in which red blood cells become unable to bind to oxygen, causing hypoxia in tissues. Comly’s report is the first description of what came to be known as ‘blue baby syndrome’ (BBS). Since his initial report, many cases of the syndrome have been reported and attributed to similar excess levels of nitrate exposure.³⁶

Over the last several decades, scientists have worked to identify the link between elevated nitrate exposure and infants developing BBS. Nitrites have been shown to impede the binding and transportation of oxygen in humans. Nitrate exposure by itself does not cause BBS—it must be converted to nitrite by bacteria in the body. Thus, individuals exposed to the same level of nitrates in drinking water may show different symptoms, making it difficult to determine safe drinking water concentrations. However, it is well established that infants’ gastrointestinal systems are particularly susceptible to these conditions, and the syndrome can prove fatal.

The SDWA and its amendments require the EPA to set MCLs at levels that ensure no adverse health effects are likely to occur. EPA sets the MCLs for 90 contaminants in addition to nitrate. To set these standards, the EPA relied on many studies of the association between nitrate exposure and BBS conducted between 1950 and 1970.³⁷ None of the cited studies found that BBS occurred in infants consuming water containing nitrate lesser than 10 milligrams per liter (mg/L), which served as the justification for the current standard. The standard has remained unchanged to date, despite a large and growing public health literature

studying the issue since 1990. The drinking water standard of nitrate has led to a heated debate among some scientists. Some believe the standard should be set substantially higher since few studies have documented cases of BBS arising when infants are exposed to low nitrate levels, while other calls for the standards to be tightened.³⁸

4.2. Chronic Health Effects of Nitrate Exposure

While the association between nitrate exposure and infants developing BBS is relatively well documented, less is understood about potential chronic health effects from long-term exposure to elevated nitrate levels. However, several studies have documented an association between chronic health outcomes and long-term exposure to nitrates in drinking water as well as short-term exposure during critical gestation periods.³⁹ These include bladder and gastric cancer, reproductive difficulties, health defects in newborns, childhood obesity, and thyroid problems.⁴⁰

Scientists and public health experts continue to study the impacts of acute and chronic nitrate exposure on human health. In 1986, scientists at the Center for Health Effects of Environmental Contamination (CHEEC) at the University of Iowa launched one of the most ambitious such efforts to date—the Iowa Women’s Health Study (IWHS).⁴¹ The study has followed more than 40,000 women in Iowa over time, collecting information on subjects’ drinking water and dietary patterns as well as exposure to nitrates in municipal water supplies. To date, the study has found a positive association between municipal water nitrate levels and risks of developing bladder and ovarian cancers. However, the findings are not consistent across study sites, and no conclusive links between excess nitrate exposure and chronic health impacts have been established.

A more recent study expanded the IWHS, updating the study to include outcomes from an additional 12 years.⁴² The study included more comprehensive drinking water exposure data and individual health information. The updated study found a strong association between bladder cancer risk and consumption of water containing nitrates, confirming findings from previous studies. Notably, the positive relationship between bladder cancer risk and nitrate exposure was found at nitrate levels well below the EPA MCL standard. In another study, researchers find an increased risk of thyroid cancer from long-term exposure to water with moderate nitrate levels (around 5 mg/L).⁴³ A recent study considered prenatal exposure to nitrates in drinking water among around 4,000 women in Iowa and Texas.⁴⁴ The authors found that prenatal exposure to nitrates in drinking water was positively associated with certain birth defects. However, the study is limited in its ability to disentangle the effects from exposure to nitrates in drinking water from exposure to nitrates from other sources, as well as those effects from other drinking water contaminants.

4.3 Future Research Needs

A fundamental problem of attributing nitrate exposure to particular health outcomes is that we never observe health outcomes of an individual exposed to high nitrates in a world where they were not exposed

and all other circumstances in their lives are held the same. Instead, we observe data on many different individuals exposed to different levels of nitrates, but that are different in many other ways. People choose where to live, are different in their knowledge of their exposure to poor drinking water quality, and have different lifestyles. All of these factors, and many more, may contribute to individuals' health. While evidence linking high nitrate exposure and infants developing BBS is relatively well established, evidence of sustained nitrate exposure and chronic health impacts are far less conclusive. Good science dictates the need for continued research on the association between nitrate exposure and specific health outcomes.⁴⁵ Below we briefly highlight two important questions in this literature.

A first challenge is correctly measuring exposure. The amount of nitrates in well water and treated water from PWS systems are, for the most part, easy to measure. However, homes have multiple sources of drinking water. They may purchase their own bottled water or have an in-home water cooler. They may also treat their water using POU or POE filters. These avoidance behaviors may also vary over time—homes may respond to news about poor local or state water quality by purchasing a filter for their home. Thus, understanding households' avoidance behaviors and determinants is of first-order importance in this setting.

A second, more difficult challenge is understanding the complex interactions between nitrates and other potential contaminants on human health. As discussed previously, some infants are more susceptible to BBS than others. However, areas with high nitrate concentrations in drinking water may also be more susceptible to other drinking water contaminants. Disentangling the separate impacts of various contaminants as well as understanding their combined effects on human health is important in updating our understanding of safe drinking water standards.

Given the findings in this report, there is an increased need to encourage and fund studies of nitrate exposure and health outcomes. There are many reasons to be optimistic. Public health experts, scientists, and economists have made tremendous strides over the past two decades in understanding the health and economic consequences of, for example, air pollution exposure and lead exposure.⁴⁶ Further efforts along these lines in drinking water are imperative.

Endnotes

¹ Throughout the report, we discuss various costs of nitrogen pollution (e.g., costs to drinking water treatment facilities, recreationists, human health). At times, we also discuss the benefits of reducing pollution through various mechanisms (e.g., the NRS). Conceptually, describing these actions as benefits is equivalent to describing these actions as a reduction in costs that individuals or society bears. These costs are separate from the costs associated with controlling or reducing pollution (e.g., costly land management actions taken as part of the NRS). These costs are not a focus of this report.

² Throughout the report, nitrate refers to nitrate-nitrogen, or NO₃-N. The drinking water standard of nitrate refers to the maximum concentration limit (MCL) set by the U.S. EPA, which is 10 milligrams per liter (mg/L).

³ Data from the economic study published on ISU AgDM Newsletter (December, 2011). See:
<https://www.extension.iastate.edu/agdm/articles/duffy/DuffyDec11.html>

⁴ Ibid.

⁵ More information on the relationship between fertilizer use in the United States and market conditions is available from the U.S. Department of Agriculture (USDA) at: <https://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets/>.

⁶ Livestock production in Iowa has increased substantially in recent decades. Data from USDA show that total hog inventories were 22 million in 2016, compared to 17 million in 1997. See: <https://quickstats.nass.usda.gov/>. A recent Iowa State University study found that the state's animal farms produce over 50 million tons of manure, 325,000 tons of available nitrogen, and 82,000 tons of phosphorus annually. See:
<http://themanurescoop.blogspot.com/2014/10/how-much-manure-is-there-in-iowa.html>.

⁷ Nitrate is an essential nutrient for plant growth. Nitrogen in the atmosphere is converted to oxidized nitrogen compounds (e.g., ammonia) by bacteria and becomes available for plants. After plants die, nitrogen compounds are converted again and released back to the atmosphere. Human activities have dramatically altered the nitrogen cycle since the 1940s. Because nitrate does not attach to soil, excessive reactive nitrogen in soils enter groundwater through infiltration and leaching, especially in areas without less permeable rock layers. The determinants of the level of nitrate include a variety of factors. We refer interested readers to: Wick, Katharina, Christine Heumesser, and Erwin Schmid. 2012. "Groundwater nitrate contamination: factors and indicators." *Journal of Environmental Management* 111: 178–186.

⁸ Prior, J.C., J.L. Boekhoff, M.R. Howes, R.D. Libra, and P.E. VanDorpe. 2003. *Iowa's groundwater basics*. Iowa Department of Natural Resources
https://www.iowadnr.gov/Portals/idnr/uploads/consites/groundwater_basics.pdf

⁹ Pennino, Michael J., Jana E. Compton, and Scott G. Leibowitz. 2017. "Trends in Drinking Water Nitrate Violations Across the United States." *Environmental Science & Technology* 51 (22): 13450–60.

¹⁰ EPA further classifies PWSs into three different categories—Community Water systems (CWS), non-transient non-community systems (NTNCS), transient non-community systems (TNCS)—based on their service time span and service frequency.

¹¹ The EPA maintains a detailed system of SDWA violations at: <https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting>

¹² Data from the State of Iowa Public Drinking Water Program 2016 Annual Compliance Report. Figure on page 22. See: <http://publications.iowa.gov/24527/>

¹³ More information on the G2C program is available at <https://idph.iowa.gov/ehs/grants-to-counties>

¹⁴ More information about the use of rivers and streams in Iowa is available at https://www.card.iastate.edu/research/resource-and-environmental/items/Rivers_Survey_Fact_Sheet.pdf

¹⁵ Hoagland, P., D. M. Anderson, Y. Kaoru, and A. W. White. 2002. "The Economic Effects of Harmful Algal Blooms in the United States: Estimates, Assessment Issues, and Information Needs." *Estuaries* 25 (4):819–37.
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¹⁶ See: <http://www.dmww.com/about-us/announcements/advisory.aspx>.

¹⁷ Violation data is collected from the Safe Drinking Water Information System Federal Reporting Services. Nitrate violations include both single sample and average sample violation records. 2017 data does not include violations from the fourth quarter. See: <https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting>

¹⁸ We are unable to distinguish whether lower/higher violation rates are due to lower/higher prevalence of nitrates or due to less/more testing.

¹⁹ Littin, G.R. 2004. "Quality of Ground Water for Selected Municipal Water Supplies in Iowa, 1997-2002." USGS Numbered Series. Open-File Report 2004-1048. US Geological Survey.

²⁰ See Hruby, Claire E., Robert D. Libra, Chad L. Fields, Dana W. Kolpin, Laura E. Hubbard, Mark R. Borchardt, Susan K. Spencer, et al. 2015. "2013 Survey of Iowa Groundwater and Evaluation of Public Well Vulnerability Classifications for Contaminants of Emerging Concern." State/Local Government Series 57. Iowa Geological and Water Survey Technical Information Series. Iowa Department of Natural Resources.

²¹ The map available at: <http://publications.iowa.gov/25744/>

²² Stoltenberg, D, and M. Vaughan. 1993. "Iowa Statewide Rural Well Water Survey — Summary of Results." IDNR and CHEEC.

²³ See: <http://s-iehr34.iehr.uiowa.edu/publications/uploads/wfs-2004-04.pdf>

²⁴ See: <https://idph.iowa.gov/ehs/grants-to-counties>.

²⁵ The PWTS system encountered some technical issues in 2004, and all nitrate concentration data in that year were corrupted. In order to dampen any bias, PWTS data from 2014 are dropped from this graph and all other analyses.

²⁶ New technologies can circumvent this problem. Biological denitrification and chemical denitrification systems transform nitrate to other nitrogen species that are less harmful to humans. Both technologies, however, have yet to be widely used by PWSs, and none are used in Iowa.

²⁷ Boiling water does not remove nitrates. In fact, it increases nitrate concentrations by evaporating water.

²⁸ Jensen, Vivian B., Jeannie L. Darby, Chad Seidel, and Craig Gorman. 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

Honeycutt, Kristin, Holly Canada, Marion Jenkins, and Jay Lund. 2012. "Alternative Water Supply Options for Nitrate Contamination. Technical Report 7 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.

More information on these studies is available at: <http://groundwaternitrate.ucdavis.edu/>.

A detailed discussion on new and emerging nitrate treatment options is available from:

Seidel, Chad, Craig Gorman, Jeannie L. Darby, and Vivian B. Jensen. 2011. "An Assessment of the State of Nitrate Treatment Alternatives." The American Water Works Association.

²⁹ More information about the Iowa Nutrient Reduction Strategy is available at:

<http://www.nutrientstrategy.iastate.edu/>

³⁰ See: <https://www.card.iastate.edu/lakes/>

³¹ Azevedo, Christopher D., et al. 2003. "Iowa lakes valuation project: Summary and findings from year one." *Final Report to the Iowa Department of Natural Resources, August 2003.* <https://www.card.iastate.edu/lakes/report-to-the-iowa-department-of-natural-resources-2014.pdf>

³² Egan, K.J., Herriges, J.A., Kling, C.L. and Downing, J.A., 2009. "Valuing Water Quality as a Function of Water Quality Measures." *American Journal of Agricultural Economics* 91(1): 106–123.

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³³ See: <https://www.epa.gov/nutrient-policy-data/cyanobacteriacyanotoxins>

³⁴ Figgatt, Mary. 2017. "Harmful Algal Bloom–Associated Illnesses in Humans and Dogs Identified Through a Pilot Surveillance System — New York, 2015." MMWR. Morbidity and Mortality Weekly Report 66
More information available at <https://www.epa.gov/nutrientpollution/harmful-algal-blooms>.

³⁵ Comly, Hunter H. 1945. "Cyanosis in Infants Caused by Nitrates in Well Water." *Journal of the American Medical Association* 129 (2): 112–116.

³⁶ See Knobeloch, Lynda, Barbara Salna, Adam Hogan, Jeffrey Postle, and Henry Anderson. 2000. "Blue Babies and Nitrate-Contaminated Well Water." *Environmental Health Perspectives* 108 (7):675.

³⁷ U.S. EPA. 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

³⁸ Addiscott, T.m., and N. Benjamin. 2004. "Nitrate and Human Health." *Soil Use and Management* 20(2): 98–104.

³⁹ Van Grinsven, Hans J.M., Mary H. Ward, Nigel Benjamin, and Theo M. de Kok. 2006. "Does the Evidence about Health Risks Associated with Nitrate Ingestion Warrant an Increase of the Nitrate Standard for Drinking Water?" *Environmental Health* 5 (September):26.

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⁴⁰ Ward, Mary H., Theo M. deKok, Patrick Levallois, Jean Brender, Gabriel Gulis, Bernard T. Nolan, and James VanDerslice. 2005. "Workgroup Report: Drinking-Water Nitrate and Health—Recent Findings and Research Needs." *Environmental Health Perspectives* 113 (11):1607–14

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⁴¹ Weyer, Peter J., James R. Cerhan, Burton C. Kross, George R. Hallberg, Jiji Kantamneni, George Breuer, Michael P. Jones, Wei Zheng, and Charles F. Lynch. 2001. "Municipal Drinking Water Nitrate Level and Cancer Risk in Older Women: The Iowa Women's Health Study." *Epidemiology* 12 (3):327–38.

⁴² Jones, Rena R., Peter J. Weyer, Curt T. DellaValle, Maki Inoue-Choi, Kristin E. Anderson, Kenneth P. Cantor, Stuart Krasner, et al. 2016. "Nitrate from Drinking Water and Diet and Bladder Cancer among Postmenopausal Women in Iowa." *Environmental Health Perspectives* 124 (11):1751–58.

⁴³ Ward, Mary H., et al. 2010. "Nitrate Intake and the Risk of Thyroid Cancer and Thyroid Disease." *Epidemiology* (Cambridge, Mass.) 21.3: 389.

⁴⁴ Brender, Jean D., Peter J. Weyer, Paul A. Romitti, Binayak P. Mohanty, Mayura U. Shinde, Ann M. Vuong, Joseph R. Sharkey, et al. 2013. "Prenatal Nitrate Intake from Drinking Water and Selected Birth Defects in Offspring of Participants in the National Birth Defects Prevention Study." *Environmental Health Perspectives*.

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