H.R. ____, The Farm Regulatory Certainty Act of 2017
THE IMPORTANCE OF CITIZEN ENFORCEMENT TO PROTECT COMMUNITIES AND DRINKING WATER FROM AGRICULTURAL POLLUTION

Testimony of Jessica Culpepper, Food Project Attorney at Public Justice
U.S. House Subcommittee on the Environment
Hearing on the Discussion Draft
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Summary

Without the Resource Conservation and Recovery Act's (RCRA) citizen enforcement provision, no existing law by itself allows private well owners to stop drinking water contamination by agricultural pollution. The Safe Drinking Water Act (SDWA) excludes private wells from regulation. The Clean Water Act only addresses impacts to surface water. RCRA supplements a number of other federal, state, and local laws that apply to agricultural waste management, but this system fits together like the gears of a clock that will not work unless citizens have the right to enforce them. Like the SDWA, but unlike the Clean Water Act, RCRA imposes no specific regulatory burden on agriculture. Rather, it provides a mechanism for citizen law enforcement where a polluter has endangered public health or the environment. But if this bill is passed, then *any* proceeding covering waste management would preclude rural Americans from enforcing the only law protecting their access to clean water.

While most farmers are dedicated members of their community and stewards of the land, there are some who ignore their own waste management plans and permits. Some irresponsible operators of concentrated animal feeding operations (CAFOs) have long been violating state and federal laws in how they manage their manure. Rural communities living near CAFOs have seen repeated instances where state and federal agencies did not effectively enforce laws designed to protect communities from the risks and pollution stemming from mismanaged waste owned by

CAFO operators. The results have been continued pollution, dangers to communities, and, for some, catastrophic loss of their drinking water.

RCRA citizen enforcement actions are lawsuits of last resort. As a member of the legal team who represented the community behind the only successful RCRA citizen enforcement action brought on behalf of a rural community against a CAFO, I can say that these actions are costly, time consuming, and extremely difficult to bring. Moreover, rural Americans do not want to take legal action against their neighbors. Because of these factors, citizen enforcement suits under RCRA only occur against the worst actors in the most egregious circumstances. But in that suit, citizen law enforcement obtained a cleanup of agricultural pollution where state agencies had not taken action, and the EPA had not taken enough action to solve the problem – the agency left hundreds of households without clean water and did not require mandatory changes that would stop further contamination of the drinking water aquifer.

In the lawsuit in Yakima Valley, Washington, the operators admitted, under oath, that they violated their own Nutrient Management Plans for years and used their fields as dumping grounds for millions of gallons of raw waste. They illegally disposed of waste in fields across the street from their neighbors. And the lawsuit worked where nothing else could. Hundreds of households who had no clean drinking water for years are now receiving critical clean water delivery, and the CAFOs have been forced to change their practices so that their production methods no longer contaminate their neighbors' drinking water. The only way this could have happened was citizen law enforcement under the Resource Conservation and Recovery Act. For this statute to serve the public purposes for which it was intended, the public – and not just state and federal government bureaucracies – must have the authority to protect themselves through citizen enforcement suits.

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Here is the proposal: A CAFO produces millions of gallons of manure and urine containing toxic substances, including nitrates, bacteria, pathogens, arsenic, and selenium. We propose to dig unlined pits that we will not properly maintain on top of an aquifer, the local community's sole source of drinking water. The CAFO will dump the manure and facility wash water into these pits for storage. These millions of wet gallons of waste will sit there untreated, where the toxic substances in this waste will leach into the groundwater, which flows into the community's wells.

Now the CAFO will spray the remaining raw animal sewage from the unlined pits onto our land. They have a management plan that they are supposed to follow, but because the CAFO produced more manure than their crops actually need, they will ignore the requirements of that plan and apply millions of gallons more than what is necessary for crop growth onto our fields. The excess manure that is not used by the crops will also leach into the groundwater and flow into the community's wells. They will continue to do that for at least a decade, even when they receive information that dangerous nitrates are rising in the drinking water, and scientists and government agencies inform them that they are likely part of that problem.

Sounds like a good idea? That is exactly what the operators of the mega-dairies admitted to in the Yakima, Washington citizen enforcement action that led to Rep. Newhouse introducing the so-called Farm Regulatory Certainty Act. It should come as no surprise that these lagoons have failures and that some operators are going to ignore the laws and mismanage their manure. It does not take a prophet to predict that, because of these few, bad actors, environmental and public health crises will happen, it does not take a rocket scientist to determine that mismanaging mass quantities of manure like this will pollute, and it does not take a legal scholar to figure out that when a person's tap water runs brown from manure, something about this is illegal.[1] And any concerned citizen can see that this is no way for agricultural waste to be handled in his or her community this age of complex engineering and agronomy plans which, if utilized properly, would prevent pollution from happening in the first place.

Yet, what we have seen across the nation is that even though some in this industry are breaking existing law in how they manage manure, and even though the manure is polluting groundwater and rivers with toxic contamination and even though there is the risk of catastrophic public health crises, the CAFOs and the state agencies that regulate them have not taken effective action to stop bad practices and protect local communities and clean water. In the *single* case brought against a CAFO, we obtained substantial clean up and convinced the CAFOs that they must change their waste management practices – but only when citizens had the right to take the future of their communities into their own hands, to bring their own enforcement action, and to thereby force the state and federal agencies and the CAFOs to face up to the harm that unlined manure storage over aquifers and massive land dumping is doing to local neighborhoods and our natural resources.

Forty-nine percent of the United States relies on groundwater for its drinking water. In the states represented by this subcommittee alone, 33 million people in California rely on groundwater;[2] 183,000 people in Colorado rely on private wells with another 1.1 million relying on groundwater in community systems;[3] 1.53 million people in Georgia rely on private wells with another 1.78 million

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[1] *See* Attachment A for news coverage of communities with brown tap water.

[2] https://www.waterboards.ca.gov/water_issues/programs/groundwater/gw_basics.shtml and see http://www.water.ca.gov/groundwater/gwinfo/index.cfm

[3] http://coloradogeologicalsurvey.org/water/groundwater/ and see http://www.ngwa.org/Documents/States/Use/co.pdf

relying on groundwater in community systems;[4] 5 million people in Illinois rely on groundwater; 446,000 people in Mississippi rely on private wells with another 2.9 relying on groundwater – almost the entire state population;[5] 2 million people in New York rely on private well water, while another 4.96 rely on groundwater in community systems;[6] 3.3 million people in North Carolina rely on private well water, while another 1.9 million rely on groundwater in community systems;[7] 26,500 people in North Dakota rely on private well water, while another 244,840 people rely on groundwater in community systems;[8] 1.8 million people in Ohio rely on private well water, while another 3.3 million rely on groundwater in community systems;[9] 225,000 people in Oregon rely on private well water, while another 789,000 people rely on groundwater in community systems;[10] 538,000 people in Tennessee rely on private well water, while another 1.49 million people rely on groundwater in community systems;[11] 2.23 million people in Texas rely on private well water, while another 6 million people rely on groundwater in community systems;[12] and 393,000 people in West Virginia rely on private well water, while another 309,600 rely on groundwater in community systems.[13]

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[4] http://coloradogeologicalsurvey.org/water/groundwater/; *see also* http://www.ngwa.org/Documents/States/Use/co.pdf

[5] http://www.ngwa.org/Documents/States/Use/ms.pdf

[6] http://www.ngwa.org/Documents/States/Use/ny.pdf

[7] http://www.ngwa.org/Documents/states/use/nc.pdf

[8] http://www.ngwa.org/Documents/States/Use/nd.pdf

[9] http://www.ngwa.org/Documents/States/Use/oh.pdf

[10] http://www.ngwa.org/Documents/States/Use/or.pdf; *see also* http://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/SOURCEWATER/Pages/whppsum.aspx.

[11] http://www.ngwa.org/Documents/States/Use/tn.pdf

[12] see http://www.ngwa.org/Documents/States/Use/tx.pdf

[13] http://www.ngwa.org/Documents/States/Use/wv.pdf

These astounding numbers show the breadth of impact the this bill will have if these people's rights are taken away.

It is worth examining RCRA, what this Discussion Draft would do to it, and what the only successful citizen enforcement action against agriculture has accomplished when the state agencies did not act, and EPA did not act enough.

A. The Importance of RCRA's Citizen Enforcement Provisions

Congress enacted RCRA in 1976 to close "the last remaining loophole in environmental law, that of unregulated land disposal of discarded materials and hazardous wastes" and "to minimize the present and future threat to human health and the environment."[14] To understand how RCRA works with the agricultural community, it is important to understand that nothing about this law has regulatory impact. The case that brought about the Rep. Newhouse's proposed bill, and the underlying statute, is about law enforcement. So the so-called Farm Regulatory Certainty Act does not reduce regulatory burden at all. It simply shields industry from liability for creating conditions that threaten public health. What the bill changes is the section of RCRA that allows citizens to enforce RCRA's prohibition against any person causing or contributing to the creation of an imminent and substantial endangerment to human health or the environment. 42 U.S.C. § 6972(a)(1)(b).

I want to set the record straight on Rep. Newhouse's letter to request a hearing on this bill. Rep. Newhouse introduces three misconceptions about RCRA's citizen enforcement provisions and the what the bill purports to do in his letter. Namely, RCRA is already doing achieving of the purported purposes in the so-called Farm Regulatory Certainty Act. That is no

[14] H.R.Rep No. 1491, 94th Cong., 2d Sess. 4, reprinted in 1976 U.S.C.C.A.N. 6238, 6241; 42 U.S.C. § 6902(b).

surprise because Congress was intentional when it set out to protect Americans' health from toxic waste, and reveals that this bill is not about reducing regulations, but about shielding the worst actors in this industry from accountability and shutting the courthouse doors on the most vulnerable in rural America.

First: RCRA citizen enforcement actions cannot be brought against a facility for the regular use of fertilizer to grow crops. Before you can bring a citizen enforcement action under RCRA, you need to have a solid waste and RCRA *already* exempts manure reused as fertilizer or soil conditioner from the definition of solid waste. It always has, and this bill does not change the fact that fertilizer used as such will never be a solid waste, and, because RCRA is only applicable to solid waste, the statute's provisions simply will not apply.

Rep. Newhouse stated in his letter requesting this hearing that Congress never intended for RCRA to govern agricultural nutrient management practices. This is simply not true, and what he fails to say is that RCRA does not apply to agriculture unless the practices being used lead to a disposal of waste that endangers public health. Congress most certainly intended to cover agricultural waste under RCRA. In the earliest versions of the law, agriculture was included in the Congressional findings as a source of waste of concern, and remains there to this day despite numerous amendments to the law. *See* P.L. 94-580 (Oct. 21, 1976) 90 STAT. 2797. The legislative history strongly suggests that agricultural waste, including manure, was considered, discussed, and was determined to be an important material regulated under RCRA. For example, in a House Report to amend RCRA, the explanation for the bill included agricultural waste in its definition of solid waste and explained the need to include it:

> Agriculture and animal wastes alone are 2 billion tons annually. So, millions of tons of solid waste are being spread as it were into our environment in the period of a year's time. Now, we can't sweep these into a corner and we can't find that quiet sanctuary and say that the problems will be taken care of in time.

Numerous statements by Congress identified the dangers caused by animal and agricultural wastes and the need for RCRA to address it as part of the statute.[15]

The court in the only citizen enforcement action to rule on this issue stated that the operators of the CAFO admitted that they ignored their own nutrient management plans and applied millions of gallons beyond what crops needed as fertilizer or soil conditioner. The massive amounts of excess manure that could not be used by the crops is what contaminated the drinking water. There is a line between fertilizer applications and dumping excess waste to dispose of it, and the court found that in that particular factual scenario, the CAFO was unquestionably past it.

Second: RCRA citizen enforcement actions would likely not be brought against small or medium sized family farms. Even if you are disposing of your manure rather than using it as fertilizer, RCRA *still* will not apply unless three very serious facts are present:

1. You have to dump such vast quantities of manure that it threatens to leave your property and gets into the water supply;

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[15] Resource Recovery Act of 1969 (Part 1), Subcomm. on Air and Water Pollution of the Comm. on Public Works (March 4, 5, AND 13, 1970, March 31, 1970), 2 (Statement by Sen. Randolph) (Mr. President, our society generates 4.4 billion tons of solid waste annually. The principal sources are animal wastes, 1.7 billion tons; and agricultural wastes, 640 million tons… To avoid an escalation of the current unsatisfactory situation, we must institute a comprehensive national materials policy which closes the present cycle of resource extraction, use, and discard to include reuse as a fundamental premise.); Resource Recovery Act of 1969 (Part 5), Subcomm. on Air and Water Pollution of the Comm. on Public Works (March 4, 5, AND 13, 1970, March 31, 1970), 2513-14 (statement of Frank Stead, called by Sen. Muskie) (Ignored as a public responsibility, and handled with little thought of the public interest in resources, are the agricultural wastes such as animal manures, orchard crops, and field and row crops, which, in the San Francisco Bay area itself, constitute half of the total waste loading ….No public agency is in a position to either prevent the mingling into the waste stream of material such as plastics, which are extremely difficult to accommodate as recycleable resources, or to insure the inclusion in the system of those materials whose handling now causes severe environmental impairment. Included in this latter category, of course, are abandoned automobiles, digested sewage sludges, and agricultural wastes);

2. The contaminants that threaten to leave your property are at such a high level that they may contribute to the violation of the drinking water standards for that contaminant; and
3. The violation of those drinking water standards is happening or is imminent in a source of drinking water such that it could endanger public health.

Without all of these additional conditions, there is still no coverage by the statute – it does not apply. And even if they did apply, RCRA allows for a notice period of ninety days before litigation can be filed, which gives an owner a period of time to fix the problem before litigation starts. Moreover, these conditions occur only in the most egregious of circumstances simply because the sheer volume of disposed waste over time to create this kind of public health risk is not the accepted or normal practices for this, or any, industry. Finally, these law suits are incredibly challenging and extremely resource-intensive to bring. And because the only remedy available under RCRA is to fix the problem, and there are no money damages available, there is no incentive to bring them against a facility unless that action will stop a substantial threat to public health and the environment.

Third: RCRA citizen enforcement actions already cannot be brought where a state or federal agency is diligently pursuing a duplicate judicial or administrative enforcement action under RCRA or another law. 42 U.S.C. §§ 6972(b)(2)(B)-(C). This is called the RCRA's "anti-duplication" provision. RCRA also has an "anti-inconsistency" provision, which similarly prohibits the statute to be used in a way that creates inconsistent requirements with other laws. 42 U.S.C. § 6905(a). So <u>RCRA *already* preempts lawsuits where a state or federal agency is addressing the issue through an enforcement action</u>. What this Discussion Draft does is blow those provisions open so that even unrelated proceedings will preclude citizens from enforcing RCRA against a polluter for contaminating their drinking water.

Finally, there is an easy way to make farmers more certain about their legal and regulatory compliance: agriculture must comply with RCRA just as it does any other law. In this case, complying with the law simply means that a CAFO must not mismanage its waste so egregiously that it creates an imminent and substantial endangerment to health or the environment. Compliance with other laws and regulations does not, and should not, shield an actor from liability under RCRA unless it is directly related to the cleanup, as is already prescribed in the anti-duplication provisions. In contrast, this Discussion Draft says that if you are speeding, and you get a ticket for that, then you can't be held liable for running a traffic light and crashing into someone else's car. And I want to emphasize that the crash must happen in addition to running the red light. Because it is not enough that an operator dump their waste to be held liable under RCRA; that manure must also threaten to get into the drinking water supply at a level endangers public health. We believe that it is reasonable to expect drivers to obey all traffic laws when on the road, just as we believe it is reasonable to expect an industry to obey all environmental and public health laws when operating a business that could potentially cause serious threats to public health.

B. Community Association for Restoration of the Environment v. Cow Palace, LLC

My characterization of why this bill is unnecessary is consistent with the only court to interpret animal manure to be a solid waste under RCRA: that the law allowed citizen enforcement leading to a cleanup that government law enforcement never sought.

Imagine you are one of the families that have lived in this community for generations, and now your sole source of household water has more than seven times the maximum limit for nitrate in it.[16] And while nitrate is a nutrient found in manure needed by crops to grow, when it is in drinking water, it can cause “blue baby syndrome” in infants, a potentially fatal disorder that causes a type of asphyxiation.[17] Nitrate has also been linked to miscarriages and higher rates of birth defects, Type 1 diabetes in children when pregnant mothers consume it, and certain kinds of cancer. What makes nitrates even more dangerous is that you cannot see it, smell it, or taste it. Boiling the water only increases the levels, even though boiling water is the common safety rule taught to parents when making their infants’ bottles. This happened to dozens of households that lived by the mega-dairies in Yakima, and this is just one of many ways that manure can make people sick when it gets into their drinking water. [18]

And as a community member, you know that there is groundwater testing information going back more than a decade showing groundwater contamination around these sites, including contaminated well water at the local elementary school. But as contamination increased, the dairy industry lobbied the state legislature to reduce the regulators charged with compliance.[19] The state agencies, though they know of the pollution problem, refused to or could not take effective action to require changes to these dangerous and polluting practices. After years of state

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[16] In fact, you do not have to imagine. Several letters from small farmers and families in these and other communities like theirs have been submitted as part of the record. More than anything I can say about this Discussion Draft, the weight of their stories, in their own words, about losing their only source of clean water and being ignored by state and federal regulators they seek out to help them fix the problem is a powerful testament to why this proposed bill should not progress.

[17] Nitrate contamination is also costly. A team of researchers led by the EPA, Attachment B, estimated in 2008 that agricultural nitrate may cost the nation $157 billion per year. Nitrate’s direct damage to drinking water supplies was estimated at $19 billion.

[18] Attachment C, Johns Hopkins Center for a Livable Future, Letter to Members of the Dunn County Livestock Operations Study Group (outlining public health risks from CAFOs). The Center also submitted into the record a critical analysis of the public health impacts of Rep. Newhouse’s bill.

[19] Leah Beth Ward, *Hidden Water, Dirty Wells*, Yakima Herald (July 30, 2009), www.yakima-herald.com/stories/2008/10/11/hidden-wells-dirty-water; *see also* News 21 Report, *Troubled Water*, http://troubledwater.news21.com/

inaction, the EPA stepped in and did a two-year study that determined the CAFOs as the most likely source of the drinking water contamination, leading to an enforcement action under their emergency powers under the SDWA. That action had two serious shortcomings: first, it only provided water provisions for one mile from the facilities even though the EPA study showed impacts from much further away. Second, the nutrient management changes were vague, often voluntary, and were insufficient to stop future contamination of the aquifer.[20]

It was only at that point that the community, after decades of trying to clean up their dirty water, decided to bring a citizen enforcement action for violations of RCRA. I was one of the attorneys representing them. The dairies made all the same arguments that are being made in support of this bill: that RCRA was never intended to apply to manure and that the EPA's consent decree under the SDWA was duplicative and addressed the problem.

The court, after reviewing hundreds of pages of evidence and in a 111-page written opinion,[21] determined that the CAFO violated RCRA. Specifically, the Court agreed with the industry that RCRA did not apply to fertilizer. The Court held that, according to the evidence and admissions made by the CAFO operator under oath, the way in which the CAFO was putting manure on the field was not fertilizer use, but rather a discarded material because it was "untethered to the [nutrient management plan] and made without regard to the fertilization needs of their crops." Cmty. Ass'n for Restoration of the Env't, Inc. v. Cow Palace, LLC, 80 F. Supp. 3d 1180, 1221 (E.D. Wash. 2015). The court also held that the EPA's consent decree under the

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[20] US EPA Region 10 Administrative Order on Consent In the Matter of Yakima Valley Dairies, Docket No. SDWA-10-2013-0080, www3.epa.gov/region10/pdf/sites/yakimagw/consent_order_yakima_valley_dairies_march2013.pdf

[21] Cmty. Ass'n for Restoration of the Env't, Inc. v. Cow Palace, LLC, 80 F. Supp. 3d 1180 (E.D. Wash. 2015),

http://www.centerforfoodsafety.org/files/320--order-granting-in-part-msj-11415_78926.pdf

SDWA was not duplicative of the citizen enforcement action under RCRA because RCRA's provisions to ensure the safe treatment and disposal of waste was far broader than the limited reach of the EPA's emergency powers under the SDWA. Cmty. Ass'n for Restoration of the Env't, Inc. v. George & Margaret LLC, 954 F. Supp. 2d 1151, 1159–60 (E.D. Wash. 2013).

Through that enforcement action, the citizens around the dairies were able to get broader and more effective relief for their harms than was possible under the EPA consent decree. Specifically, the citizens obtained bottled water delivery for households three miles downstream from the CAFOs rather than the more limited boundaries set by the EPA. The community was also able to get reasonable but meaningful changes to the CAFOs' waste management system, including liners for their storage lagoons, limiting manure applications on land to only what the crops actually need, and careful monitoring of the groundwater flow from the CAFOs.

CONCLUSION

The record is absolutely clear. RCRA as it stands already achieves the purported purpose of the so-called Farm Regulatory Certainty Act, and the bill merely stands to shield an entire industry from liability. Without the citizens' right to enforce the law, local communities cannot count on state agencies to effectively protect them from illegal, polluting, and dangerous manure contamination. Local citizens must have the ability to enforce this law because it is their only tool to protect their sole source of drinking water. State agencies have been reluctant to take action for violations of manure management, and federal agencies have not taken the measures necessary to fix the problem in rural communities who have dirty water. If RCRA was designed to help local communities to be safe, to protect their economies, and to stop public health threats, citizens must have the right and ability to protect themselves and enforce it without constraints that would render that right meaningless.

ATTACHMENT A

PACIFIC NORTHWEST NEWS

Farm communities face contaminated water from manure, nitrates, records reveal

Updated Aug 15, 2017;
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By Special to The Oregonian

By Jackie Wang, Nicole Tyau and Chelsea Rae Ybanez

Yakima County in Washington state, home to around 67 dairy farms, sits on aquifers contaminated by nitrates.

In California's San Joaquin Valley, which grows nearly one-quarter of the nation's food, fertilizer and manure spread on farms' fields and orchards have contributed to unsafe nitrate levels in drinking water sources.

The drinking water of millions of Americans living in or near farming communities across the country is contaminated by dangerous amounts of nitrates and coliform bacteria from fertilizer and manure widely used in agriculture, a News21 analysis of Environmental Protection Agency records shows. The records reveal that community water systems serving over 2 million people across the country were cited for excessive nitrate levels.

Those records don't cover the millions of private wells that many Americans use, which are left vulnerable to pollution of shallow groundwater in agricultural areas.

Many farmworkers who live in these communities still have to pay for the contaminated water coming from the faucet, as well as buying bottled water to drink. But the farmers who employ them don't agree with their concerns.

More information

This report is part of a project on drinking water contamination in the United States produced by the Carnegie-Knight News21 program. See the entire project and documentary here.

"They say, 'Why are you complaining? You have jobs? We are giving you jobs. You eat because of us,' " said Irma Medellin, who works with Latino farmworkers in Tulare County to clean up the drinking water. "They contaminate our water, and we, the poor, are paying for water as if we were rich. And we are not rich. But we are paying the price of contaminated water."

While the analysis shows 5,000 nitrate violations can largely be traced back to agricultural activity, 22,971 total coliform violations could be from either human or animal feces. However, in heavily farmed areas, much of the coliform bacteria can be attributed to manure.

A 2012 University of California, Davis, study attributed high nitrate levels in the San Joaquin Valley groundwater to crop and animal agriculture activities based on an analysis of land use and the amount of nitrogen entering the water. Farmers' heavy use of fertilizers and manure on their crops account for most of the nitrate found in the studied area.

People living farther away from agricultural areas also are vulnerable to farming pollution because contaminants can flow downstream in rivers and groundwater.

FARMING-CONTAMINATED DRINKING WATER POSES SERIOUS HEALTH RISKS

Two of the most prominent farming contaminants in water are nitrates and total coliform bacteria.

Nitrate-related contamination comes from fertilizer for crops and manure. The body digests nitrates and turns it into nitrites, which inhibits red blood cells' ability to carry oxygen. The EPA limits nitrate levels to prevent infants from contracting blue baby syndrome, a potentially fatal disorder that deprives infants of oxygen. Research indicates that long-term exposure may affect adults as well.

For the past 20 years, National Cancer Institute researcher Mary Ward has been researching drinking water contaminants, focusing on nitrates and cancer risk. She followed a group of people in Iowa to do so. Though studies need to be repeated before drawing conclusions, she said her research suggests drinking water with high levels of nitrates increases the risk for gastrointestinal and urinary tract cancers.

Tom Nolan, a hydrologist with the USGS, said in agriculturally intense areas, it's fair to say the majority of nitrate pollution comes from agricultural sources.

"That's just because that's where the sources are," Nolan said. "In agricultural areas, there are higher applications of fertilizer ... You can look at (nitrate) exceedance rates and they're highest in shallow groundwater in agricultural areas."

Fertilizer and manure not only increase nitrates in drinking water sources, but also fuel algae blooms that make water unsafe to drink and harder to treat. Cyanobacteria grows in phosphorous-heavy waters, which is primarily caused by manure and fertilizer runoff. Also known as blue-green algae, cyanobacteria becomes problematic for drinking water systems in treatment facilities. During the sanitation process, water treatment facilities apply chemicals to kill the cyanobacteria. When the cell dies, it releases cyanotoxins, which can have health effects ranging from fever to pneumonia to death, according to the EPA.

"The blue-green algae is not regulated. There's no EPA requirement to test for it," said Bill Stowe, the CEO and general manager of Des Moines Water Works. "We test for it because we know from our experience that it is an adverse risk that is unregulated now, but smaller communities don't have the resources or knowledge to do that."

Beyond the problems cyanotoxins create, the chemicals that kill the algae react with organic material in the water and create disinfection byproducts, which increase cancer risk. The News21 analysis showed that water systems across the U.S. were cited over 28,000 times in the last decade for exceeding the byproduct legal limit, exposing over 25 million people to unsafe levels.

Cyanotoxins and cyanobacteria "are significant risks for us because we increase our use of chlorine," Stowe said. "When you increase one, you increase the likelihood of creating carcinogens."

The other major source of water contamination from farming is total coliform bacteria from raw, untreated manure. When rain falls on recently fertilized fields, it pushes contaminants from the surface deeper into the soil, and eventually into groundwater. People can see and smell the brown water from their taps. But in the days before or after, water can continue to be contaminated even if the water runs clear.

Drinking water with total coliform bacteria can cause gastrointestinal illnesses, which are linked to diarrhea, stomach cramps, nausea and fever.

ENVIRONMENTAL REGULATION OF AGRICULTURE IS MOSTLY VOLUNTARY

On a still day in the northwest corner of Washington state, a brown, swirling pool burps methane as liquid manure shoots from a pipe propped up by a tractor. But when a breeze comes by, the smell of 1.5 million gallons of liquid cow manure hits the nose and then lingers in the back of the throat for hours.

This is the manure lagoon on Terry Lenssen's 710-cow dairy farm. Lenssen has only fallen into his manure lagoon once, accidentally backing a tractor into the pit. He's steered clear of the lagoon ever since.

Thousands of dairy farmers around the United States store their cows' manure like Lenssen does, in separate forms: liquid into a large pit, and the solids heaped into soft, dry mountains. Hog and chicken farmers also store vast amounts of manure to use later as fertilizer.

Dairy farmers usually take the liquid manure and apply it to their fields where they grow corn and alfalfa to feed their cattle. But when a farmer applies too much manure for plants to absorb, the rest finds its way out. In addition to that, lagoons can spill over or spring a leak. In a 2013 report about the Lower Yakima Valley in Washington state, the EPA estimated one dairy's lagoon leaked between 482,000 to 5.9 million gallons of liquid manure per year into the surrounding soil.

The EPA started regulating what goes into federal waterways in the 1972 Clean Water Act amendments. Many industries must apply for permits that allow certain discharges into national waterways. But farming is exempt from the Clean Water Act, unless the EPA designates a farm as a concentrated animal feeding operation.

And many operations have not applied for discharge permits. Although the number of feed operations increased by 956 between 2011 and 2016 to a total of 19,496 in the United States, the number of discharge permits has gone down 1,806 in the same five-year period.

Lenssen has not registered as a concentrated feeding operation yet. Washington state implemented a new permit in March, but both environmental groups and dairy organizations immediately filed appeals against the new regulations. In the meantime, Lenssen has a 2-inch-thick binder holding his voluntary nutrient management plan as a testament to his environmental responsibility.

Nutrient management plans are intended to hold farmers accountable for what they apply and how much of it. States decide if they require these plans and how detailed they need to be. While some states, such as Maryland, require farmers to work with a certified professional to construct a nutrient management plan, others don't require consultation with an engineer or nutrient management expert, and farmers can submit their own plans for approval.

"Frankly, if I was to go and open a business today, I would need a business plan but also a permit of some kind," said Meyer, of the Ohio Environmental Council. "Why shouldn't one of the largest industries in the United States be required to have a permit?"

The Natural Resources Conservation Service, an arm of the Department of Agriculture, works with farmers to craft nutrient management plans on a voluntary basis. Each region of the U.S. has different priorities in its plans. Groundwater varies by geographic location. Conditions in one region of a state may drastically differ from a neighboring region of the same state. Aquifers are underground sections of rock that water moves through, and the type and amount of rock, soil and gravel it contains vary by region. Porous rock, such as karst, allows surface water to move quickly into the aquifer below, making it more vulnerable to contamination.

FARMERS AND THOSE SUPPORTED BY FARMERS' MONEY SHAPE AGRICULTURAL POLICY

If an aquifer is contaminated, the private wells that draw water from it become contaminated too.

Larry Fendell, a 60-year-old ex-farmer, regularly attends Lower Yakima Valley groundwater meetings. Stakeholders first met in 2012 to solve nitrate contamination problems in the Lower Yakima Valley groundwater, but Fendell has been fighting for stricter regulations of large dairy farms for 20 years.

"And even if there are regulations, so many things are suggestions," Fendell said. "Nutrient management plans are suggestions. There's no teeth behind them. Everything is voluntary."

Dairyman Dan DeGroot represents the Yakima Dairy Foundation at the meetings. He's part of the advisory committee steering the research and planning to reduce nitrate concentration in groundwater. DeGroot said he defends himself from people who accuse dairy farms of being the biggest polluter of groundwater.

"I said, 'You know what, I care more about drinking water than any of you people in here,'" DeGroot said. "It's of critical importance because I've got 3,500 animals, plus 35 people, plus seven in my family – all drinking this water. I care. A lot."

Though Yakima County is 49 percent Hispanic, the 22-person groundwater management board is all white, save for one Latino representing the Washington State Department of Health. It has not had an active Latino community representative since April. This leaves an already vulnerable community out of the discussion to remedy high nitrate levels, which significantly affect lower-income Latino farmworkers who rely on private wells.

For over three decades, the American Farm Bureau Federation has pushed to exempt farming from environmental regulation. For example, fertilizer and manure are not regulated by the Clean Water Act because agricultural activities are considered "nonpoint source pollution," which means it comes from many sources.

In 2015, a federal judge ruled that over-applied manure could be regulated as waste after examining a case brought against a Washington dairy. The Washington State Dairy Federation, dairy organizations and farm publications opposed the ruling, but also cautioned dairy farms to exceed manure management expectations and prove that more environmental regulation was unnecessary.

U.S. Rep. Dan Newhouse, a well-to-do farmer and Republican congressman who represents farming-focused counties in Washington state, even filed a bill that would exempt fertilizer and animal manure from being regulated as solid waste entirely. Out of the $747,916 Newhouse received from political action committees between 2015 to 2016, 29 percent came from agriculture and food-related PACs.

The American Farm Bureau alone spent almost $3.8 million in lobbying nationally in the 2016 election cycle, according to the Center for Responsive Politics. The center also reported agribusiness organizations – which include farming, food production and stores – spent $127.5 million last year in lobbying the federal government.

Back in California, the Division of Drinking Water is supplying 20 communities in the agricultural San Joaquin Valley with bottled water because of nitrate or coliform bacteria pollution. According to the News21 analysis, the most nitrate citations in the United States over the past 10 years were recorded in Tulare County, which is in the valley. Though nitrates and bacteria are currently below the legal limit, the department still delivers water to them because of historic issues with contamination.

Each resident of unincorporated community Tooleville in Tulare County receives half a gallon of water for drinking and cooking per day, delivered every month and paid for by the state. For many residents, it isn't enough.

One Tooleville resident, Esther Ceballos, buys extra cases of water for herself, her two children and her husband. She still pays $40 a month for tap water she does not use for drinking or cooking.

Rosa Rubio, who lives next to Ceballos, relies on the bottled water delivery for herself, her husband and their four dogs. She said they've known their water was undrinkable since they first moved in, thanks to a neighbor who warned them. Sometimes, their tap water comes out white.

"Even if they say it's OK, we're scared to use that water," she said.

News21 reporter Andrea Jaramillo contributed to this article.

This report is part of a project on drinking water contamination in the United States produced by the Carnegie-Knight News21 program.

HEADLINES

Brown Water

By Jim Lundstrom, Peninsula Pulse – September 17th, 2014

On Sept. 23, the Kewaunee County Board will consider a groundwater ordinance that will ban the spreading of liquid manure on thin topsoil land (20 feet or less) from Jan. 1 to April 15. The following tells the story of one family's exodus from Kewaunee County due to the proliferation of concentrated animal feeding operations (CAFOs).

Thanks to brown, smelly water coming out of her tap in 2004, Judy Treml went from not having a clue about groundwater to being an advocate for others whose wells have been polluted by foolish farm practices.

It all began for the Treml family in February 2004. Six-month-old daughter Samantha was exclusively breast fed, and now her pediatrician wanted her to have a bottle of water daily for the fluoride content, but first he asked the family to test their well water for fluoride.

“On Feb. 4 we had our well tested,” Judy said. “Tests showed minimal amounts of fluoride, no coliform bacteria and nitrate levels were under the cutoff.”

Samantha’s doctor prescribed a fluoride supplement for her.

About 2 1/2 weeks later, a CAFO operator began spreading 80,000 gallons of liquid manure on a 40-acre field across the road from the Tremls, with the permission of the Department of Natural Resources. The farmer’s manure pit was at capacity, so he was told to spread the excess manure. The field was covered by 18 inches of snow that was in active melt at the time he decided to do the spreading.

“It was 40 degrees outside,” Judy said.

Worse yet, the field had fractured outcroppings of bedrock.

“He should never have spread there, not even on a summer day, because the fractured bedrock was so close to the surface,” Treml said.

When her husband, Scott, came home from work, he saw the manure running off the field and across the front yard of a neighbor across the street.

“So he went out there and stopped the farmer in the tractor and told him to stop spreading because it’s running off the field. The farmer said he was going to continue because he was in compliance with the DNR,” Judy said.

Scott contacted the DNR enforcement person for Northeast Wisconsin at that time, who said he would check it out. They never heard from him, so Scott started videotaping the flow of liquid manure from the field, into a ditch, across the neighbor’s property and into Rio Creek, which ran through the back of the Treml’s 80-acre property.

Three days later the Tremls neighbor from across the street brought them a mason jar of black water that came from her tap.

“I felt bad about her water, but I thought, better her than us,” Judy said. “I had no idea that manure can seep through the soil into our well. Our well was a great distance from where he was spreading. I had given Samantha a bath on Sunday, not even thinking about it. Our water had just tested clean a few weeks before. I thought, ‘We’re good.’”

Scott offered to bring the jar of tainted water to work with him in Green Bay on Monday and show it to DNR officials. He first called the DNR office and was told by the person in charge of water quality that he was a busy man and didn’t have time to talk about a jar of black well water.

When Scott got home from work, he was telling Judy about his encounter with the DNR official while she was doing something in the kitchen. She turned on the tap and the water ran brown.

“It smelled like cow manure, like I was standing in the middle of a barn. I turned it off and turned it on, and it was getting browner. The more I ran it, the browner it got,” she said. “I turned around and said to Scott, ‘You need to contact the DNR and get them out here.’ He said, ‘Judy, you don’t

wasn’t helping. Every one of them said the same thing, their first question was, if we come out to your house, will we see manure coming out of your tap? The next day, every news station in Green Bay turned up. In spite of that, the DNR never contacted us."

The same day the TV cameras came to the Treml property, the Kewaunee County Land and Water Committee was meeting, so Judy bundled up her kids and brought a jar of her water and another of her neighbor's water. The DNR was also there, and when they were invited to respond to what was going on, they said the farmer had done nothing wrong.

"Even though they knew manure was running everywhere," Judy said.

As she and her kids were leaving the meeting, a man she never met said, "The DNR won't help you."

"He handed me the card of Andrew Hanson of the Midwest Environmental Advocates (MEA)," Judy said.

"I was not a litigious person. I didn't believe in that," Judy said, "but we didn't know what to do. We didn't know if the kids were going to get sick."

The next day, a DNR representative arrived at the Treml residence to take a water sample.

"Two days later I got a call from the Public Health Department, telling me to shut my water off and remove the kids from the house. The e-coli count was 10,000 parts per milliliter. The coliform counts were 100,000 parts per milliliter. It only takes 1,000 parts per milliliter of e-coli to close the Algoma beach. I didn't know where to go with three kids."

The Tremls learned the DNR had no interest in pursuing the case.

“That forced our hand,” Judy said. “So we called MEA and met with Andrew Hanson. We gave him our information and the evidence we had. He said, ‘I think you have a good case.’ So we hired them. Because we had video evidence of manure running into Rio Creek, that was a violation of the (federal) Clean Water Act. That’s how we started litigation, in federal court, not state court.”

The day after the Tremls went public with their notice of intent to sue, the DNR issued a notice of violation to the farmer.

“What that did to our clean water case in federal court, their case trumped our case. Instead of being pulled out of federal court, the judge let us petition to become interveners,” Judy said.

The Tremls eventually won a damage award, and the CAFO operator was issued a fine, but in the process, the Tremls learned more about the shoddy CAFO implementation procedures.

“The DNR gave the CAFO operator a permit on July 18, the year before our well was polluted, and at that time he didn’t have adequate manure storage. They gave him a permit to expand his herd, knowing he did not have adequate manure storage and not writing anything in his permit that he had to improve his storage,” Judy said. “That’s how we ended up with the predicament he found himself in February. He was able to add to his herd without adding to his storage. Over the years, that has been a bone of contention. CAFOs are required to have six months worth of storage. The ordinance (coming before the Kewaunee County Board on Sept. 23) is asking them to stop spreading from January to April. If they are required to have six months of storage, this should be a non-issue.”

Because of all the publicity the Tremls received during the court battle, Judy started getting phone calls from other distressed families in the same circumstances.

“In 2005 the Town of Morrison had more than 100 wells go bad,” she said. “The Town of Morrison called the DNR and the DNR was not responsive to their calls. So who did they call? I was getting calls from the Town of Morrison about what they should do. That’s how I started working with communities. After Morrison, it was the Town of Cooperstown in southern Brown County. I had a family from Beaver Dam call me, with a situation identical to mine, a husband, wife and three daughters. They had brown, smelly water coming out of their tap after a CAFO spread manure on frozen ground. The DNR did respond to that case.”

In 2010, the family made the bittersweet decision to move from their rural Luxemburg home to Green Bay.

“That was a family farm. It was my husband’s great-grandfather’s homestead. We remodeled it and lived in it. It was something my husband always wanted to do. It was a three-story brick foursquare house. We had no plans on moving but we needed our kids to be safe,” Judy said. “When we bought our house, there was one CAFO within a two-mile radius of our home. In 2010 when we decided to sell, we were going on our sixth CAFO in a two-mile radius. My husband runs a successful business in Green Bay. He saw the writing on the wall. He said if we don’t get out now, our land is going to be worthless. We didn’t want to leave. I would call it more of a business decision. That land was our equity. It was going to be part of our retirement. That was our asset, if you will. But having that many CAFOs in that concentrated of an area, that house was not going to be worth anything. Yes, we did move because of that, the changing landscape of that area. It had just become overwhelming.”

Like others who testified at a Sept. 9 public hearing on Kewaunee County’s proposed groundwater ordinance, Judy said if it passes, it is just a very small step in the needed direction.

“This ordinance is just a tiny little part of Wisconsin that will be impacted. We need this statewide,” she said. “Kewaunee County needs it right now, but we need to close this gap in the state. Right now, nobody in the state is responsible. They have no way to regulate animal waste.”

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The New York Times

U.S.

Health Ills Abound as Farm Runoff Fouls Wells

By CHARLES DUHIGG SEPT. 17, 2009

MORRISON, Wis. — All it took was an early thaw for the drinking water here to become unsafe.

There are 41,000 dairy cows in Brown County, which includes Morrison, and they produce more than 260 million gallons of manure each year, much of which is spread on nearby grain fields. Other farmers receive fees to cover their land with slaughterhouse waste and treated sewage.

In measured amounts, that waste acts as fertilizer. But if the amounts are excessive, bacteria and chemicals can flow into the ground and contaminate residents' tap water.

In Morrison, more than 100 wells were polluted by agricultural runoff within a few months, according to local officials. As parasites and bacteria seeped into drinking water, residents suffered from chronic diarrhea, stomach illnesses and severe ear infections.

"Sometimes it smells like a barn coming out of the faucet," said Lisa Barnard, who lives a few towns over, and just 15 miles from the city of Green Bay.

Tests of her water showed it contained E. coli, coliform bacteria and other contaminants found in manure. Last year, her 5-year-old son developed ear infections that eventually required an operation. Her doctor told her they were most likely caused by bathing in polluted water, she said.

Yet runoff from all but the largest farms is essentially unregulated by many of the federal laws intended to prevent pollution and protect drinking water sources. The Clean Water Act of 1972 largely regulates only chemicals or contaminants that move through pipes or ditches, which means it does not typically apply to waste that is sprayed on a field and seeps into groundwater.

As a result, many of the agricultural pollutants that contaminate drinking water sources are often subject only to state or county regulations. And those laws have failed to protect some residents living nearby.

To address this problem, the federal Environmental Protection Agency has created special rules for the biggest farms, like those with at least 700 cows.

But thousands of large animal feedlots that should be regulated by those rules are effectively ignored because farmers never file paperwork, E.P.A. officials say.

And regulations passed during the administration of President George W. Bush allow many of those farms to self-certify that they will not pollute, and thereby largely escape regulation.

In a statement, the E.P.A. wrote that officials were working closely with the Agriculture Department and other federal agencies to reduce pollution and bring large farms into compliance.

Agricultural runoff is the single largest source of water pollution in the nation's rivers and streams, according to the E.P.A. An estimated 19.5 million Americans fall ill each year from waterborne parasites, viruses or bacteria, including those stemming from human and animal waste, according to a study published last year in the scientific journal Reviews of Environmental Contamination and Toxicology.

The problem is not limited to Wisconsin. In California, up to 15 percent of wells in agricultural areas exceed a federal contaminant threshold, according to studies. Major waterways like the Chesapeake Bay have been seriously damaged by agricultural pollution, according to government reports.

In Arkansas and Maryland, residents have accused chicken farm owners of polluting drinking water. In 2005, Oklahoma's attorney general sued 13 poultry companies, claiming they had damaged one of the state's most important watersheds.

It is often difficult to definitively link a specific instance of disease to one particular cause, like water pollution. Even when tests show that drinking water is polluted, it can be hard to pinpoint the source of the contamination.

Despite such caveats, regulators in Brown County say they believe that manure has contaminated tap water, making residents ill.

"One cow produces as much waste as 18 people," said Bill Hafs, a county official who has lobbied the state Legislature for stricter waste rules.

"There just isn't enough land to absorb that much manure, but we don't have laws to force people to stop," he added.

In Brown County, part of one of the nation's largest milk-producing regions, agriculture brings in $3 billion a year. But the dairies collectively also create as much as a million gallons of waste each day. Many cows are fed a high-protein diet, which creates a more liquid manure that is easier to spray on fields.

In 2006, an unusually early thaw in Brown County melted frozen fields, including some that were covered in manure. Within days, according to a county study, more than 100 wells were contaminated with coliform bacteria, E. coli, or nitrates — byproducts of manure or other fertilizers.

"Land application requirements in place at that time were not sufficiently designed or monitored to prevent the pollution of wells," one official wrote.

Some residents did not realize that their water was contaminated until their neighbors fell ill, which prompted them to test their own water.

"We were terrified," said Aleisha Petri, whose water was polluted for months, until her husband dumped enough bleach in the well to kill the contaminants. Neighbors spent thousands of dollars digging new wells.

At a town hall meeting, angry homeowners yelled at dairy owners, some of whom are perceived as among the most wealthy and powerful people in town.

One resident said that he had seen cow organs dumped on a neighboring field, and his dog had dug up animal carcasses and bones.

“More than 30 percent of the wells in one town alone violated basic health standards,” said Mr. Hafs, the Brown County regulator responsible for land and water conservation, in an interview. “It’s obvious we’ve got a problem.”

But dairy owners said it was unfair to blame them for the county’s water problems. They noted that state regulators, in their reports, were unable to definitively establish the source of the 2006 contamination.

One of those farmers, Dan Natzke, owns Wayside Dairy, one of the largest farms around here. Just a few decades ago, it had just 60 cows. Today, its 1,400 animals live in enormous barns and are milked by suction pumps.

In June, Mr. Natzke explained to visiting kindergarteners that his cows produced 1.5 million gallons of manure a month. The dairy owns 1,000 acres and rents another 1,800 acres to dispose of that waste and grow crops to feed the cows.

“Where does the poop go?” one boy asked. “And what happens to the cow when it gets old?”

“The waste helps grow food,” Mr. Natzke replied. “And that’s what the cow becomes, too.”

His farm abides by dozens of state laws, Mr. Natzke said.

“All of our waste management is reviewed by our agronomist and by the state’s regulators,” he added. “We follow all the rules.”

But records show that his farm was fined $56,000 last October for spreading excessive waste. Mr. Natzke declined to comment.

Many environmental advocates argue that agricultural pollution will be reduced only through stronger federal laws. Lisa P. Jackson, the E.P.A. administrator, has recently ordered an increase in enforcement of the Clean Water Act. Tom Vilsack, the agriculture secretary, has said that clean water is a priority, and President Obama promised in campaign speeches to regulate water pollution from livestock.

But Congress has not created many new rules on the topic and, as a result, officials say their powers remain limited.

Part of the problem, according to data collected from the E.P.A. and every state, is that environmental agencies are already overtaxed. And it is unclear how to design effective laws, say regulators, including Ms. Jackson, who was confirmed to head the E.P.A. in January.

To fix the problem of agricultural runoff, “I don’t think there’s a solution in my head yet that I could say, right now, write this piece of legislation, this will get it done,” Ms. Jackson said in an interview.

She added that “the challenge now is for E.P.A. and Congress to develop solutions that represent the next step in protecting our nation’s waters and people’s health.”

A potential solution, regulators say, is to find new uses for manure. In Wisconsin, Gov. Jim Doyle has financed projects to use farm waste to generate electricity.

But environmentalists and some lawmakers say real change will occur only when Congress passes laws giving the E.P.A. broad powers to regulate farms. Tougher statutes should permit drastic steps — like shutting down farms or blocking expansion — when watersheds become threatened, they argue.

However, a powerful farm lobby has blocked previous environmental efforts on Capital Hill. Even when state legislatures have acted, they have often encountered unexpected difficulties.

After Brown County's wells became polluted, for instance, Wisconsin created new rules prohibiting farmers in many areas from spraying manure during winter, and creating additional requirements for large dairies.

But agriculture is among the state's most powerful industries. After intense lobbying, the farmers' association won a provision requiring the state often to finance up to 70 percent of the cost of following the new regulations. Unless regulators pay, some farmers do not have to comply.

In a statement, Adam Collins, a spokesman for the Wisconsin Department of Natural Resources, said farmers can only apply waste to fields "according to a nutrient management plan, which, among other things, requires that manure runoff be minimized."

When there is evidence that a farm has "contaminated a water source, we can and do take enforcement action," he wrote.

"Wisconsin has a long history of continuously working to improve water quality and a strong reputation nationally for our clean water efforts," he added. "Approximately 800,000 private drinking water wells serve rural Wisconsin residents. The vast majority of wells provide safe drinking water."

But anger in some towns remains. At the elementary school a few miles from Mr. Natzke's dairy, there are signs above drinking fountains warning that the water may be dangerous for infants.

"I go to church with the Natzkes," said Joel Reetz, who spent $16,000 digging a deeper well after he learned his water was polluted. "Our kid goes to school with their kids. It puts us in a terrible position, because everyone knows each other.

"But what's happening to this town isn't right," he said.

TOXIC WATERS: Articles in this series are examining the worsening pollution in American waters and regulators' response.

A version of this article appears in print on , on Page A1 of the New York edition with the headline: Health Ills Abound as Farm Runoff Fouls Wells.

ATTACHMENT B

Environmental Research Letters

LETTER • OPEN ACCESS

Cost of reactive nitrogen release from human activities to the environment in the United States

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LETTER

Cost of reactive nitrogen release from human activities to the environment in the United States

Daniel J Sobota[1,5], **Jana E Compton**[2], **Michelle L McCrackin**[3] **and Shweta Singh**[4]

[1] Oak Ridge Institute for Science and Education, in residence at the Western Ecology Division, US Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR-97333, USA
[2] Western Ecology Division, US Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR-97333, USA
[3] Baltic Sea Centre, Stockholm University, Stockholm, SE-106 91, Sweden
[4] University of Toronto, Toronto, Ontario, Canada
[5] Current address: Environmental Solutions Division, Oregon Department of Environmental Quality, 811 SW 6th Avenue, Portland, OR 97206, USA.

E-mail: sobota.daniel@deq.state.or.us

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Abstract

Leakage of reactive nitrogen (N) from human activities to the environment can cause human health and ecological problems. Often these harmful effects are not reflected in the costs of food, fuel, and fiber that derive from N use. Spatial analyses of damage costs attributable to source at management-relevant scales could inform decisions in areas where anthropogenic N leakage causes harm. We used recently compiled data describing N inputs in the conterminous United States (US) to assess potential damage costs associated with anthropogenic N. We estimated fates of N leaked to the environment (air/deposition, surface freshwater, groundwater, and coastal zones) in the early 2000s by multiplying watershed-level N inputs (8-digit US Geologic Survey Hydrologic Unit Codes; HUC8s) with published coefficients describing nutrient uptake efficiency, leaching losses, and gaseous emissions. We scaled these N leakage estimates with mitigation, remediation, direct damage, and substitution costs associated with human health, agriculture, ecosystems, and climate (per kg of N) to calculate annual damage cost (US dollars in 2008 or as reported) of anthropogenic N per HUC8. Estimates of N leakage by HUC8 ranged from <1 to 125 kg N ha^{-1} yr^{-1}, with most N leaked to freshwater ecosystems. Estimates of potential damages (based on median estimates) ranged from \$1.94 to \$2255 ha^{-1} yr^{-1} across watersheds, with a median of \$252 ha^{-1} yr^{-1}. Eutrophication of freshwater ecosystems and respiratory effects of atmospheric N pollution were important across HUC8s. However, significant data gaps remain in our ability to fully assess N damages, such as damage costs from harmful algal blooms and drinking water contamination. Nationally, potential health and environmental damages of anthropogenic N in the early 2000s totaled \$210 billion yr^{-1} USD (range: \$81–\$441 billion yr^{-1}). While a number of gaps and uncertainties remain in these estimates, overall this work represents a starting point to inform decisions and engage stakeholders on the costs of N pollution.

Introduction

Human modification of biogeochemical cycles is essential to sustain food production and advance technology; but release of chemicals beyond these intended uses can harm human health, ecosystem function, and the global climate system (Bennett *et al* 2001, Galloway *et al* 2003, Davidson *et al* 2012, Leach *et al* 2012). Finding common measures to assess the damages of human-altered biogeochemical cycles has proven complex because of the diversity of effects, multiple spatial and temporal scales on which they are felt, and ambiguity over how alterations are caused by and affect stakeholders (Galloway *et al* 2003, Banerjee *et al* 2013, Ringold *et al* 2013). Additionally, many ecosystem service-related costs are not well understood, are not transferable to dollar values, or are unknown (Bockstael *et al* 2000). Nevertheless, cost-benefit analyses inform the development of effective management policies (Fisher *et al* 2009, Birch *et al* 2011, van Grinsven *et al* 2013). Frameworks developed to analyze the social cost of carbon (Pearce 2003) and ecosystem services (Boyd and Banzhaf 2007) provide ways to conduct such analyses and have been used to guide policy decisions (Rose 2012). However, analyses of the damages from anthropogenic nutrient use at management-relevant scales remain largely absent.

In this paper, we examined potential damage costs associated with human-moderated inputs of reactive nitrogen (N) across the conterminous United States (US). Application of synthetic N fertilizers and cultivation of N-fixing crops are essential components of the US and global agricultural economy (Smil 2002, Houlton *et al* 2013). Anthropogenic N-fixation also creates important industrial products such as explosives, nylon, and plastics (Domene and Ayers 2001). However, numerous human health and environmental problems result from use and unintentional leakage (e.g., during fossil fuel combustion) of N. These problems include increased mortality and morbidity due to air pollution, contamination of drinking water supplies by NO_3^- (a form of N that can cause blue baby syndrome or other health problems in excess amounts), increased frequency and severity of toxic algal blooms and hypoxia in freshwater and coastal marine ecosystems, and global climate change via emission of the potent greenhouse and ozone-depleting gas N_2O (Davidson *et al* 2012). The intensity of N leakage to ecosystems across the US is nearly twice that of the global average and expected to rise in the future (Galloway *et al* 2004, Sobota *et al* 2013). This makes comparisons of damages to benefits associated with N loading particularly important at regional scales across the country.

Damages of reactive N can be attributed to a given source according to economic values (Birch *et al* 2011, Compton *et al* 2011, van Grinsven *et al* 2013). In this approach, the change in damage cost (mitigation, remediation, direct damage, or substitution) according to change in N loading was calculated for specific N sources (e.g., synthetic fertilizer) and specific human health or environmental impacts (e.g., respiratory effects of air pollution or damage to fisheries production). We used this approach to produce the first estimates of damages of external N release for the entire US and to scale damage costs across watersheds.

Our objective was to assess the magnitude and spatial distribution of damages associated with N loading and leakages across the conterminous US. We connected spatial data describing current N loading and leakages by source across the conterminous US with new information on economic damages of N on agricultural production, human health, ecosystems, and climate (Birch *et al* 2011, Compton *et al* 2011, van Grinsven *et al* 2013). Damages to human health were expected to exceed costs associated with altered ecosystem functions, based on high values placed on human health (Chestnut and Mills 2005, Birch *et al* 2011).

Methods

1. Spatial distribution of N inputs

We compiled spatial data describing new (fixed directly from the atmosphere) and recycled (waste disposal and airborne ammonia) N inputs from human-mediated sources in the early 2000s for the conterminous US. We chose spatial datasets that offered complete coverage of the US land area, the highest spatial resolution, and complete metadata describing data acquisition and representation (Sobota *et al* 2013). We chose the range of the early 2000s because selected datasets did not always have common years. Although N loading rates from specific sources can vary annually, we assume that the individual years captured here approximately represent N loading for this period because year-to-year variation for most inputs is small relative to the amount of the inputs (Sobota *et al* 2013). Also, by choosing this window for comparison, we minimize effects of long-term trends in N inputs, such as decadal trends in declining NO_x emissions and increasing N fertilizer use (Sobota *et al* 2013). We summarized inputs at the spatial resolution of USGS 8-digit Hydrologic Unit Codes (HUC8s; http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml) using the Zonal Statistics tool in the Spatial Analyst feature of ArcMap 10.0 (ESRI Inc., Redlands, CA).

For agricultural N inputs (synthetic fertilizer, cultivated biological nitrogen fixation (C-BNF), and confined animal feeding operations (CAFO) manure), we used county-level data for years 2001–2002 (Ruddy *et al* 2006, USDA 2013a). All county-level estimates originate from Ruddy *et al* (2006) except C-BNF, which was estimated by applying coefficients described in Smil (1999) and Howarth *et al* (2002) to areas planted in N-fixing crops or in pasture for 2002 (USDA 2013a). County-scale data were converted to HUC8-scale data by rasterizing county-scale data to 30 arcsecond resolution (~1 km × ~1 km at the equator) and summarizing by HUC8 using the Zonal Statistics tool in ArcMap 10.0.

We estimated the spatial distributions of wastewater and inorganic N deposition to the US using the following methods. For wastewater, we applied the treatment-corrected per capita excretion rate of N (2.8 kg N person yr^{-1}; Van Drecht *et al* 2009) to a 1 km × 1 km gridded dataset of the US population in 2000 (http://lwf.ncdc.noaa.gov/oa/climate/research/population/; rounded to the nearest 10 000). We used 36 km × 36 km gridded data modeled by CMAQ for 2002 (US EPA 2013a) to estimate atmospheric N deposition (inorganic) in the US, assuming that oxidized N (NO_x) originated primarily as new N and ammonia (NH_3) originated as recycled N (Holland *et al* 2005). We summarized annual N inputs of sewage and atmospheric N deposition by HUC8 by rasterizing data (deposition data only; wastewater data were already converted to the appropriate resolution) to 30 arcsecond resolution and summarizing by HUC8 using the Zonal Statistics tool in ArcMap 10.0.

We acknowledge that fine scale variation in N deposition from agricultural activities and roadways may not be sufficiently captured at this resolution. However, our objective was to provide broad watershed and regional estimates of N inputs and ultimately damages. Thus we believe 36×36 km gridded data were sufficient for this purpose, especially when summarizing by HUC8 watershed scales. New, multiyear national scale data describing N inputs at finer scales would help improve these estimates.

2. N leakage to the environment

We estimated N leaked to the environment for individual HUC8s by multiplying the published observed and modeled data describing N inputs to land surfaces (detailed in the previous section) with published coefficients describing the transfer of N to crops, air, land, and water. We did this to calculate damage costs of N at different locations in the N cascade (Galloway *et al* 2003). For simplicity, we assumed that the loss coefficients were spatially homogeneous across the conterminous US, which is likely an oversimplification that could be improved with more unified spatially explicit modeling across systems at the national scale.

We used deposition rates of NO_x–N and NH_3–N (described in the previous section) to characterize leakage of airborne N to HUC8s. Portions of reactive N emitted to the atmosphere can be transported long distances; however, a substantial fraction, particularly ammonia, is deposited locally (Galloway *et al* 2004).

Atmospheric N_2O was estimated by multiplying published coefficients describing fractions of various land-based inputs of N converted to N_2O by the loading rates of land-based N inputs not converted to products (e.g., 60% of synthetic N fertilizer input; Houlton *et al* 2013). We used estimates that 1.1% of N inputs associated with C-BNF, 2.2% of synthetic N fertilizer and manure inputs, and 6% of anthropogenic NO_x emissions (characterized by NO_x deposition rates) were emitted as N_2O (Bouwman 1996, US EPA 2008, Davidson 2009, US EPA 2013b).

N loading to waters included proportions entering surface freshwater, groundwater, and coastal zones. We estimated the proportion of N entering surface freshwater as one-third of the sum of new and recycled anthropogenic non-point N inputs plus sewage N (SAB 2011, Houlton *et al* 2013). Of the remaining two-thirds of anthropogenic non-point N inputs, we calculated that one-third was stored in soil organic matter or denitrified, while one-third leached to groundwater (Houlton *et al* 2013). Though uncertainty behind these splits remains large, N pools calculated using this approach compares well with previous national-scale estimates (SAB 2011). Additional monitoring is needed to improve these estimates. Finally, N delivered to coastal waters from anthropogenic sources was calculated as 40% of anthropogenic N delivered to surface waters within individual HUC8s that eventually drain to coastal areas (McCrackin *et al* 2013).

3. Potential damage costs associated with N inputs

Damage costs associated with specific N inputs were compiled from Compton *et al* (2011) and van Grinsven *et al* (2013) in terms of damage cost (US dollars in the year 2008 or as reported) per kg of N input (table 1). Most of these estimates were taken from large-scale studies (national or regional in nature) to avoid the problems associated with benefit transfer where using site-specific information can produce unreasonable costs for different areas (Plummer 2009). Though we have N loading data from most HUC8s, we do not have cost data for all areas of the US. For these reasons, we consider our estimates to be potential damage costs. These values represent incremental or marginal increases in cost from a current value on a per unit of N basis and assume a linear response function. Nonlinear responses, particularly related to thresholds at low or high N loading rates, might occur but cannot be modeled currently due to limited data (Compton *et al* 2011). This could be a very important consideration, but currently there is not enough information to construct cost estimates using nonlinear effects. For more details on how damage costs associated with N were calculated and compiled, see Compton *et al* (2011) and Birch *et al* (2011).

N can cause damages multiple times along an N cascade from fixation back to N_2 gas (Galloway *et al* 2003). We therefore did not use a mass balance approach to calculate damages, because a single N input could have multiple damages. For example, oxidized N emitted during fossil fuel combustion damages human health while in the atmosphere, damages and (or) benefits to crop production when deposited, and damages water quality when leached into surface- or groundwater. We calculated the spatial distribution of damage costs by multiplying specific damage costs with corresponding N loss pathways in individual HUC8s (table 1). We summed individual damages to produce total damage costs at the scale of HUC8s and the conterminous US. For these calculations, we chose to attribute the atmospheric damages occurred where $NO_x$and NH_3 were deposited. We classified individual damage costs as having effects on air/climate, land, freshwater, drinking water, or coastal zones. All

Table 1. Potential damage costs of N (\$/kg N; 2008 or as reported) to air, land, and water resources in the conterminous United States in the early 2000s. Low, median, and high costs derive from the specific damage cost reference. Negative values indicate an economic benefit.

		Cost (\$/kg N)			
N damage type	System	Low	Median	High	Reference
From atmospheric NO_x					
Increased incidence of respiratory disease	Air/Climate	12.88	23.10	38.63	Birch *et al* (2011), van Grinsven *et al* (2013)
Declining visibility—loss of aesthetics	Air/Climate	0.31	0.31	0.31	Birch *et al* (2011)
Increased effects of airborne particulates/increased carbon sequestration in forests (includes benefits)	Air/Climate	−11.59	−4.51	2.58	van Grinsven *et al* (2013)
Increased damages to buildings from acid	Land	0.09	0.09	0.09	Birch *et al* (2011)
Increased ozone exposure to crops	Land	1.29	1.51	2.58	Birch *et al* (2011), van Grinsven *et al* (2013)
Increased ozone exposure to forests	Land	0.89	0.89	0.89	Birch *et al* (2011)
Increased loss of plant biodiversity from N enrichment	Land	2.58	7.73	12.88	van Grinsven *et al* (2013)
From atmospheric NH_3					
Increased incidence of respiratory disease	Air/Climate	2.58	4.93	25.75	Birch *et al* (2011), van Grinsven *et al* (2013)
Declining visibility—loss of aesthetics	Air/Climate	0.31	0.31	0.31	Birch *et al* (2011)
Increased effects of airborne particulates/increased carbon sequestration in forests (includes benefits)	Air/Climate	−3.86	−1.93	−1.93	van Grinsven *et al* (2013)
Increased damages to buildings from particulates	Land	0.09	0.09	0.09	Birch *et al* (2011)
Increased loss of plant biodiversity	Land	2.58	7.73	12.88	van Grinsven *et al* (2013)
From N_2O					
Increased ultra-violet light exposure from ozone—humans	Air/Climate	1.29	1.33	3.86	Compton *et al* (2011), van Grinsven *et al* (2013)
Increased emission of a greenhouse gas	Air/Climate	5.15	13.52	21.89	van Grinsven *et al* (2013)
Increased ultra-violet light exposure from ozone—crops	Air/Climate	1.33	1.33	1.33	Birch *et al* (2011)
From surface freshwater N loading					
Declining waterfront property value	Freshwater	0.21	0.21	0.21	Dodds *et al* (2009)
Loss of recreational use	Freshwater	0.17	0.17	0.17	Dodds *et al* (2009)
Loss of endangered species	Freshwater	0.01	0.01	0.01	Dodds *et al* (2009)
Increased eutrophication	Freshwater	6.44	16.10	25.75	Compton *et al* (2011), van Grinsven *et al* (2013)
Undesirable odor and taste	Drinking water	0.14	0.14	0.14	Kusiima and Powers (2010)
Nitrate contamination	Drinking water	0.54	0.54	0.54	Compton *et al* (2011)
Increased colon cancer risk	Drinking water	1.76	1.76	5.15	van Grinsven *et al* (2013)
From groundwater N loading					
Undesirable odor and taste	Drinking water	0.14	0.14	0.14	Kusiima and Powers (2010)
Nitrate contamination	Drinking water	0.54	0.54	0.54	Compton *et al* (2011)
Increased colon cancer risk	Drinking water	1.76	1.76	5.15	van Grinsven *et al* (2013)
From coastal N loading					
Loss of recreational use	Coastal zone	6.38	6.38	6.38	Birch *et al* (2011)
Declines in fisheries and estuarine/marine habitat	Coastal zone	6.00	15.84[a]	26.00	Compton *et al* (2011), van Grinsven *et al* (2013)

[a] Excluding \$56/kg N from submerged aquatic vegetation loss in the Gulf of Mexico from Compton *et al* (2011)

statistical analyses were conducted in R v.3.0.0 (R Development Core Team 2011).

Results

4. Anthropogenic N inputs

Median input of new human-mediated N to HUC8s in US (in the early 2000s) was 26 kg N ha^{-1} yr^{-1}, with a minimum and maximum of <1 and 130 kg N ha^{-1} yr^{-1}, respectively (figures 1(A) and 2(A)). At the national scale, we estimate that 19.4 Tg of new N entered US air, land, and waterways in the early 2000s (figure 2(B)). The average input of recycled human-mediated N to HUC8s was 9 kg N ha^{-1} yr^{-1}, with a minimum and maximum of <1 and 85 kg N ha^{-1} yr^{-1}, respectively (figures 1(B) and 2(A)). Nationally, we

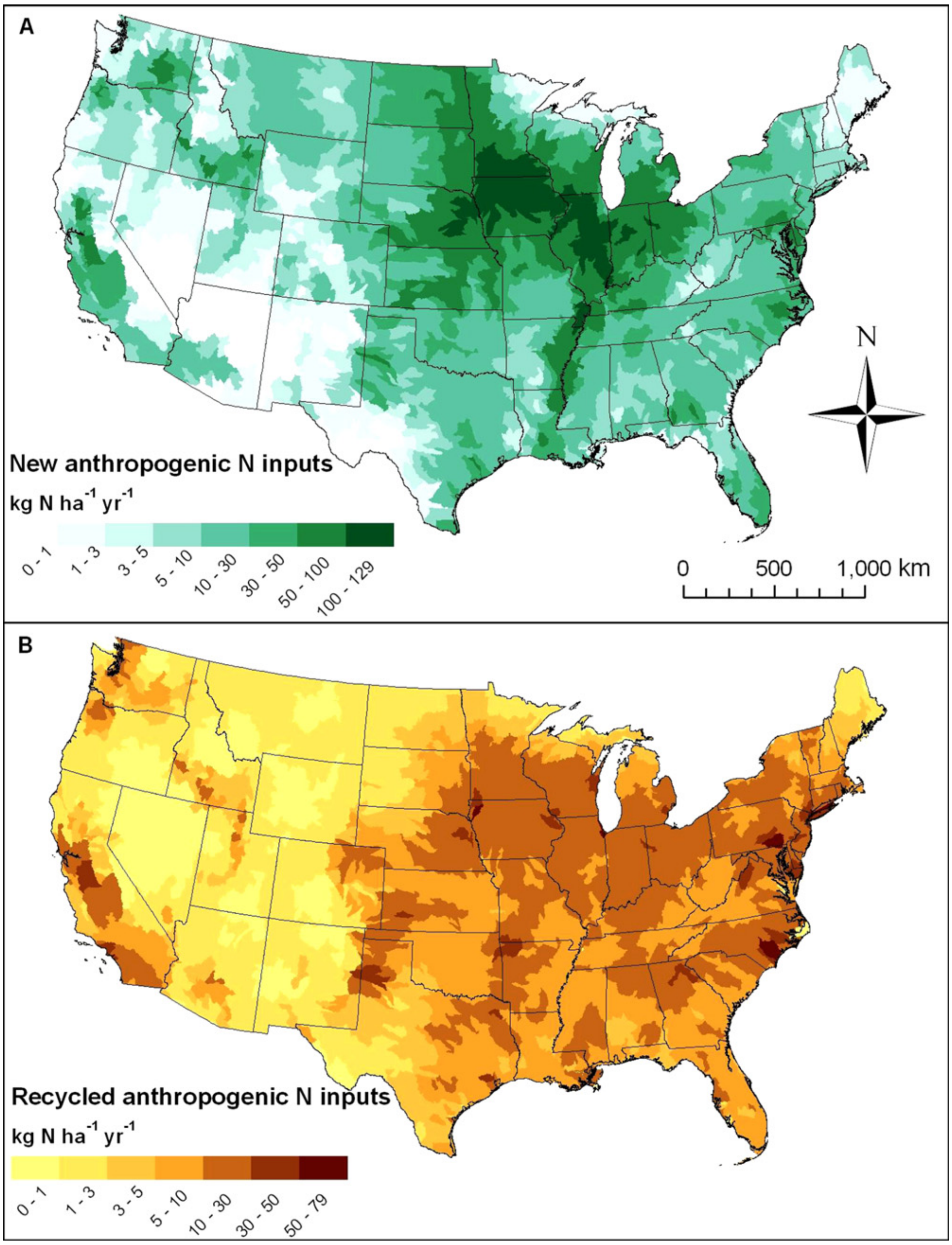

Figure 1. Distribution of new (A) and recycled (B) anthropogenic N inputs to 8-digit US Geologic Survey Hydrologic Unit Code (HUC8) watersheds in the United States in the early 2000s. New anthropogenic N inputs include synthetic fertilizer, cultivated biological N fixation (C-BNF), and the emission/deposition of oxidized forms of N associated with fossil fuel combustion. Recycled anthropogenic N inputs include emission/deposition of ammonia, spread of manure collected on confined animal feeding operations onto agricultural fields, and sewage discharge. N inputs represent average per area N input to the entire HUC8 watershed.

estimate that 6.3 Tg N of recycled N entered US air, land, and waterways in the early 2000s (figure 2(B)).

Across the conterminous US, synthetic N fertilizer and C-BNF were the largest and second-largest overall human-mediated N sources by HUC8 and at the national scale (figure 2). Oxidized N deposition was the third largest new N source by HUC8 and nationally, but dominated total inputs in many urban areas (e.g., portions of the East Coast, the Upper Great Lakes region, the Southwest, and the Pacific Northwest). Ammonia and manure N from CAFOs were the first and second largest sources of recycled N to HUC8s and nationally, and were most important in areas with high livestock populations, such as Eastern North Carolina, Northern Georgia, and Western Arkansas. Inputs of N from sewage were the smallest of either new or recycled N sources across HUC8s and nationally (figure 2), although sewage dominated overall N inputs in some HUC8s draining major urban areas such as New York, Denver, Las Vegas, and Los Angeles.

5. Anthropogenic N leaked to the environment

The amount of anthropogenic N leaked to the environment in HUC8s ranged from 0.1 to 104 kg

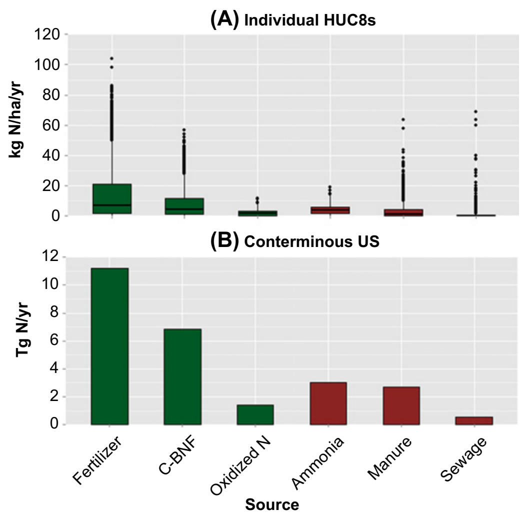

Figure 2. Boxplots of (A) per area anthropogenic N inputs by source to HUC8 watersheds in the early 2000s ($n = 2107$ per N input) and (B) total anthropogenic N input to the conterminous US in the early 2000s. For panel (A), bottom and top whiskers indicate 10th and 90th percentiles, bottom and top box edges depict 25th and 75th percentiles, and the line in the box is the median. Green indicates newly fixed N while brown indicates recycled N in both panels.

N ha^{-1} yr^{-1} with a median of 17 kg N ha^{-1} yr^{-1} (figure 3). N leakages followed a spatial pattern similar to that as new and recycled N inputs to HUC8s, with the upper Midwest and Central California losing the largest amounts of N to the environment. Based on median values of all HUC8s, the ranking of leakages was as follows: surface freshwater (4.5 kg N ha^{-1} yr^{-1}), ammonia to the atmosphere and eventually land surfaces (3.8 kg N ha^{-1} yr^{-1}), groundwater (3.7 kg N ha^{-1} yr^{-1}), oxidized N from fossil fuel combustion to the atmosphere and eventually land surfaces (3.3 kg N ha^{-1}yr^{-1}), coastal zones (1.8 kg N ha^{-1}yr^{-1}), and N_2O (0.4 kg N ha^{-1} yr^{-1}) (figure 4(A)). At the national scale, the ranking of leakages was as follows: surface freshwater (4.8 Tg N yr^{-1}), groundwater (4.2 Tg N yr^{-1}), ammonia (3.0 Tg N yr^{-1}), coastal zones (1.9 Tg N yr^{-1}), and oxidized N from fossil fuel combustion (1.4 Tg N yr^{-1}) (figure 4(B)).

6. Potential damage costs associated N inputs

Potential damage costs associated with anthropogenic N leakage ranged from \$1.94 to \$2255.00 ha^{-1} yr^{-1} across HUC8s in 2000 (figure 5). Between 73 and 77% (median = 75%) of the potential damage costs were associated with leakage of agricultural N, driven by harmful effects on aquatic habitat and eutrophication. Another 14–24% of the potential damage costs (14–\$94 billion; median = \$50 billion or 24% of the median total of \$210 billion) were associated with fossil fuel combustion. Areas with the largest damage costs corresponded to areas with the largest N inputs and leakages (figures 1 and 3), such as the upper Midwest and Central California. However, due to the differential costs of damages to human health/society, ecosystems, agriculture, and climate, several regions with smaller N inputs and leakages had damage costs comparable to areas with higher overall N loads (figures 1, 3, and 5). For example, the mid-Atlantic, Pacific Northwest, and Southern California received less N annually than intense agricultural areas such as the upper Midwest; yet damage costs associated with N leakages were similar because of the high cost of air pollution on human health.

Potential damages to aquatic ecosystems generally followed the spatial distribution of total N inputs (figure 6). In contrast, potential damages to air and climate were more evenly distributed across the conterminous US because of the high cost of air pollution on human health (figure 7). Potential damage costs of anthropogenic N to HUC8s by system ranged from median values of \$17.73 ha^{-1} yr^{-1} to drinking water to \$73.73 ha^{-1} yr^{-1} to freshwater ecosystems (figure 8(A)). At the national scale, best estimates of potential damages ranged from \$19 billion associated with drinking water impacts to \$78 billion associated with impacts on freshwater ecosystems (figure 8(B)). However, substantial ranges of total damages occur within and across systems affected based on all available damage cost estimates (error bars in figure 8(B)). Summing up HUC8 estimates across the US suggests that anthropogenic N leaked to the environment contributed \$81–\$441 billion (median estimate of \$210 billion) in potential damage costs annually to the US economy in the early 2000s. Summaries of damages to endpoint effects are detailed in appendices A and B.

Discussion

7. Fates and damages of N leaked to the environment

This work represents a first attempt to assess damage costs associated with N leakage to the environment from all human activities in the US. Nearly 75% of the damage costs were associated with agricultural N leakage and effects on aquatic systems. Although fossil fuel combustion represents less than 17% of the release to the environmental, 24% of the damages were associated with fossil fuel combustion. Fossil fuel sources cause disproportionally higher relative costs due valuation of human health impacts resulting in comparatively larger unit damage costs (through respiratory and cardio-vascular effects of particulate matter and ground level ozone) than is the case for ecosystem and crop impacts (Muller and Mendelsohn 2007, Birch et al 2011). The damage costs represent the sum of all available costs associated with N leakage; because damage cost estimates are linearly proportional to leakage, marginal reductions in a source (e.g., a 25% reduction in release of N from agriculture or sewage) would be expected to result in a concomitant reduction in damages. This assumption

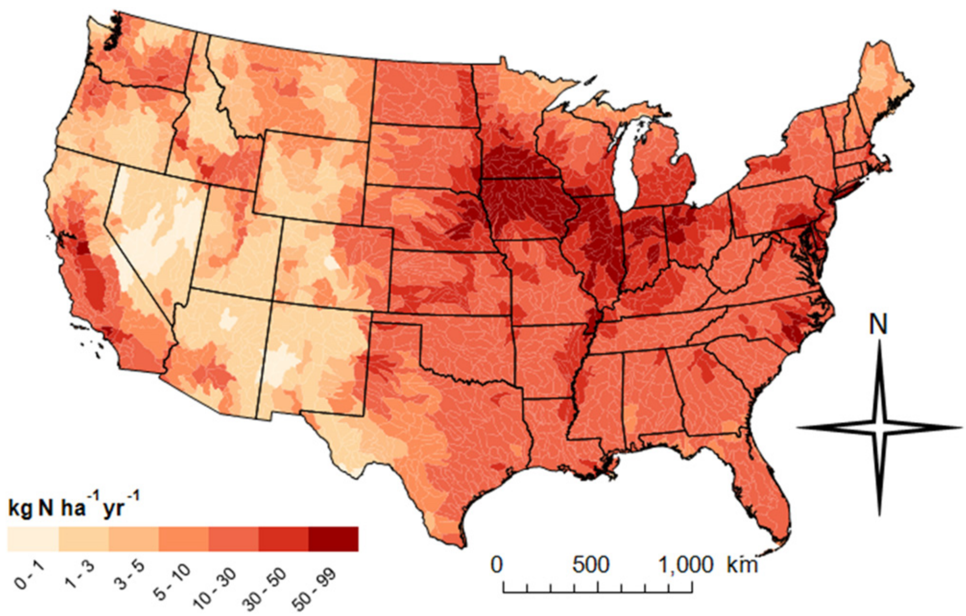

Figure 3. Distribution of total anthropogenic N leaked to the environment in HUC8 watersheds across the conterminous US in the early 2000s. Leaked N consists of the fractions of new and recycled anthropogenic N inputs that are not utilized directly in human products and are lost to air, land, or water resources (see text for details). N leakages represent average per area N leakages for the entire HUC8 watershed.

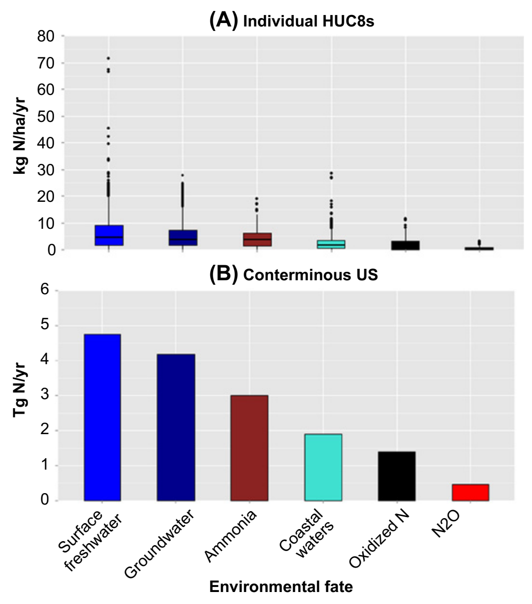

Figure 4. Boxplots of (A) per area anthropogenic N leakage to the environment to HUC8 watersheds of the conterminous United States in the early 2000s ($n = 2107$ per N input) and (B) total anthropogenic N leakage to the environment the conterminous US in the early 2000s. For panel (A), bottom and top whiskers indicate 10th and 90th percentiles, bottom and top box edges depict 25th and 75th percentiles, and the line in the box is the median.

of linearity is an important topic for further research. Nearly 71% of anthropogenic N leaked to the environment ended up in water resources, which is consistent with previous N cycling studies in the US (Jordan and Weller 1996, Howarth *et al* 2002, Alexander *et al* 2008, SAB 2011, Davidson *et al* 2012).

Areas with substantial agricultural N inputs tended to have greater damage costs due to high N loading rates compared to urban and non-cultivated lands. Within agricultural regions, application of synthetic N fertilizers, C-BNF by crops such as soybeans and alfalfa, and land application of manure generated on CAFOs largely drove N loading and leakages. Improvements to fertilizer application practices and the development of crop strains with high nutrient uptake efficiency over the past 40 years have prevented much larger N leakages (Cassman *et al* 2002). In spite of these improvements in efficiency, cultivation of major grain and fodder crops still contribute the largest share of N leaked to the environment, and economic damages, in many US watersheds (Jordan and Weller 1996, Alexander *et al* 2008).

8. Opportunities to reduce damages

Although we did not specifically examine reduction strategies, others have suggested actions to improve nutrient management and slow the release of N to air and water that in turn could reduce damages in many watersheds. Many of these efforts, such as crop breeding and improvements to N application methods, are currently underway (Cassman *et al* 2002, Robertson and Vitousek 2009). For example, N use efficiency by corn has nearly doubled since the 1970s (Cassman *et al* 2002). Improvements to N use efficiency are still possible because the complete set of recommended practices has a low adoption rate in up

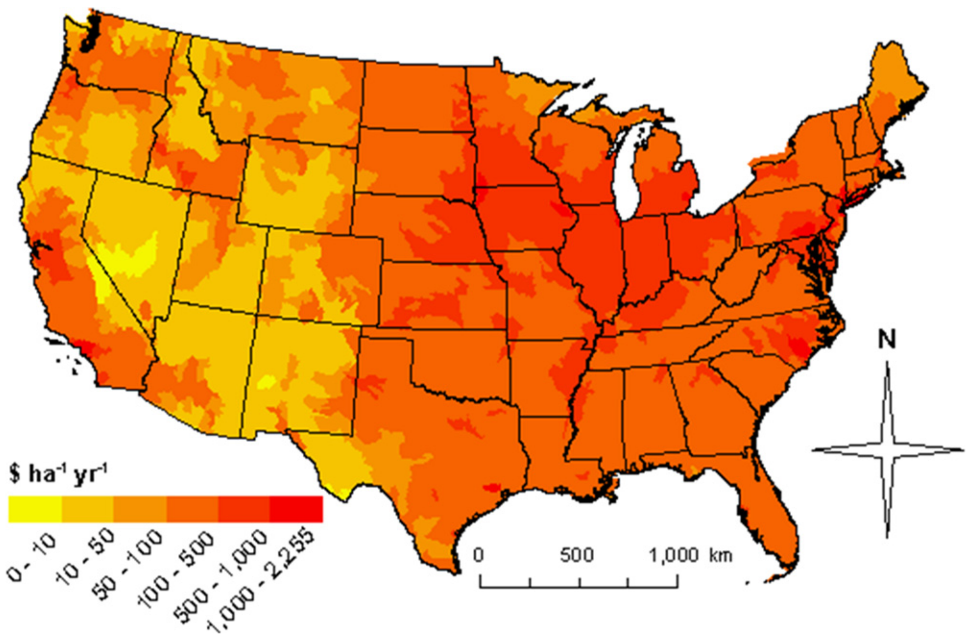

Figure 5. Distribution of total potential damage costs caused by anthropogenic N leaked to the environment by HUC8 watersheds of the conterminous United States in the early 2000s. Potential damage costs were calculated by multiplying specific new and recycled anthropogenic N inputs by source with the central damage cost estimate of US dollars (2008 or as reported) per kg of N leaked to the environment.

to 70% of croplands across the US (Ribaudo *et al* 2011). Increased N use efficiency could also be achieved in livestock production since of the nearly 7 Tg N yr^{-1} fed to livestock (SAB 2011, Foley *et al* 2011), ~70% leaks to air, land, and water via ammonia emissions and manure spreading (Sobota *et al* 2013). From a human health perspective, ammonia emissions are particularly damaging, causing significant respiratory illness with damage costs of over $100/kg N in some locations (Paulot and Jacob 2014). Nitrate derived from manure also impacts drinking water supplies in areas where CAFOs are clustered (Rosenstock *et al* 2014). Due to social and economic realities, better agricultural N management will require increased efforts in watershed education, technical support and funding focused on nutrient management (Osmond *et al* 2014).

Social changes at the scale of individual choices could improve N use efficiency in products and reduce demand for N. Three such changes include reducing food waste (USDA 2013b), promoting diets with more plant-based protein (Howarth *et al* 2002), and increasing the use of mass transit systems (Leach *et al* 2012). Additional reductions can be achieved through continued improvements in sewage treatment and maintaining the N reductions associated with Clean Air Act regulations (SAB 2011). The damage cost information here could represent an opportunity for decision-makers to identify places and sources of N where the tradeoffs are worth these investments in improved N management.

9. Context of damage costs associated with N use

Addressing the benefits of N use within the US was beyond the scope of this study, and more work is needed to fully assess the overall costs and benefits of N use. Our national estimate of potential damages ($210 billion yr^{-1}; range $81–$441 billion yr^{-1}) was equivalent to 1–3% of the national gross domestic product in 2000 (IMF 2013). This range of damages is similar in magnitude to a recent continental scale assessment for the European Union ($97–625 billion USD, van Grinsven *et al* 2013). Our estimated potential damages associated with NO_x and NH_3 were approximately $43 billion yr^{-1}; quite similar to $29.5 billion gross annual damages associated with NO_x and NH_3 from Muller and Mendelsohn (2007). Potential damages from agricultural N use ($59–$340 billion yr^{-1}; median of $157 billion yr^{-1}) were a large portion of the total damages. In the European Union, van Grinsven *et al* (2013) estimated that damages of agricultural N pollution exceeded economic benefits of increased agricultural production by up to fourfold.

Anthropogenic N fixation is essential to modern society and technology. In particular, at least one-third of the world's population would not be alive without synthetic N fertilizers (Smil 1997). The nutritional value of food is also greatly enhanced through use of synthetic N fertilizers or legume-based N (Smil 2002). Additionally, a number of indirect economic benefits result from anthropogenic N fixation in agriculture and industry that

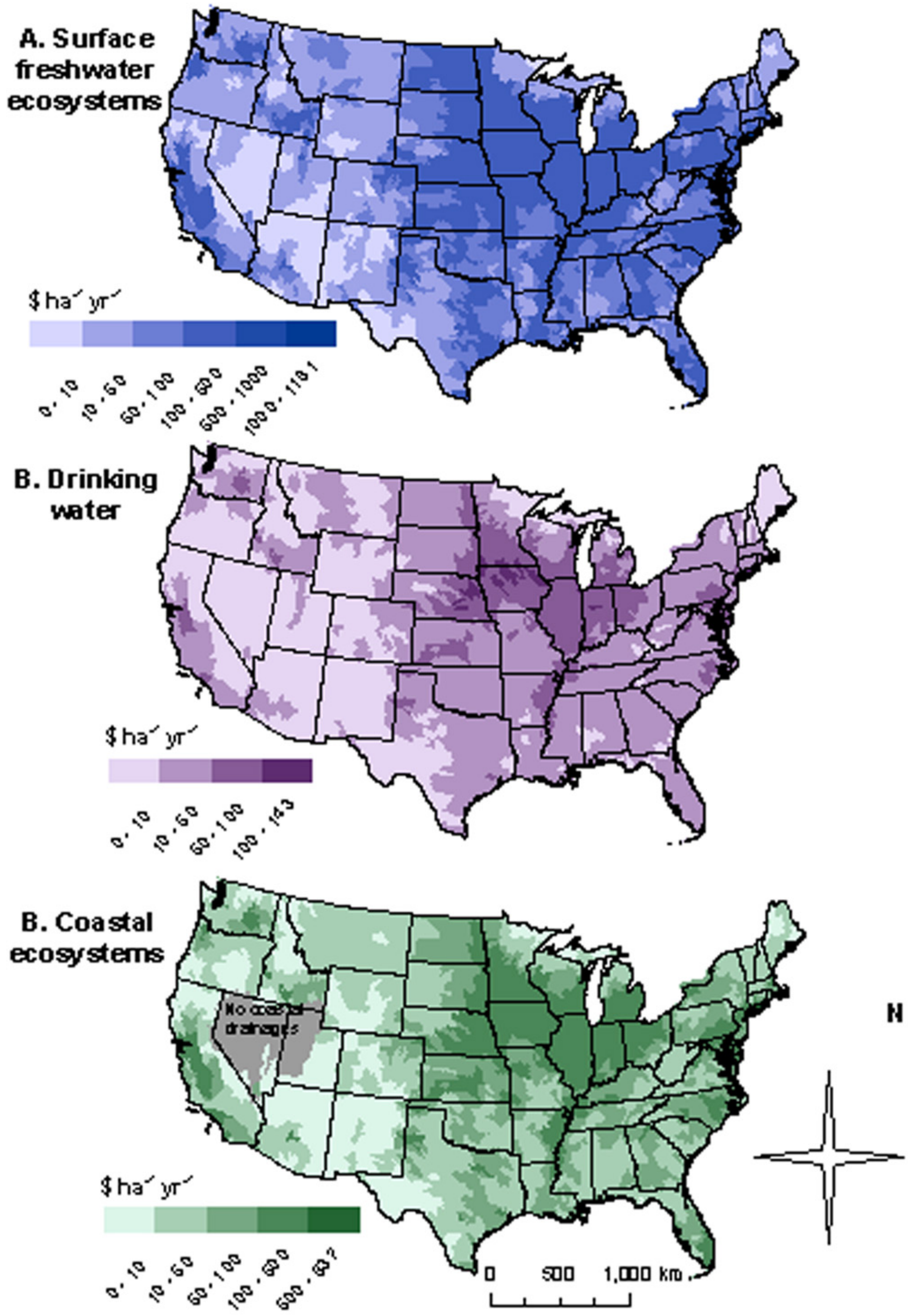

Figure 6. Distribution of potential damage costs to (A) freshwater ecosystems, (B) drinking water, and (C) coastal ecosystems caused by anthropogenic N leaked to the environment by HUC8 watersheds of the conterminous United States in the early 2000s. Potential damage costs were calculated by multiplying specific new and recycled anthropogenic N inputs by source with the median damage cost per kg of N leaked to the environment.

are not directly quantified by on-site farm profit margins (Singh and Bakshi 2013). These include retail sales, transportation, and international transport of agricultural goods and industrial products reliant on anthropogenic N fixation. Our estimate of the damages of reactive N leakage to the environment thus could serve as a starting point for the costs component of needed research to assess the tradeoffs associated with N use and release.

10. Limitations and research needs

Our estimates highlight the need for improved spatial estimates of N leakages throughout the US and more data describing the link between N overabundance and damages to health and the environment. Key research needs include:

- *Response curves of damage costs.* Because of the lack of data describing marginal response curves of

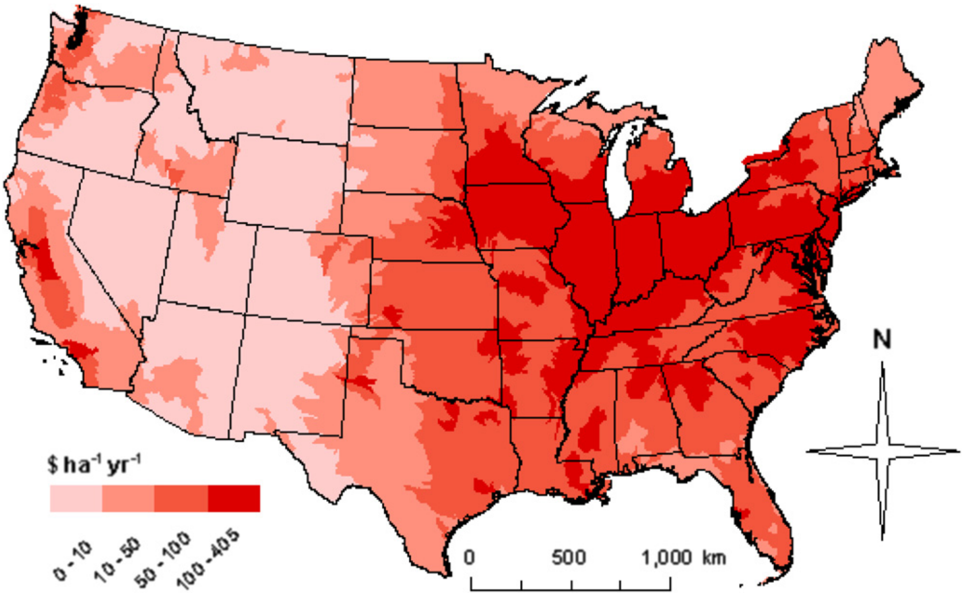

Figure 7. Distribution of potential damage costs (2008 or as reported) to air and climate caused by anthropogenic N leaked to the environment by HUC8 watersheds of the conterminous United States in the early 2000s. Potential damage costs were calculated by multiplying specific new and recycled anthropogenic N inputs by source with the median damage costs in US dollars (2008 or as reported) per kg of N leaked to the environment.

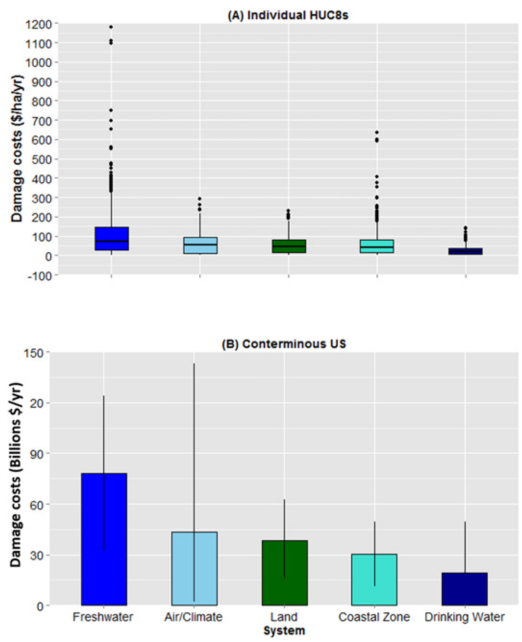

Figure 8. Boxplots of (A) per area potential damage costs (2008 or as reported) from anthropogenic N by system affected to HUC8 watersheds in the early 2000s ($n = 2107$ per system) and (B) total potential damage costs from anthropogenic N input to the conterminous US in the early 2000s. For panel (A), bottom and top whiskers indicate 10th and 90th percentiles, bottom and top box edges depict 25th and 75th percentiles, and the line in the box is the median of the median potential damage costs listed in table 1. For panel (B), bars represent potential damage costs from median damage costs in table 1 while the whiskers represent total damage costs calculated from low and high damage cost estimates.

economic damages with incremental increases in N loading by source, our estimates are constrained by an assumption of linear scaling of damages with loading rates. Many marginal costs respond nonlinearly to incremental changes in stressors (Boyd and Banzhaf 2007); undoubtedly this is the case with N loading. Improved marginal cost response curves of N loading to freshwater ecosystems, coastal zones, and air are particularly important because they have the highest per area damage costs identified in our analysis. One way to address this in the future would be to incorporate a critical loads approach, where there is a threshold below which damages are minimal and above which costs are asymptotic (Pardo *et al* 2011, Clark *et al* 2013). For economic damages we are not yet able to define such a threshold.

- *Costs associated with aquatic eutrophication.* Data describing damage costs associated with eutrophication in freshwater and coastal ecosystems are sparse and may not capture the full range of important effects (Dodds *et al* 2009). Future studies that link N loading to aquatic ecosystems with short and long-term health impacts (e.g., hospital visits and chronic diseases) as well as with loss of economic development (e.g., loss of recreational activities) would advance our understanding of the widespread impacts of N leakages to freshwater systems.
- *Health and treatment costs of N contamination of drinking water.* As the number of community water supplies with NO_3^- violations have increased over the past two decades (US EPA 2013c), more information is needed concerning the long-range health consequences with N pollution of drinking

water supplies (Davidson *et al* 2012, Brender *et al* 2013). Research is needed that examines spatial variability of these costs due to differences in treatment technologies or the magnitude, frequency, and duration of exposure to harmful N levels.

- *Economic impacts of atmospheric N emissions on global climate.* Atmospheric levels of N_2O have increased significantly over the past century (Davidson 2008). At the same time, particulates formed from oxidized N and ammonia have had a cooling effect on the global climate (Pinder *et al* 2013). Additionally, broad-scale N fertilization of terrestrial ecosystems from N deposition may be enhancing carbon sequestration (Pinder *et al* 2013), offsetting effects of increased carbon emissions. Uncertainty about these interactions makes research linking N leakages with climate critical.

Conclusions

Here we provide initial estimates of damage costs associated with leakages of anthropogenic N to the environment across the conterminous US. Most N (71% of leakage) ended up in water resources (surface freshwater, groundwater, and coastal zones), where it led to several costly effects. Health impacts of air pollution were also costly across the nation, disproportionately more expensive relative to the amount of N leaked to air versus water because of the high cost of respiratory illnesses associated with ozone and particulate matter precursors. Cooling associated with particulates had a slight climate benefit based on current data. Improving N use efficiency, particularly in agricultural ecosystems, and modifying social behavior to demand less N will be critical to reduce damages to human health and aquatic ecosystems.

Currently, damages of N leakages from agriculture and other non-point sources are considered externalities not captured in the cost of doing business. Our current analysis could provide a starting point to aid N management at watershed, regional, and national scales in the US. It could also allow stakeholders to illustrate benefits associated with targeted N reductions by agricultural or industrial sector. This information could provide insight on N use choices in individual HUC8s, and illustrate to decision-makers and key stakeholders the ecosystem and human health benefits of improved N management. Although there are a number of gaps and uncertainties in these estimates, overall this work represents a starting point to inform decisions and engage stakeholders on the costs of nitrogen pollution.

Acknowledgments

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Appendix A

Table A1 Table of codes used for boxplots of potential damage costs to the conterminous US in appendix B.

N damage type	Code
From atmospheric NO_x	
Human health-respiratory	HH-NOx
Visibility	VIS
Climate change	COOL
Infrastructure damage	ID
Ozone effects on crops	O_3AG
Ozone effects on forests	O_3FOR
Plant biodiversity loss	BIOD
From atmospheric NH_3	
Human health-respiratory	HH-NH_3
Visibility	VIS
Climate change	COOL
Infrastructure damage	ID
Plant biodiversity loss	BIOD
From N_2O	
Ozone–UV light exposure	HH-UV
Greenhouse gases	GHG
Ozone–UV damage	AG-UV
From surface freshwater N loading	
Waterfront property value	WFP
Recreational use	FWREC
Endangered species	END
Eutrophication	EUT
Odor and taste	ODOR
Nitrate level	NIT
Colon cancer risk	CANC
From groundwater N loading	
Odor and taste	ODOR
Nitrate level	NIT
Colon cancer risk	CANC
From coastal N loading	
Recreational use	CZREC
Fisheries	FISH

Appendix B

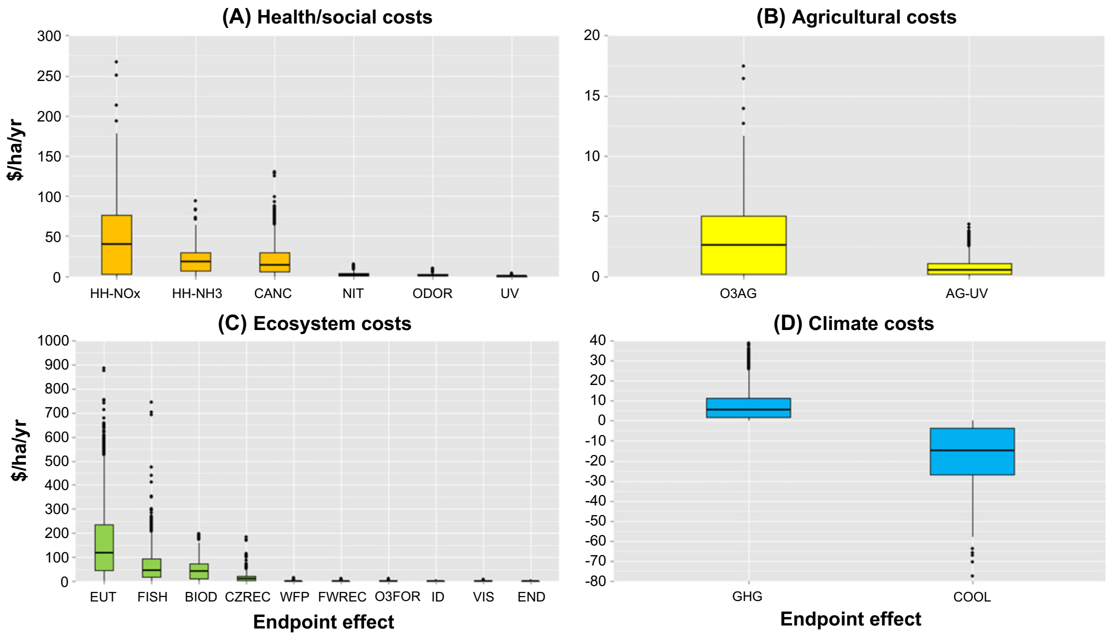

Figure B1. Boxplots of potential damage costs (2008 or as reported) associated with anthropogenic N leaked to the environment by HUC8 watershed in the early 2000s for different endpoint effects ($n = 2107$ each) by (A) health/social costs, (B) agricultural costs, (C) ecosystem costs, and (D) climate costs. Letter code identifications are listed in appendix A. For each boxplot, bottom and top whiskers indicate 10th and 90th percentiles, bottom and top box edges depict 25th and 75th percentiles, and the line in the box is the median. Damage cost calculations represent median damage costs presented in table 1.

References

Alexander R B, Smith R A, Schwarz G E, Boyer E W, Nolan J V and Brakebill J W 2008 Differences in phosphorus and nitrogen delivery to the gulf of Mexico from the Mississippi river basin *Environ. Sci. Technol.* **42** 822–30

Banerjee S, Secchi S, Fargoine J, Polasky S and Kraft S 2013 How to sell ecosystem services: a guide for designing new markets *Frontiers Ecology Environ.* **11** 297–304

Bennett E M, Carpenter S R and Caraco N F 2001 Human impact on erodible phosphorus and eutrophication: a global perspective *Bioscience* **51** 227–34

Birch M B L, Gramig B M, Moomaw W R, Doering O and Reeling C J 2011 Why metrics matter: evaluating policy choices for reactive nitrogen in the chesapeake bay watershed *Environ. Sci. Technol.* **45** 168–74

Bockstael N E, Freeman A M III, Kopp R J, Portney P R and Smith V K 2000 On measuring the economic values for nature *Environ. Sci. Technol.* **34** 1384–9

Bouwman A F 1996 Direct emission of nitrous oxide from agricultural soils *Nutrient cycling Agroecosystems* **46** 53–70

Boyd J and Banzhaf S 2007 What are ecosystem services? The need for standardized environmental accounting units *Ecological Econ.* **63** 616–26

Brender J D, Weyer P J, Romitti P A, Mohanty B P, Shinde M U, Vuong A M and Canfield M A 2013 Prenatal nitrate intake from drinking water and selected birth defects in offspring of participants in the national birth defects prevention study *Environ. Health Perspect.* **121** 1083–9

Cassman K G, Dobermann A and Walters D T 2002 Agroecosystems, nitrogen-use efficiency, and nitrogen management *Ambio* **31** 132–40

Chestnut L G and Mills D M 2005 A fresh look at the benefits and costs of the US acid rain program *J. Environ. Manag.* **77** 252–66

Clark C M, Morefield P E, Gilliam F S and Pardo L H 2013 Estimated losses of plant diversity in the United States from historical N deposition (1985–2010) *Ecology* **94** 1441–8

Compton J E, Harrison J A, Dennis R L, Greaver T, Hill B H, Jordan S J, Walker H and Campbell H V 2011 Ecosystem services altered by changes in reactive nitrogen: a new perspective for US decision making *Ecology Lett.* **14** 804–15

Cui S, Shi Y, Groffman P M, Schlesinger W H and Zhu Y G 2013 Centennial-scale analysis of the creation and fate of reactive nitrogen in China (1910–2010)*Proc. Natl Acad. Sci.* **110** 2052–7

Davidson E A 2009 The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860 *Nat. Geosci.* **2** 659–62

Davidson E A *et al* 2012 Excess nitrogen in the US environment: trends, risks, and solutions *ESA Issues Ecology* **15** 1–16

Dodds W K, Bouska W W, Eitzmann J L, Pilger T J, Pitts K L, Riley A J, Schoesser J T and Thornbrugh D J 2009 Eutrophication of US freshwaters: analysis of potential economic damages *Environ. Sci. Technol.* **43** 12–9

Domene L A F and Ayres R U 2001 Nitrogen's role in industrial systems *J. Ind. Ecology* **5** 77–103

Fisher B, Turner R K and Morling P 2009 Defining and classifying ecosystem services for decision making *Ecological Econ.* **68** 643–53

Foley J A *et al* 2011 Solutions for a cultivated planet *Nature* **478** 337–42

Galloway J N, Aber J D, Erisman J W, Seitzinger S P, Howarth R W, Cowling E B and Cosby B J 2003 The nitrogen cascade *Bioscience* **53** 341–56

Galloway J N *et al* 2004 Nitrogen cycles: past, present, and future *Biogeochemistry* **70** 153–226

Holland E A, Braswell B H, Sulzman J and Laamarque J-F 2005 Nitrogen deposition onto the United States and western Europe: synthesis of observations and models *Ecological Appl.* **15** 38–57

Houlton B Z, Boyer E, Finzi A, Galloway J, Leach A, Liptzin D, Mellilo J, Rosenstock T S, Sobota D and Townsend A R 2013 Intentional versus unintentional nitrogen use in the United States: trends, efficiency, and implications *Biogeochemistry* **114** 11–23

Howarth R W, Boyer EW E W, Pabich W J and Galloway J N 2002 Nitrogen use in the United States from 1961 to 2000 and potential future trends *Ambio* **31** 88–96

IMF [International Monetary Fund] 2013 IMF eLibrary Data (www.imf.org/external/data.htm#global) Viewed 9 October 2013

Jordan T E and Weller D E 1996 Human contributions to terrestrial nitrogen flux *Bioscience* **46** 655–64

Kusiima J M and Powers S E 2010 Monetary value of the environmental and health externalities associated with production of ethanol from biomass feedstocks *Energy Policy* **38** 2785–96

Leach A M, Galloway J N, Bleeker A, Erisman J W, Kohn R and Kitzes J 2012 A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment *Environ. Dev.* **1** 40–66

McCrackin M L, Harrison J A and Compton J E 2013 A comparison of news and sparrow models to understand sources of nitrogen delivered to US coastal waters *Biogeochemistry* **114** 281–97

Muller N Z and Mendelsohn R 2007 Measuring the damages of air pollution in the United States *J. Environ. Econ. Manag.* **54** 1–14

Osmond D L, Hoag D L, Luloff A E, Meals D W and Neas K 2014 Farmers' use of nutrient management: lessons from watershed case studies *J. Environ. Qual.* doi:10.2134/jeq2014.02.0091

Pardo L H *et al* 2011 Effects of nitrogen deposition and empirical nitrogen critical loads for ecoregions of the United States *Ecological Appl.* **21** 3049–82

Paulot F and Jacob D J 2014 Hidden cost of US agricultural exports: particulate matter from ammonia emissions *Environ. Sci. Technol.* **43** 903–8

Pearce D 2003 The social cost of carbon and its policy implications *Oxford Rev. Econ. Policy* **19** 362–84

Pinder R W, Bettez N D, Bonan G B, Greaver T L, Widier W R, Schlesinger W H and Davidson E A 2013 Impacts of human alteration of the nitrogen cycle in the US on radiative forcing *Biogeochemistry* **114** 25–40

Plummer M L 2009 Assessing benefit transfer for the valuation of ecosystem services *Frontiers Ecology Environ.* **7** 38–45

R Development Core Team 2011 *R: A Language and Environment for Statistical Computing* (Vienna, Austria : R Foundation for Statistical Computing)

Ribaudo M, Delgado M J, Hansen L, Livingston M, Mosheim R and Williamson J 2011 Nitrogen in agricultural systems: implications for conservation policy *USDA Economic Research Report* ERR-127 Washington, DC 89

Ringold P L, Boyd J, Landers D and Weber M 2013 What data should we collect? A framework for identifying indicators of ecosystem contributions to human well-being *Frontiers Ecology Environ.* **11** 98–105

Robertson G P and Vitousek P M 2009 Nitrogen in agriculture: balancing the cost of an essential resource *Annu. Rev. Environ. Resour.* **34** 97–125

Rose S K 2012 The role of the social cost of carbon in policy *Wiley Interdiscip. Rev.: Clim. Change* **3** 195–212

Rosenstock T S *et al* 2014 Agriculture's contribution to nitrate contamination of Californian groundwater (1945–2005) *J. Environ. Qual.* doi:10.2134/jeq2013.10.0411

Ruddy B C, Lorenz D L and Mueller D K 2006 County-level estimates of nutrient inputs to the land surface of the conterminous United States, 1982–2001 *Scientific Investigations Report* 2006–501 US Geological Survey: Reston, VA NAQWA

SAB [Science Advisory Board to the US Environmental Protection Agency] 2011 *Reactive Nitrogen in The United States; an Analysis of Inputs, Flows, Consequences, and Management Options* (Washington, DC: US Environmental Protection Agency) (http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/INCSupplemental?OpenDocument)

Singh S and Bakshi B R 2013 Accounting for the biogeochemical cycle of nitrogen in input-output life cycle assessment *Environ. Sci. Technol.* **47** 9388–96

Smil V 1997 Global population and the nitrogen cycle *Sci. Am.* **277** 76–81

Smil V 1999 Nitrogen in crop production: an account of global flows *Glob. Biogeochem. Cycles* **13** 647–62

Smil V 2002 Nitrogen and food production: proteins for human diets *Ambio* **31** 126–31

Sobota D J, Compton J E and Harrison J A 2013 Reactive nitrogen in US lands and waterways: how certain are we about sources and fluxes? *Frontiers Ecology Environ.* **11** 82–90

USDA [US Department of Agriculture] 2013a The Census of Agriculture (www.agcensus.usda.gov/) viewed 29 September 2013

USDA [US Department of Agriculture] 2013b USDA and EPA Launch US Food Waste Challenge (www.usda.gov/wps/portal/usda/usdahome?contentid=2013/06/0112.xml) viewed 26 July 2014

US EPA [US Environmental Protection Agency] 2008 National Emissions Inventory Data (www.epa.gov/ttn/chief/net/2008inventory.html) viewed 29 September 2013

US EPA [US Environmental Protection Agency] 2013a Watershed Deposition Tool (www.epa.gov/AMD/EcoExposure/depositionMapping.html) viewed 29 September 2013.

US EPA [US Environmental Protection Agency] 2013b National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data (www.epa.gov/ttn/chief/trends/index.html) viewed 29 September 2013

US EPA [US Environmental Protection Agency] 2013c How to access local drinking water information (http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/howtoaccessdata.cfm) viewed 12 February 2014

Van Drecht G, Bouwman A F, Harrison J and Knoop J M 2009 Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050 *Glob. Biogeochem. Cycles* **23** GB0A03

van Grinsven H J M, Holland M, Jacobsen B H, Klimont Z, Sutton M A and Willems W J 2013 Costs and benefits of nitrogen for Europe and implications for mitigation *Environ. Sci. Technol.* **47** 3571–9

ATTACHMENT C

JOHNS HOPKINS
CENTER *for* A LIVABLE FUTURE

The Johns Hopkins Center for a Livable Future
Bloomberg School of Public Health
615 North Wolfe Street, W7010
Baltimore, MD 21205

February 14, 2017

Mr. Thomas Quinn
Chair, Livestock Operations Study Group
100 West Tainter Street
Downing, WI 54734

Mr. Bob Colson
Planning and Zoning Administrator, Dunn County
800 Wilson Ave. Room 310
Menomonie, WI 54751

Disclaimer: The opinions expressed herein are our own and do not necessarily reflect the views of The Johns Hopkins University.

RE: Dunn County Six-Month Moratorium on Livestock Operations

Dear Members of the Dunn County Livestock Operations Study Group,

We are researchers at The Johns Hopkins Center for a Livable Future, based at the Bloomberg School of Public Health in the Department of Environmental Health and Engineering. The Center engages in research, policy analysis, education, and other activities guided by an ecologic perspective that diet, food production, the environment, and public health are interwoven elements of a complex system. We recognize the prominent role that food animal production plays regarding a wide range of public health issues surrounding that system.

We have been contacted by Ms. Kathy Stahl, a member of the Livestock Operations Study Group, about Dunn County's six-month moratorium on the licensing and expansion of livestock operations and the study group's review of research related to the public health and environmental impacts of industrial food animal production (IFAP). In response to Ms. Stahl's request for information and in an effort to serve as a resource to the committee, we have compiled research articles related to the large-scale production of dairy cows and swine (Appendices A and B, respectively); abstracts from the research articles are included in the appendices. Below, we summarize the public health concerns associated with IFAP operations, and an annotated bibliography is provided on pages 5-15.

Summary of Public Health Concerns Associated with IFAP

The primary human health concerns related to IFAP include: infections resulting from transmission of harmful microorganisms from animal operations to nearby residents; respiratory effects from increased exposure to air pollution from animal operations; and multiple negative health impacts due to increased exposure to ground and/or surface waters that can be contaminated by manure from animal operations. These concerns are described in more detail below.

Disease Transmission

The poor conditions, including crowding, characteristic of industrial animal operations present opportunities for disease transmission among animals, and between animals and humans. [1,2] Nearby residents, especially if they live in close proximity to multiple operations, may have an increased risk of infection from the transmission of harmful microorganisms from operations via flies or contaminated air and water. [3-9]

Of additional concern is exposure to pathogens that are resistant to antibiotics used in human medicine. Administering antibiotics to animals at levels too low to treat disease (non-therapeutic use) fosters the proliferation of antibiotic-resistant pathogens, and this practice is common in IFAP. Resistant infections in humans are more difficult and expensive to treat [10] and more often fatal [11] than infections with non-resistant strains. A growing body of evidence provides support that antibiotic-resistant pathogens are found on animal operations that administer antibiotics for non-therapeutic purposes [12,13] and are also found in the environment in and around production facilities, [13-15] specifically in the manure, [16-18] air, [13] and flies. [19]

Manure runoff from IFAP operations may introduce these harmful microorganisms into nearby water sources. [20] Land application of manure presents an opportunity for pathogens contained in the manure to leach into the ground or run off into recreational water and drinking water sources, potentially causing a waterborne disease outbreak. [17] This is of particular concern for the approximately 53% of Dunn County residents who rely on private wells for drinking water and household use; [21] private wells are not monitored by government agencies to ensure safe levels of pathogens.

Air Pollution

Community members living near IFAP operations also face increased exposure to air pollution from these operations, which can cause or exacerbate respiratory conditions including asthma [22-24]; eye irritation, difficulty breathing, wheezing, sore throat, chest tightness, nausea [25]; and bronchitis and allergic reactions. [23] Air emissions include particulates, volatile organic compounds, and gases such as nitrous oxide, hydrogen sulfide, and ammonia. [22,26] Odors associated with air pollutants from large-scale hog operations have been shown to interfere with daily activities, quality of life, social gatherings, and community cohesion [22,27-29] and contribute to stress and acute increased blood pressure. [29,30]

Contaminated Ground and Surface Water

The increase in concentration of livestock and poultry and transition to large, high-density, confined animal feeding operations over the last several decades has resulted in the concentration of animal waste over small geographic areas. [17] Although animal manure is an invaluable fertilizer, waste quantities of the magnitude produced by IFAP operations represent a public health and ecological hazard through the degradation of surface and ground water resources. [17]

Manure from these operations can contaminate ground and surface waters with nitrates, drug residues, and other hazards, [6,31-33] and studies have demonstrated that humans can be exposed to waterborne contaminants from livestock and poultry operations through the recreational use of contaminated surface water and the ingestion of contaminated drinking water. [32-34] Exposure to elevated levels of nitrates in drinking water is associated with adverse health effects, including cancer, [35-38] birth defects and other reproductive problems, [34,35,39,40] thyroid problems, [34,35] and methemoglobinemia. [34,41]

Nutrient runoff (including nitrogen and phosphorus) has also been implicated in the growth of harmful algal blooms, [17,42] which may pose health risks for people who swim or fish in recreational waters, or who consume contaminated fish and shellfish. Exposure to algal toxins has been linked to neurological impairments, liver damage, gastrointestinal illness, severe dermatitis, and other adverse health effects. [43,44]

We hope that this description of public health concerns associated with IFAP is helpful. Through our research, we know that local agencies can face many barriers in addressing issues surrounding IFAP due to narrow regulations and limited resources, [45,46] and we are prepared to serve as a scientific resource to your Livestock Operations Study Group. In addition to relevant studies included in appendices A and B, we are also attaching a copy of a local ordinance that establishes health, safety, and welfare regulations for large-scale animal production as an example of measures that have been taken by other local governments. Please do not hesitate to contact us if you have any questions.

Sincerely,

Robert S. Lawrence, MD, MACP
The Center for a Livable Future Professor Emeritus in Environmental Health & Engineering
Professor Emeritus, Departments Health Policy and Management and International Health
Johns Hopkins Bloomberg School of Public Health

Robert Martin
Senior Lecturer, Department of Environmental Health & Engineering
Johns Hopkins Bloomberg School of Public Health
Program Director, Food System Policy
Johns Hopkins Center for a Livable Future
Johns Hopkins University

Jillian P. Fry, PhD, MPH
Assistant Scientist, Departments of Environmental Health & Engineering and Health, Behavior and Society
Johns Hopkins Bloomberg School of Public Health
Project Director, Food Production and Public Health
Johns Hopkins Center for a Livable Future
Johns Hopkins University

Claire M. Fitch, MSPH
Senior Research Program Manager, Food System Policy

Johns Hopkins Center for a Livable Future
Johns Hopkins University
Department of Environmental Health & Engineering
Johns Hopkins Bloomberg School of Public Health

Carolyn Hricko, MPH
Research Assistant, Food System Policy
Johns Hopkins Center for a Livable Future
Johns Hopkins University
Department of Environmental Health & Engineering
Johns Hopkins Bloomberg School of Public Health

References

1. Gomes A, Quinteiro-Filho W, Ribeiro A, et al. Overcrowding stress decreases macrophage activity and increases *Salmonella* enteritidis invasion in broiler chickens. *Avian Pathol*. 2014;43(1):82-90.
Link: https://www.ncbi.nlm.nih.gov/pubmed/24350836

> This study sought to characterize the immunosuppressive effect of overcrowding stress in broiler chickens. Overcrowding was found to compromise the intestinal immune barrier and integrity of the small intestine, resulting in inflammation and decreased nutrient absorption. The study concludes that animal welfare measures and avoiding overcrowding stress factors in maintaining poultry health and decreased susceptibility to *Salmonella* infection.

2. Rostagno MH. Can stress in farm animals increase food safety risk? *Foodborne pathogens and disease*. 2009;6(7):767-776.
Link: http://online.liebertpub.com/doi/pdf/10.1089/fpd.2009.0315

> This study reviewed current knowledge to assess the potential impact of stress—such as that from inadequate nutrition, deprivation of water and/or feed, heat, cold, overcrowding, handling and transport—in farm animals on food safety risk. The review focused on stress mechanisms influencing the colonization and shedding of enteric pathogens in food animals due to the potential for their dissemination into the human food chain, a serious public health and economic concern. The review concluded that there is a growing body of evidence that demonstrates the negative impact of stress on food safety through a variety of potential mechanisms, and recommends additional research to optimize animal welfare and minimize production loses and food safety risks.

3. Rule AM, Evans SL, Silbergeld EK. Food animal transport: A potential source of community exposures to health hazards from industrial farming (CAFOs). *Journal of Infection and Public Health*. 2008;1(1):33-39.
Link: https://www.ncbi.nlm.nih.gov/pubmed/20701843

> The results of this study support the hypothesis that current methods of food animal transport from farm to slaughterhouse result in the transfer of bacteria, including antibiotic-resistant bacteria, to the vehicles travelling the same road. Bacteria were isolated from air and surface samples from vehicles following open poultry trucks, suggesting a new route of exposure to pathogens and the further dissemination of these pathogens to the general environment.

4. Price LB, Graham JP, Lackey LG, Roess A, Vailes R, Silbergeld E. Elevated risk of carrying gentamicin-resistant *Escherichia coli* among US poultry workers. *Environ Health Perspect*. 2007:1738-1742.
Link: https://www.ncbi.nlm.nih.gov/pubmed/18087592

> Occupational and environmental pathways of human exposure to antimicrobial-resistant bacteria were explored in this study by comparing the relative risk of antimicrobial-resistant *E. coli* among poultry workers compared with community referents. The study concluded that occupational exposure to antimicrobial-resistant bacteria may be an important route of entry for the bacteria into the community, as poultry workers had 32 times the odds of carrying resistant *E. coli* compared to the community referents.

5. Baykov B, Stoyanov M. Microbial air pollution caused by intensive broiler chicken breeding. *FEMS Microbiol Ecol*. 1999;29(4):389-392.
Link: https://academic.oup.com/femsec/article/29/4/389/527380/Microbial-air-pollution-caused-by-intensive

This study examined the extent of microbial atmospheric pollution caused by industrial broiler breeding operations and found that as birds aged, microbial numbers increased in the indoor air and were spread into the environment to a greater degree. The study also found that microorganisms could be spread by air flow up to 3000 meters from the production buildings.

6. Spencer JL, Guan J. Public health implications related to spread of pathogens in manure from livestock and poultry operations. *Public Health Microbiology: Methods and Protocols*. 2004:503-515.
Link: https://www.ncbi.nlm.nih.gov/pubmed/15156064

Objectionable odors, flies, excessive levels of nitrogen and phosphorus and the potential spread of human pathogens are among the public concerns with the disposal of animal manure and the spread of dust and manure blown from powerful building fans. The study also finds that importance of animal manure in the spread of infectious pathogens is often underestimated despite the linkages between livestock operations and gastroenteritis in humans.

7. Graham JP, Leibler JH, Price LB, et al. The animal-human interface and infectious disease in industrial food animal production: Rethinking biosecurity and biocontainment. *Public Health Rep*. 2008:282-299.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19006971

The transition of food animal production from small-scale methods to industrial-scale operations has been accompanied by substantial evidence of the transfer of pathogens between and among industrial food animal facilities, the environment, and exposure to farm workers. This challenges the notion that modern animal production is more biosecure than smaller operations in regards to the introduction and release of pathogens. The study concludes that industrialized food animal production risk factors must be included in strategies to mitigate or prevent the emergence of pandemic avian influenza.
Refer to page 21 of this document for the complete article abstract.

8. Jahne MA, Rogers SW, Holsen TM, Grimberg SJ, Ramler IP. Emission and dispersion of bioaerosols from dairy manure application sites: Human health risk assessment. *Environ Sci Technol*. 2015;49(16):9842-9849.
Link: https://www.ncbi.nlm.nih.gov/pubmed/26158489

The risk of human gastrointestinal infection associated with exposure to airborne pathogens following the land application of dairy manure was explored in this study. It was concluded that bioaerosol emissions from manure application sites may present significant public health risks to downwind receptors, and improved manure management practices that include better controls for bioaerosols were recommended to reduce the risk of disease transmission.
Refer to page 16 of this document for the complete article abstract.

9. Casey JA, Curriero FC, Cosgrove SE, Nachman KE, Schwartz BS. High-density livestock operations, crop field application of manure, and risk of community-associated methicillin-resistant *Staphylococcus aureus* infection in Pennsylvania. *JAMA Internal Medicine*. 2013;173(21):1980-1990.
Link: https://www.ncbi.nlm.nih.gov/pubmed/24043228

This study assessed the association between exposure to swine and dairy/veal industrial agriculture and the risk of methicillin-resistant *Staphylococcus aureus* (MRSA) infection. The study found that proximity to livestock operations and crop fields treated with swine manure were each associated with MRSA, skin and soft-tissue infection.
Refer to page 20 of this document for the complete article abstract.

10. Roberts RR, Hota B, Ahmad I, et al. Hospital and societal costs of antimicrobial-resistant infections in a Chicago teaching hospital: Implications for antibiotic stewardship. *Clin Infect Dis*. 2009;49(8):1175-1184.
Link: https://academic.oup.com/cid/article/49/8/1175/425330/Hospital-and-Societal-Costs-of-Antimicrobial

Medical and societal costs attributable to antimicrobial-resistant infections are considerable, and important factors in understanding the potential benefits of prevention programs. Medical costs attributable to antimicrobial-resistant infections range from $18,588 to $29,069 per patient, hospital stay durations from 6.4-12.7 days, and mortality of 6.5%. Societal costs were estimated at $10.7-$15 million.

11. Filice GA, Nyman JA, Lexau C, et al. Excess costs and utilization associated with methicillin resistance for patients with *Staphylococcus aureus* infection. *Infection Control & Hospital Epidemiology*. 2010;31(04):365-373.
Link: https://www.ncbi.nlm.nih.gov/pubmed/20184420

Healthcare costs of methicillin-resistant *S. aureus* (MRSA) infections and methicillin-susceptible *S. aureus* (MSSA) were compared in this study. MRSA infections were found to be independently associated with higher costs, more comorbidities, and higher likelihood of death than MSSA infections.

12. Price LB, Lackey LG, Vailes R, Silbergeld E. The persistence of fluoroquinolone-resistant *Campylobacter* in poultry production. *Environ Health Perspect*. 2007:1035-1039.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1913601/

Halting fluoroquinolone use was not found to have an impact on the proportion of fluoroquinolone-resistant *Campylobacter* on products from the conventional producers, indicating that antibiotic-resistant bacteria may persistently contaminate poultry products even after on-farm use of the antibiotic has ceased. Also, *Campylobacter* strains from the conventional producers were more likely to be resistant to fluoroquinolone than those from the antibiotic-free producers, indicating that antibiotic use in food animal production contributes to the develop of antibiotic-resistant pathogens.

13. Schulz J, Friese A, Klees S, et al. Longitudinal study of the contamination of air and of soil surfaces in the vicinity of pig barns by livestock-associated methicillin-resistant *Staphylococcus aureus*. *Appl Environ Microbiol*. 2012;78(16):5666-5671.
Link: https://www.ncbi.nlm.nih.gov/pubmed/22685139

This study examined the presence and concentration of MRSA in air and soil downwind from swine CAFOs. The results demonstrate regular transmission and deposition of airborne livestock-associated MRSA to areas up to at least 300 meters around pig barns that tested positive for MRSA, suggesting that swine CAFOs can expose other farm animals, wildlife, and people to MRSA.

Refer to page 25 of this document for the complete article abstract.

14. Burgos J, Ellington B, Varela M. Presence of multidrug-resistant enteric bacteria in dairy farm topsoil. *J Dairy Sci*. 2005;88(4):1391-1398.
Link: https://www.ncbi.nlm.nih.gov/pubmed/15778307

This study was conducted to better understand how widespread antibiotic-resistant bacteria are in agricultural settings, particularly in dairy farm environments. The study concluded that dairy farm topsoil contains multidrug resistant enteric bacteria and antibiotic-resistant plasmids, and suggests that dairy topsoils serve as a reservoir for the development of bacterial resistance to antibiotics relevant in clinical medicine.
Refer to page 16 of this document for the complete article abstract.

15. Sapkota AR, Curriero FC, Gibson KE, Schwab KJ. Antibiotic-resistant enterococci and fecal indicators in surface water and groundwater impacted by a concentrated swine feeding operation. *Environ Health Perspect*. 2007:1040-1045.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1913567/

Surface and groundwater located up and down gradient from a swine facility was analyzed for the presence of antibiotic-resistant enterococci and other fecal indicators in this study. Both were detected at elevated levels in down gradient water sources relative to the swine facility compared to up-gradient sources, providing evidence that water contaminated with swine manure can contribute to the spread of antibiotic resistance.
Refer to page 24 of this document for the complete article abstract.

16. Graham JP, Evans SL, Price LB, Silbergeld EK. Fate of antimicrobial-resistant enterococci and staphylococci and resistance determinants in stored poultry litter. *Environ Res*. 2009;109(6):682-689.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19541298

This study examined the survival of anti-microbial resistant enterococci and staphylococci and resistance genes in poultry litter to better understand how land application of poultry litter can affect the surrounding populations environment. The study found that poultry litter storage practices do not eliminate drug-resistant bacterial strains, thus allowing the spread of these drug-resistant pathogens into and through the environment via land application of poultry litter.

17. United States Environmental Protection Agency. Literature review of contaminants in livestock and poultry manure and implications for water quality. July 2013:1-137.
Link: http://ow.ly/mTDw308qwbZ

This EPA report on the environmental occurrence and potential effects of livestock and poultry manure related contaminants on water quality found that 60-70% of manure nitrogen and phosphorus may not be assimilated by the farmland where it was generated due to the increasing concentration of industrial animal production. The report also notes the variety of pathogens contained in livestock and poultry manure, as well as the potential for their spread to humans when surface and groundwater and food crops come into contact with manure through runoff, spills, and land-application of manure. It also refers to research indicating that antimicrobial use in livestock and poultry production has contributed to the occurrence of anti-microbial resistant pathogens in animal operations and nearby environments. The report also presents that manure discharge to surface waters can occur by various means and have deleterious effects on aquatic life and contribute to toxic algal blooms harmful to animals, and to humans when exposed via contact with contaminated drinking water or recreational use of contaminated water.

18. Wichmann F, Udikovic-Kolic N, Andrew S, Handelsman J. Diverse antibiotic resistance genes in dairy cow manure. *MBio*. 2014;5(2):e01017-13.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3993861/

This study was conducted to better understand the cow microbiome and the role of the land application of cow manure in the spread of antibiotic resistance. The study reports the discovery of new and diverse antibiotic resistant genes in the cow microbiome, and provides evidence that it is a significant reservoir of antibiotic resistant genes.
Refer to page 18 of this document for the complete article abstract.

19. Graham JP, Price LB, Evans SL, Graczyk TK, Silbergeld EK. Antibiotic resistant enterococci and staphylococci isolated from flies collected near confined poultry feeding operations. *Sci Total Environ*. 2009;407(8):2701-2710.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19157515

This study examined if and how antibiotic resistant bacteria are transferred from poultry operations to nearby communities, and found that flies caught near poultry operations carried the same drug-resistant pathogens as those found in poultry litter. The study concludes that flies may be an important vector in the spread of drug resistant bacteria from poultry operations and may increase human exposure to these resistant pathogens.

20. Heaney CD, Myers K, Wing S, Hall D, Baron D, Stewart JR. Source tracking swine fecal waste in surface water proximal to swine concentrated animal feeding operations. *Sci Total Environ*. 2015;511:676-683.
Link: https://www.ncbi.nlm.nih.gov/pubmed/25600418

The microbial quality of surface water proximal to swine CAFOs was investigated in this study to better understand the impact of CAFOs on the surrounding environment. The results demonstrate overall poor water quality in areas with a high density of swine CAFOs, with high fecal indicator bacteria concentrations in waters both up- and down-stream of CAFO lagoon waste land application sites. The swine-specific microbial source tracking markers used in the study were also shown to be useful for tracking off-site conveyance of swine fecal wastes and during rain events.
Refer to page 21 of this document for the complete article abstract.

21. United States Geological Survey (USGS). USGS water use data for the nation. http://waterdata.usgs.gov/nwis/wu. Updated June 8, 2016. Accessed January 31, 2017.

This United States Geological Survey website provides national water use data by area type (aquifer, watershed, county, state), source (rivers or groundwater), and category such as irrigation or public supply.

22. Heederik D, Sigsgaard T, Thorne PS, et al. Health effects of airborne exposures from concentrated animal feeding operations. *Environ Health Perspect*. 2007:298-302.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1817709/

This report from a Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions working group states that toxic gases, vapors and particles are emitted from CAFOs into the general environment, and that while these agents are known to be harmful to human health, there are few studies that explore the health risks of exposure to these agents for the people living near CAFOs. While there is evidence that psychophysiologic changes may result from exposure to malodors and that microbial exposures are related to deleterious respiratory health effects, the working group concluded that there is great need to study and evaluate the health effects of community exposure to these CAFO related air pollutants to better understand the impact of CAFOs on the health of community members and farm workers.

23. Cambra-López M, Aarnink AJ, Zhao Y, Calvet S, Torres AG. Airborne particulate matter from livestock production systems: A review of an air pollution problem. *Environmental Pollution*. 2010;158(1):1-17.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19656601

This paper reviews research on particulate matter inside and emitted from livestock production system and reports that livestock housing is an important source of particulate matter emissions. The paper recommends additional research to characterize and control particulate matter in livestock houses, as high concentrations such as those found in livestock houses can threaten the environment and the health and welfare of humans and animals.

24. Mirabelli MC, Wing S, Marshall SW, Wilcosky TC. Asthma symptoms among adolescents who attend public schools that are located near confined swine feeding operations. *Pediatrics*. 2006;118(1):e66-75.
Link: http://pediatrics.aappublications.org/content/118/1/e66

The relationship between exposure to airborne effluent from swine CAFOs and asthma symptoms in adolescents age 12-14 years old was assessed in this study to better understand the health effects of living near industrial swine facilities. The study found that estimated exposure to swine CAFO air-pollution was associated with wheezing symptoms in adolescents.
Refer to page 23 of this document for the complete article abstract.

25. Schinasi L, Horton RA, Guidry VT, Wing S, Marshall SW, Morland KB. Air pollution, lung function, and physical symptoms in communities near concentrated swine feeding operations. *Epidemiology*. 2011;22(2):208-215.
Link: https://www.ncbi.nlm.nih.gov/pubmed/21228696

This study examined the associations between reported malodor and monitored air pollutants with lung function and physical symptoms in people residing within 1.5 miles of hog operations to better understand the effect of CAFO air pollutants on human health. The study reported that acute physical symptoms, including eye irritation, respiratory symptoms, difficulty breathing, wheezing, declined forced expiratory volume, sore throat, chest tightness, and nausea were related to pollutants measured near hog operations.
Refer to page 25 of this document for the complete article abstract.

26. Hribar C, Schultz M. Understanding concentrated animal feeding operations and their impact on communities. *Bowling Green, OH: National Association of Local Boards of Health*. 2010.
Link: https://www.cdc.gov/nceh/ehs/docs/understanding_cafos_nalboh.pdf

The National Association of Local Boards of Health produced this report with the support of the Centers for Disease Control and Prevention and the National Center for Environmental Health to assist local board of health members better understand their role in mitigating potential issues with CAFOs. The report concludes that large-scale industrial food animal production can cause numerous public health and environmental problems and should thus be monitored to prevent harm to surrounding communities. Suggested actions include passing ordinances and regulations, and increasing water and air quality monitoring and testing. The report also concludes that local boards of health, in collaboration with state and local agencies, are an appropriate body for instituting these actions due to the local nature of CAFO concerns and risks.

27. Donham KJ, Wing S, Osterberg D, et al. Community health and socioeconomic issues surrounding concentrated animal feeding operations. *Environ Health Perspect*. 2007:317-320.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1817697/

The Workgroup on Community and Socioeconomic Issues examined the impacts of CAFOs on the health of rural communities, using the World Health Organization's definition of health, "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." The workgroup recommended more stringent CAFO permitting, limiting animal density per watershed, improving local control, mandating environmental impact statements and considering bonding for manure storage basins.
Refer to page 20 of this document for the complete article abstract.

28. Wing S, Wolf S. Intensive livestock operations, health, and quality of life among eastern North Carolina residents. *Environ Health Perspect*. 2000;108(3):233-238.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1637983/

Reports of decreased health and quality of life from people who live near industrial animal operations were explored in this study through community surveys in three rural communities, one located near a large swine operation, one near two intensive cattle operations, and one area without nearby livestock operations using liquid waste management systems. Residents near the swine operation reported increased occurrences of poor health, such as headaches, diarrhea, sore throat, excessive coughing and burning eyes and reduced quality of life compared to those in the other two communities.

29. Horton RA, Wing S, Marshall SW, Brownley KA. Malodor as a trigger of stress and negative mood in neighbors of industrial hog operations. *Am J Public Health*. 2009;99(S3):S610-S615.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19890165

The association between malodor and air pollutants from nearby hog CAFOs and reported stress and negative mood was evaluated in this study to better understand the role of CAFOs in human health. The study found that malodor and air pollutants acted as environmental stressors and triggers of negative mood and recommended their inclusion in studies of the health impacts of environmental injustice.
Refer to page 22 of this document for the complete article abstract.

30. Wing S, Horton RA, Rose KM. Air pollution from industrial swine operations and blood pressure of neighboring residents. *Environmental Health Perspectives (Online)*. 2013;121(1):92.
Link: https://ehp.niehs.nih.gov/1205109/

The association of air pollution and malodor with stress and blood pressure were assessed in this study to improve understanding of the effects of industrial swine operations on human health. Malodor and some air pollutants were found to be associated with blood pressure increases and reported stress, which could contribute to the development of chronic hypertension.
Refer to page 26 of this document for the complete article abstract.

31. Graham JP, Nachman KE. Managing waste from confined animal feeding operations in the United States: The need for sanitary reform. *Journal of Water and Health*. 2010;8(4):646-670.
Link: https://www.ncbi.nlm.nih.gov/pubmed/20705978

Trends affecting food animal waste production, risks associated with food-animal wastes, and differences between food-animal waste and human biosolid management practices were examined in this study. The study found that no standards exist for the 335 million tons of food animal waste applied to land in the US, while human biosolids, which make up just 1% of all land-applied wastes, are subject to standards. Hormones, arsenicals, high nutrient loads, antibiotics, and pathogens, including antibiotic-resistant pathogens, are often present in animal waste. The authors made recommendations for improving management of food-animal waste through existing and new policies.

32. Showers WJ, Genna B, McDade T, Bolich R, Fountain JC. Nitrate contamination in groundwater on an urbanized dairy farm. *Environ Sci Technol*. 2008;42(13):4683-4688.
Link: https://www.ncbi.nlm.nih.gov/pubmed/18677991

This study sought to identify sources of drinking water well nitrate contamination in a housing development built on a dairy farm site using isotopic compositions of nitrate, ammonia, groundwater and chemical ratios. The results indicate that the elevated nitrate levels were due to the leaching of animal waste from pastures into groundwater during the 35 years of dairy operations. The study suggests enacting statutes requiring well water tests prior to the sale of homes built on urbanized farmland to protect the health of homeowners.
Refer to page 17 of this document for the complete article abstract.

33. Relation between nitrates in water wells and potential sources in the lower Yakima Valley, Washington state. U.S. Environmental Protection Agency, Washington, D.C., 2012. Link: Https://Www3.epa.gov/region10/pdf/sites/yakimagw/nitrate_in_water_wells_study_9-27-2012.pdf.

This study examined the effectiveness of various techniques to identify specific sources of high nitrate levels in residential drinking water well. Dairy waste was concluded to be a likely source of nitrate contamination in the wells due to isotopic data and contextual evidence such as the historical and current volumes of dairy waste in the area, lack of other potential sources of nitrogen in the area, and soil indicators.
For more detail on this report, refer to page 18 of this document.

34. Burkholder J, Libra B, Weyer P, et al. Impacts of waste from concentrated animal feeding operations on water quality. *Environ Health Perspect*. 2007:308-312.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1817674/

This work-group, part of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions, found that current and generally accepted livestock waste management practices do not protect water resources from the pathogens, pharmaceuticals and excessive nutrients found in animal waste. As concern about the potential human and environmental health impact of long-term exposure to contaminated water grows, there is greater need for rigorous monitoring of CAFOs, improved understanding of the major toxicants affecting human and environmental health, and a system to enforce these practices.

35. Ward MH. Too much of a good thing? Nitrate from nitrogen fertilizers and cancer. *Rev Environ Health*. 2009;24(4):357-363.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3068045/

Nitrate, the breakdown product of nitrogen fertilizers, accumulates in groundwater under agricultural land and can spread through waterways due to agricultural field runoff. Nitrates are associated with a range of adverse health effects, including methemoglobinemia, various cancers, negative reproductive outcomes, diabetes, and thyroid conditions. Additional research is needed to further evaluate the health effects of nitrate exposure, especially as environmental exposure to nitrates has increased over the last 50 years and 90% of rural Americans depend on groundwater for drinking water, many relying on private wells, which are not regulated by the Safe Drinking Water Act.

36. Chiu H, Tsai S, Yang C. Nitrate in drinking water and risk of death from bladder cancer: An ecological case-control study in Taiwan. *Journal of Toxicology and Environmental Health, Part A*. 2007;70(12):1000-1004.
Link: https://www.ncbi.nlm.nih.gov/pubmed/17497410

The association between bladder cancer mortality and nitrate exposure from Taiwan drinking water was investigated in this study. The results showed a significant positive relationship between the levels of nitrates in the drinking water and the risk of death from bladder cancer, indicating that environmental exposure to nitrates plays a role in the development of bladder cancer.

37. Ward MH, Kilfoy BA, Weyer PJ, Anderson KE, Folsom AR, Cerhan JR. Nitrate intake and the risk of thyroid cancer and thyroid disease. *Epidemiology*. 2010;21(3):389-395.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2879161/

This study examined the association between nitrate intake through public water and diet with the risk of thyroid cancer and hypo- and hyperthyroidism. The study found an increased risk of thyroid cancer with high water nitrate levels and with longer consumption of water containing nitrates. The increased intake of dietary nitrate was associated with an increased risk of thyroid cancer, and with the prevalence of hypothyroidism.

38. Gulis G, Czompolyova M, Cerhan JR. An ecologic study of nitrate in municipal drinking water and cancer incidence in Trnava district, Slovakia. *Environ Res*. 2002;88(3):182-187.
Link: https://www.ncbi.nlm.nih.gov/pubmed/12051796

This ecologic study was conducted to assess the association between nitrate levels in drinking water with non-Hodgkin lymphoma and cancers of the digestive and urinary tracts in an agricultural district. The study found is that a higher incidence of some cancers was associated with higher levels of nitrate in drinking water. The trend was found in women for overall cancer cases, stomach cancer, colorectal cancer and non-Hodgkin lymphoma, and in men for non-Hodgkin lymphoma and colorectal cancer.

39. Manassaram DM, Backer LC, Moll DM. A review of nitrates in drinking water: Maternal exposure and adverse reproductive and developmental outcomes. *Environmental Health Perspectives*. 2006.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1392223/

> The relationship between maternal exposure to nitrates through drinking water and adverse reproductive and developmental outcomes was reviewed in this study. Animal studies support the association between nitrate exposure and adverse reproductive effects, and some studies report an association between nitrates in drinking water and spontaneous abortion, intrauterine growth restriction and various birth defects, though a direct exposure-response relationship remains unclear and there is insufficient evidence to establish a causal relationship.

40. Brender JD, Weyer PJ, Romitti PA, et al. Prenatal nitrate intake from drinking water and selected birth defects in offspring of participants in the national birth defects prevention study. *Environ Health Perspect*. 2013;121(9):1083-1089.
Link: https://www.ncbi.nlm.nih.gov/pubmed/23771435

> The relationship between prenatal exposure to nitrates in drinking water and birth defects was examined in this study. The study concluded that higher maternal water nitrate consumption was associated with birth defects, including spina bifida, limb deficiency, cleft palate, and cleft lip.

41. Knobeloch L, Salna B, Hogan A, Postle J, Anderson H. Blue babies and nitrate-contaminated well water. *Environ Health Perspect*. 2000;108(7):675-678.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1638204/

> Two cases of infant methemoglobinemia associated with nitrate contaminated private well water were described in this paper. The case studies underscore the danger that this contaminated water poses to infants during the first six months of life, as well as the risks of long-term exposure, which include cancer, thyroid disease and diabetes. Steps to reduce nitrate inputs in groundwater and routine well water testing are recommended to protect health.

42. Heisler J, Glibert PM, Burkholder JM, et al. Eutrophication and harmful algal blooms: A scientific consensus. *Harmful Algae*. 2008;8(1):3-13.
Link: http://www.sciencedirect.com/science/article/pii/S1568988308001066

> The US EPA held a roundtable discussion to develop consensus among academic, federal and state agency representatives on the relationship between eutrophication and harmful algal blooms. Seven statements were adopted during the session, which include acknowledgement of the important role of nutrient pollution and degraded water quality in the development and persistence of many harmful algal blooms.

43. Carmichael WW. Health effects of toxin-producing cyanobacteria: “The CyanoHABs”. *Human and Ecological Risk Assessment: An International Journal*. 2001;7(5):1393-1407.
Link: http://www.tandfonline.com/doi/abs/10.1080/20018091095087

> Current understandings of cyanobacteria toxin poisonings (CTPs) and their risk to human health were reviewed in this paper. CTPs occur in fresh and brackish waters throughout the world as a result of eutrophication and climate change. Cyanobacteria toxins are responsible for acute lethal, acute, chronic and sub-chronic poisonings of wild and domestic animals and humans. These poisonings result in respiratory and allergic reactions, gastrointestinal disturbances, acute hepatotoxicosis and peracute neurotoxicosis.

44. Paerl HW, Fulton RS,3rd, Moisander PH, Dyble J. Harmful freshwater algal blooms, with an emphasis on cyanobacteria. *Scientific World Journal*. 2001;1:76-113.

This paper reviews the effects of harmful freshwater algal blooms, resulting from nutrient oversupply and eutrophication, on water quality. Algal blooms contribute to water quality degradation, including malodor and foul taste, fish kills, toxicity, and food web alterations, while algal bloom toxins can adversely affect human and animal health through exposure to contaminated recreational and drinking water. The control and management of blooms, and their negative outcomes, must include nutrient input constraints, particularly on nitrogen and phosphorus.

45. Fry JP, Laestadius LI, Grechis C, Nachman KE, Neff RA. Investigating the role of state and local health departments in addressing public health concerns related to industrial food animal production sites. *PloS one*. 2013;8(1):e54720.
Link: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0054720

The role of local and state health departments in responding to and preventing community concerns with industrial food animal production are explored in this study through qualitative interviews with state and county health department staff and community members in eight states. Political barriers, lack of jurisdiction, and limited resources, expertise and staff all limit health departments' ability to respond to IFAP concerns, while community members reported difficulty in engaging with health departments. These limitations and difficulties contribute to limited health department engagement on these issues.

46. Fry JP, Laestadius LI, Grechis C, Nachman KE, Neff RA. Investigating the role of state permitting and agriculture agencies in addressing public health concerns related to industrial food animal production. *PloS one*. 2014;9(2):e89870.
Link: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0089870

This study explored how state permitting and agriculture agencies respond to environmental public health concerns regarding industrial food animal production through qualitative interviews with state agency staff in seven states. The study found that the agencies were unable to adequately address these environmental public health concerns due to narrow regulations, limited resources and a lack of public health expertise. When these constraints are considered alongside those faced by health departments, significant gaps in the ability to respond to and prevent public health concerns and issues are revealed.

Appendix A: Research Articles Related to Dairy Production
We have underlined sections of the abstracts in the appendices to highlight main points.

Burgos, J. M., B. A. Ellington, and M. F. Varela. "Presence of multidrug-resistant enteric bacteria in dairy farm topsoil." *Journal of Dairy Science* 88.4 (2005): 1391-1398.
Link: https://www.ncbi.nlm.nih.gov/pubmed/15778307

> In addition to human and veterinary medicine, antibiotics are extensively used in agricultural settings, such as for treatment of infections, growth enhancement, and prophylaxis in food animals, leading to selection of drug and multidrug-resistant bacteria. To help circumvent the problem of bacterial antibiotic resistance, it is first necessary to understand the scope of the problem. However, it is not fully understood how widespread antibiotic-resistant bacteria are in agricultural settings. The lack of such surveillance data is especially evident in dairy farm environments, such as soil. It is also unknown to what extent various physiological modulators, such as salicylate, a component of aspirin and known model modulator of multiple antibiotic resistance (mar) genes, influence bacterial multi-drug resistance. We isolated and identified enteric soil bacteria from local dairy farms within Roosevelt County, NM, determined the resistance profiles to antibiotics associated with mar, such as chloramphenicol, nalidixic acid, penicillin G, and tetracycline. We then purified and characterized plasmid DNA and detected mar phenotypic activity. The minimal inhibitory concentrations (MIC) of antibiotics for the isolates ranged from 6 to >50 microg/mL for chloramphenicol, 2 to 8 microg/mL for nalidixic acid, 25 to >300 microg/mL for penicillin G, and 1 to >80 microg/mL for tetracycline. On the other hand, many of the isolates had significantly enhanced MIC for the same antibiotics in the presence of 5 mM salicylate. Plasmid DNA extracted from 12 randomly chosen isolates ranged in size from 6 to 12.5 kb and, in several cases, conferred resistance to chloramphenicol and penicillin G. <u>It is concluded that enteric bacteria from dairy farm topsoil are multidrug resistant and harbor antibiotic-resistance plasmids. A role for dairy topsoil in zoonoses is suggested, implicating this environment as a reservoir for development of bacterial resistance against clinically relevant antibiotics.</u>

Jahne, Michael A., et al. "Emission and Dispersion of Bioaerosols from Dairy Manure Application Sites: Human Health Risk Assessment." *Environmental Science & Technology* 49.16 (2015): 9842-9849.
Link: http://pubs.acs.org/doi/pdfplus/10.1021/acs.est.5b01981

> In this study, we report the <u>human health risk of gastrointestinal infection associated with inhalation exposure to airborne zoonotic pathogens emitted following application of dairy cattle manure to land</u>. Inverse dispersion modeling with the USEPA's AERMOD dispersion model was used to determine bioaerosol emission rates based on edge-of-field bioaerosol and source material samples analyzed by real-time quantitative polymerase chain reaction (qPCR). Bioaerosol emissions and transport simulated with AERMOD, previously reported viable manure pathogen contents, relevant exposure pathways, and pathogen-specific dose-response relationships were then used to estimate potential downwind risks with a quantitative microbial risk assessment (QMRA) approach. Median 8-h infection risks decreased exponentially with distance from a median of 1:2700 at edge-of-field to 1:13 000 at 100 m and 1:200 000 at 1000 m; peak risks were considerably greater (1:33, 1:170, and 1:2500, respectively). <u>These results indicate that bioaerosols emitted from manure application sites following manure application may present significant public health risks to downwind receptors.</u> Manure management

practices should consider improved controls for bioaerosols in order to reduce the risk of disease transmission.

Schmalzried, Hans D., and L. Fleming Fallon Jr. "Proposed Mega-Dairies and Quality-of-Life Concerns: Using Public Health Practices to Engage Neighbors." *Public Health Reports* 125.5 (2010): 754.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2925014/

This article describes the steps taken by the Henry County Health Department (Ohio) to engage with concerned community members by collaborating in baseline data collection prior to the arrival of a large-scale dairy operation. Data collection included water quality testing of residential wells neighboring the dairy operation, a fly trapping and counting program, and a review of local property values. As a dairy with 690 cows will have average water requirements of 35,000 gallons/day, the Health Department coordinated a pumping test to assess groundwater levels and found that groundwater volumes were sufficient to supply the needs of the dairy and the surrounding residential wells. Residential wells were tested for coliform bacteria and field-tested for nitrates and hydrogen sulfide gas, and some of the wells tested unsafe for bacteria. In these cases, homeowners were given instructions on how to disinfect their wells and advised to do follow-up testing. The narrative concludes that data obtained prior to operations can be very useful and that local health departments can work with neighbors and facility operators to ensure that appropriate preventive measures are in place before operation to protect the public.

Showers, William J., et al. "Nitrate contamination in groundwater on an urbanized dairy farm." *Environmental Science & Technology* 42.13 (2008): 4683-4688.
Link: http://pubs.acs.org/doi/full/10.1021/es071551t

Urbanization of rural farmland is a pervasive trend around the globe, and maintaining and protecting adequate water supplies in suburban areas is a growing problem. Identification of the sources of groundwater contamination in urbanized areas is problematic, but will become important in areas of rapid population growth and development. The isotopic composition of NO3(δ15NNO3 and δ18O NO3), NH4 (δ15NNH4), groundwater (δ2Hwt and δ18Owt) and chloride/bromide ratios were used to determine the source of nitrate contamination in drinking water wells in a housing development that was built on the site of a dairy farm in the North Carolina Piedmont, U.S. The δ15NNO3 and δ18O NO3 compositions imply that elevated nitrate levels at this site in drinking well water are the result of waste contamination, and that denitrification has not significantly attenuated the groundwater nitrate concentrations. δ15NNO3 and δ18ONO3compositions in groundwater could not differentiate between septic effluent and animal waste contamination. Chloride/bromide ratios in the most contaminated drinking water wells were similar to ratios found in animal waste application fields, and were higher than Cl/Br ratios observed in septic drain fields in the area. δ18Owt was depleted near the site of a buried waste lagoon without an accompanying shift in δ2Hwt suggesting water oxygen exchange with CO2. This water−CO2 exchange resulted from the reduction of buried lagoon organic matter, and oxidation of the released gases in aerobic soils. δ18Owt is not depleted in the contaminated drinking water wells, indicating that the buried dairy lagoon is not a source of waste contamination. The isotope and Cl/Br ratios indicate that nitrate contamination in these drinking wells are not from septic systems, but are the result of animal waste leached from pastures into groundwater during 35 years of dairy operations which did not violate any existing regulations. Statutes need to be enacted to protect the health of the homeowners that require well water to be tested prior to the sale of homes built on urbanized farmland.

Wichmann, Fabienne, et al. "Diverse antibiotic resistance genes in dairy cow manure." *MBio* 5.2 (2014): e01017-13.
Link: http://mbio.asm.org/content/5/2/e01017-13.short

> Application of manure from antibiotic-treated animals to crops facilitates the dissemination of antibiotic resistance determinants into the environment. However, our knowledge of the identity, diversity, and patterns of distribution of these antibiotic resistance determinants remains limited. We used a new combination of methods to examine the resistome of dairy cow manure, a common soil amendment. Metagenomic libraries constructed with DNA extracted from manure were screened for resistance to beta-lactams, phenicols, aminoglycosides, and tetracyclines. Functional screening of fosmid and small-insert libraries identified 80 different antibiotic resistance genes whose deduced protein sequences were on average 50 to 60% identical to sequences deposited in GenBank. The resistance genes were frequently found in clusters and originated from a taxonomically diverse set of species, suggesting that some microorganisms in manure harbor multiple resistance genes. Furthermore, amid the great genetic diversity in manure, we discovered a novel clade of chloramphenicol acetyltransferases. Our study combined functional metagenomics with third-generation PacBio sequencing to significantly extend the roster of functional antibiotic resistance genes found in animal gut bacteria, providing a particularly broad resource for understanding the origins and dispersal of antibiotic resistance genes in agriculture and clinical settings. The increasing prevalence of antibiotic resistance among bacteria is one of the most intractable challenges in 21st-century public health. The origins of resistance are complex, and a better understanding of the impacts of antibiotics used on farms would produce a more robust platform for public policy. Microbiomes of farm animals are reservoirs of antibiotic resistance genes, which may affect distribution of antibiotic resistance genes in human pathogens. Previous studies have focused on antibiotic resistance genes in manures of animals subjected to intensive antibiotic use, such as pigs and chickens. Cow manure has received less attention, although it is commonly used in crop production. Here, we report the discovery of novel and diverse antibiotic resistance genes in the cow microbiome, demonstrating that it is a significant reservoir of antibiotic resistance genes. The genomic resource presented here lays the groundwork for understanding the dispersal of antibiotic resistance from the agroecosystem to other settings.

Relation between Nitrates in Water Wells and Potential Sources in the Lower Yakima Valley, Washington State. U.S. Environmental Protection Agency, Washington, D.C., 2012.
Link: https://www3.epa.gov/region10/pdf/sites/yakimagw/nitrate_in_water_wells_study_9-27-2012.pdf

> Several investigations relating to nitrate contamination in the Lower Yakima Valley in Washington State have shown nitrate levels in drinking water above the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 mg/L. From February through April 2010, EPA conducted sampling of drinking water wells and potential sources of nitrate contamination in the Lower

Yakima Valley, in central Washington State. This report presents the results of these sampling efforts. EPA collected over 331 samples from residential drinking water wells for nitrate and bacteria, and multi-parameter sampling on 29 water wells (26 residential drinking water wells and three dairy supply wells), 12 dairy lagoons (15 samples), 11 soil samples (five at dairy application fields and six at irrigated and fertilized crop fields), five dairy manure pile samples, and three wastewater treatment plant (WWTP) influent samples. EPA's data provide some indication of the likely nitrate sources for seven of the 25 residential wells tested--animal waste was determined to be the source for six of the wells, and synthetic fertilizer the source for one of the wells. Given the historic and current volumes of wastes generated and stored by dairies, and the application of nitrogen-rich fertilizers including dairy waste in the Lower Yakima Valley, it is expected that dairies are a likely source of high nitrate levels in downgradient drinking water wells. The total nitrogen, major ions, alkalinity and barium data provide strong evidence that the dairies evaluated in this study are likely sources of the high nitrate levels in the drinking water wells downgradient of the dairies. Additional information that supports this conclusion includes: there are few potential sources of nitrogen located upgradient of the dairies; the dairy lagoons are likely leaking large quantities of nitrogen-rich liquid into the subsurface; and Washington State Department of Agriculture inspectors have reported elevated levels of nitrogen in application fields of the dairies in the study. Evaluating actions to reduce nitrate concentrations in residential drinking water wells was beyond the scope of the EPA's report. EPA concluded that actions to reduce nitrate levels are needed, although it may take many years to reduce nitrates in residential drinking water wells to safe levels because of the extent of the nitrate contamination in the Lower Yakima Valley and the persistence of nitrate in the environment.

Appendix B: Research Articles Related to Swine Production
We have underlined sections of the abstracts in the appendices to highlight main points.

Casey JA, Curriero FC, Cosgrove SE, Nachman KE, Schwartz BS. High-Density Livestock Operations, Crop Field Application of Manure, and Risk of Community-Associated Methicillin-Resistant *Staphylococcus aureus* Infection in Pennsylvania. JAMA Intern Med. 2013 Sep 16;21205(21):1980–90.
Link: https://www.ncbi.nlm.nih.gov/pubmed/24043228

> Nearly 80% of antibiotics in the United States are sold for use in livestock feeds. The manure produced by these animals contains antibiotic-resistant bacteria, resistance genes, and antibiotics and is subsequently applied to crop fields, where it may put community members at risk for antibiotic-resistant infections. The objective of this study was to assess the association between individual exposure to swine and dairy/veal industrial agriculture and risk of methicillin-resistant *Staphylococcus aureus* (MRSA) infection. This study was a population-based, nested case-control study of primary care patients from a single health care system in Pennsylvania from 2005 to 2010. Incident MRSA cases were identified using electronic health records, classified as community-associated MRSA or health care–associated MRSA, and frequency matched to randomly selected controls and patients with skin and soft-tissue infection. Nutrient management plans were used to create 2 exposure variables: seasonal crop field manure application and number of livestock animals at the operation. In a substudy, we collected 200 isolates from patients stratified by location of diagnosis and proximity to livestock operations. The study measured community-associated MRSA, health care–associated MRSA, and skin and soft-tissue infection status (with no history of MRSA) compared with controls. From a total population of 446,480 patients, 1,539 community-associated MRSA, 1335 health care-associated MRSA, 2895 skin and soft-tissue infection cases, and 2914 controls were included. After adjustment for MRSA risk factors, the highest quartile of swine crop field exposure was significantly associated with community-associated MRSA, health care-associated MRSA, and skin and soft-tissue infection case status (adjusted odds ratios, 1.38 [95% CI, 1.13-1.69], 1.30 [95% CI, 1.05-1.61], and 1.37 [95% CI, 1.18-1.60], respectively); and there was a trend of increasing odds across quartiles for each outcome ($P \leq .01$ for trend in all comparisons). There were similar but weaker associations of swine operations with community-associated MRSA and skin and soft-tissue infection. Molecular testing of 200 isolates identified 31 unique *spa* types, none of which corresponded to CC398 (clonal complex 398), but some have been previously found in swine. Proximity to swine manure application to crop fields and livestock operations each was associated with MRSA and skin and soft-tissue infection. These findings contribute to the growing concern about the potential public health impacts of high-density livestock production.

Donham KJ, Wing S, Osterberg D, al et, Flora JL, Hodne C, et al. Community health and socioeconomic issues surrounding concentrated animal feeding operations. Environ Health Perspect. 2007 Feb;115(2):317–20.
Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1817697/

> A consensus of the Workgroup on Community and Socioeconomic Issues was that improving and sustaining healthy rural communities depends on integrating socioeconomic development and environmental protection. The workgroup agreed

> that the World Health Organization's definition of health, "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity," applies to rural communities. These principles are embodied in the following main points agreed upon by this workgroup. Healthy rural communities ensure a) the physical and mental health of individuals, b) financial security for individuals and the greater community, c) social well-being, d) social and environmental justice, and e) political equity and access. This workgroup evaluated impacts of the proliferation of concentrated animal feeding operations (CAFOs) on sustaining the health of rural communities. Recommended policy changes include a more stringent process for issuing permits for CAFOs, considering bonding for manure storage basins, limiting animal density per watershed, enhancing local control, and mandating environmental impact statements.

Graham JP, Leibler JH, Price LB, Otte JM, Pfeiffer DU, Tiensin T, et al. The animal-human interface and infectious disease in industrial food animal production: rethinking biosecurity and biocontainment. Public Health Rep. 2008;123(3):282–99.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19006971

> Understanding interactions between animals and humans is critical in preventing outbreaks of zoonotic disease. This is particularly important for avian influenza. Food animal production has been transformed since the 1918 influenza pandemic. Poultry and swine production have changed from small-scale methods to industrial-scale operations. There is substantial evidence of pathogen movement between and among these industrial facilities, release to the external environment, and exposure to farm workers, which challenges the assumption that modern poultry production is more biosecure and biocontained as compared with backyard or small holder operations in preventing introduction and release of pathogens. An analysis of data from the Thai government investigation in 2004 indicates that the odds of H5N1 outbreaks and infections were significantly higher in large-scale commercial poultry operations as compared with backyard flocks. These data suggest that successful strategies to prevent or mitigate the emergence of pandemic avian influenza must consider risk factors specific to modern industrialized food animal production.

Heaney CD, Myers K, Wing S, Hall D, Baron D, Stewart JR. Source tracking swine fecal waste in surface water proximal to swine concentrated animal feeding operations. Sci Total Environ. Elsevier; 2015;511:676–83.
Link: http://www.sciencedirect.com/science/article/pii/S0048969714017641

> Swine farming has gone through many changes in the last few decades, resulting in operations with a high animal density known as confined animal feeding operations (CAFOs). These operations produce a large quantity of fecal waste whose environmental impacts are not well understood. The purpose of this study was to investigate microbial water quality in surface waters proximal to swine CAFOs including microbial source tracking of fecal microbes specific to swine. For one year, surface water samples at up- and downstream sites proximal to swine CAFO lagoon waste land application sites were tested for fecal indicator bacteria (fecal coliforms, Escherichia coli and Enterococcus) and candidate swine-specific microbial source-tracking (MST) markers (Bacteroidales Pig-1-Bac, Pig-2-Bac, and Pig-Bac-2, and methanogen P23-2). Testing of 187 samples showed

high fecal indicator bacteria concentrations at both up- and downstream sites. Overall, 40%, 23%, and 61% of samples exceeded state and federal recreational water quality guidelines for fecal coliforms, E. coli, and Enterococcus, respectively. Pig-1-Bac and Pig-2-Bac showed the highest specificity to swine fecal wastes and were 2.47 (95% confidence interval [CI] = 1.03, 5.94) and 2.30 times (95% CI = 0.90, 5.88) as prevalent proximal down- than proximal upstream of swine CAFOs, respectively. Pig-1-Bac and Pig-2-Bac were also 2.87 (95% CI = 1.21, 6.80) and 3.36 (95% CI = 1.34, 8.41) times as prevalent when 48 hour antecedent rainfall was greater than versus less than the mean, respectively. Results suggest diffuse and overall poor sanitary quality of surface waters where swine CAFO density is high. Pig-1-Bac and Pig-2-Bac are useful for tracking off-site conveyance of swine fecal wastes into surface waters proximal to and downstream of swine CAFOs and during rain events.

Horton RA, Wing S, Marshall SW, Brownley KA. Malodor as a trigger of stress and negative mood in neighbors of industrial hog operations. Am J Public Health. 2009 Nov;99 Suppl 3:S610–5.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19890165

Objectives. We evaluated malodor and air pollutants near industrial hog operations as environmental stressors and negative mood triggers.
Methods. We collected data from 101 nonsmoking adults in 16 neighborhoods within 1.5 miles of at least 1 industrial hog operation in eastern North Carolina. Participants rated malodor intensity, stress, and mood for 2 weeks while air pollutants were monitored.
Results. Reported malodor was associated with stress and 4 mood states; odds ratios (ORs) for a 1-unit change on the 0-to-8 odor scale ranged from 1.31 (95% confidence interval [CI] = 1.16, 1.50) to 1.81 (95% CI = 1.63, 2.00). ORs for stress and feeling nervous or anxious were 1.18 (95% CI = 1.08, 1.30) and 1.12 (95% CI = 1.03, 1.22), respectively, for a 1 ppb change in hydrogen sulfide and 1.06 (95% CI = 1.00, 1.11) and 1.10 (95% CI = 1.03, 1.17), respectively, for a 1 $\mu g/m^3$ change in semivolatile particulate matter less than 10 μm in aerodynamic diameter (PM_{10}).
Conclusions. Hog odor, hydrogen sulfide, and semivolatile PM_{10} are related to stress and negative mood in disproportionately low-income communities near industrial hog operations in eastern North Carolina. Malodor should be considered in studies of health impacts of environmental injustice.

Ma W, Lager KM, Vincent AL, Janke BH, Gramer MR, Richt JA. The role of swine in the generation of novel influenza viruses. Zoonoses Public Health. 2009 Aug;56(6-7):326–37.
Link: https://www.ncbi.nlm.nih.gov/pubmed/19486316

The ecology of influenza A viruses is very complicated involving multiple host species and viral genes. Avian species have variable susceptibility to influenza A viruses with wild aquatic birds being the reservoir for this group of pathogens. Occasionally, influenza A viruses are transmitted to mammals from avian species, which can lead to the development of human pandemic strains by direct or indirect transmission to man. Because swine are also susceptible to infection with avian and human influenza viruses, genetic reassortment between these viruses and/or swine influenza viruses can occur. The potential to generate novel influenza viruses has resulted in swine being labelled 'mixing vessels'. The mixing vessel theory is one mechanism by which unique viruses can be transmitted from an avian reservoir to man. Although swine can generate novel influenza viruses capable of infecting man, at present, it is difficult to predict which viruses, if any, will cause a human pandemic. Clearly, the ecology of influenza A viruses is dynamic and can impact human health, companion animals, as well as the health of livestock and poultry for production of valuable protein commodities. For these reasons, influenza is, and will continue to be, a serious threat to the wellbeing of mankind.

Mirabelli MC, Wing S, Marshall SW, Wilcosky TC. Asthma symptoms among adolescents who attend public schools that are located near confined swine feeding operations. Pediatrics. 2006 Jul;118(1):e66–75.
Link: http://pediatrics.aappublications.org/content/118/1/e66

Objectives. Little is known about the health effects of living in close proximity to industrial swine operations. We assessed the relationship between estimated exposure to airborne effluent from confined swine feeding operations and asthma symptoms among adolescents who were aged 12 to 14 years.
Methods. During the 1999–2000 school year, 58169 adolescents in North Carolina answered questions about their respiratory symptoms, allergies, medications, socioeconomic status, and household environments. To estimate the extent to which these students may have been exposed during the school day to air pollution from confined swine feeding operations, we used publicly available data about schools (n = 265) and swine operations (n = 2343) to generate estimates of exposure for each public school. Prevalence ratios and 95% confidence intervals for wheezing within the past year were estimated using random-intercepts binary regression models, adjusting for potential confounders, including age, race, socioeconomic status, smoking, school exposures, and household exposures.
Results. The prevalence of wheezing during the past year was slightly higher at schools that were estimated to be exposed to airborne effluent from confined swine feeding operations. For students who reported allergies, the prevalence of wheezing within the past year was 5% higher at schools that were located within 3 miles of an operation relative to those beyond 3 miles and 24% higher at schools in which livestock odor was noticeable indoors twice per month or more relative to those with no odor.
Conclusions. Estimated exposure to airborne pollution from confined swine feeding operations is associated with adolescents' wheezing symptoms.

Rinsky JL, Nadimpalli M, Wing S, Hall D, Baron D, Price LB, et al. Livestock-Associated Methicillin and Multidrug Resistant *Staphylococcus aureus* Is Present among Industrial, Not Antibiotic-Free Livestock Operation Workers in North Carolina. PLoS One. 2013;8(7).
Link: https://www.ncbi.nlm.nih.gov/pubmed/23844044

Objectives. Administration of antibiotics to food animals may select for drug-resistant pathogens of clinical significance, such as methicillin-resistant *Staphylococcus aureus* (MRSA). In the United States, studies have examined prevalence of MRSA carriage among individuals exposed to livestock, but prevalence of multidrug-resistant *S. aureus* (MDRSA) carriage and the association with livestock raised with versus without antibiotic selective pressure remains unclear. We aimed to examine prevalence, antibiotic susceptibility, and molecular characteristics of *S. aureus* among industrial livestock operation (ILO) and antibiotic-free livestock operation (AFLO) workers and household members in North Carolina.

Methods. Participants in this cross-sectional study were interviewed and provided a nasal swab for *S. aureus* analysis. Resulting *S. aureus* isolates were assessed for antibiotic susceptibility, multi-locus sequence type, and absence of the scn gene (a marker of livestock association).
Results. Among 99 ILO and 105 AFLO participants, *S. aureus* nasal carriage prevalence was 41% and 40%, respectively. Among ILO and AFLO *S. aureus* carriers, MRSA was detected in 7% (3/41) and 7% (3/42), respectively. Thirty seven percent of 41 ILO versus 19% of 42 AFLO *S. aureus*-positive participants carried MDRSA. *S. aureus* clonal complex (CC) 398 was observed only among workers and predominated among ILO (13/34) compared with AFLO (1/35) *S. aureus*-positive workers. Only ILO workers carried scn-negative MRSA CC398 (2/34) and scn-negative MDRSA CC398 (6/34), and all of these isolates were tetracycline resistant.
Conclusions. Despite similar *S. aureus* and MRSA prevalence among ILO and AFLO-exposed individuals, livestock-associated MRSA and MDRSA (tetracycline-resistant, CC398, scn-negative) were only present among ILO-exposed individuals. These findings support growing concern about antibiotics use and confinement in livestock production, raising questions about the potential for occupational exposure to an opportunistic and drug-resistant pathogen, which in other settings including hospitals and the community is of broad public health importance.

Sapkota AR, Curriero FC, Gibson KE, Schwab KJ. Antibiotic-resistant enterococci and fecal indicators in surface water and groundwater impacted by a concentrated swine feeding operation. Environ Health Perspect. 2007 Jul;115(7):1040–5.
Link: https://www.ncbi.nlm.nih.gov/pubmed/17637920

Background. The nontherapeutic use of antibiotics in swine feed can select for antibiotic resistance in swine enteric bacteria. Leaking swine waste storage pits and the land-application of swine manure can result in the dispersion of resistant bacteria to water sources. However, there are few data comparing levels of resistant bacteria in swine manure–impacted water sources versus unaffected sources.
Objectives. The goal of this study was to analyze surface water and groundwater situated up and down gradient from a swine facility for antibiotic-resistant enterococci and other fecal indicators.
Methods. Surface water and groundwater samples (n = 28) were collected up and down gradient from a swine facility from 2002 to 2004. Fecal indicators were isolated by membrane filtration, and enterococci (n = 200) were tested for susceptibility to erythromycin, tetracycline, clindamycin, virginiamycin, and vancomycin.
Results. Median concentrations of enterococci, fecal coliforms, and Escherichia coli were 4- to 33-fold higher in down-gradient versus up-gradient surface water and groundwater. We observed higher minimal inhibitory concentrations for four antibiotics in enterococci isolated from down-gradient versus up-gradient surface water and groundwater. Elevated percentages of erythromycin- ($p = 0.02$) and tetracycline-resistant ($p = 0.06$) enterococci were detected in down-gradient surface waters, and higher percentages of tetracycline- ($p = 0.07$) and clindamycin-resistant ($p < 0.001$) enterococci were detected in down-gradient groundwater.
Conclusions. We detected elevated levels of fecal indicators and antibiotic-resistant enterococci in water sources situated down gradient from a swine facility compared with up-gradient sources. These findings provide additional evidence that water

contaminated with swine manure could contribute to the spread of antibiotic resistance.

Schinasi L, Horton RA, Guidry VT, Wing S, Marshall SW, Morland KB. Air pollution, lung function, and physical symptoms in communities near concentrated swine feeding operations. Epidemiology. 2011 Mar;22(2):208–15.
Link: https://www.ncbi.nlm.nih.gov/pubmed/21228696

Background. Concentrated animal feeding operations emit air pollutants that may affect health. We examined associations of reported hog odor and of monitored air pollutants with physical symptoms and lung function in people living within 1.5 miles of hog operations.
Methods. Between September 2003 and September 2005, we measured hydrogen sulfide (H2S), endotoxin, and particulate matter (PM10, PM2.5, and PM2.5–10) for approximately 2-week periods in each of 16 eastern North Carolina communities. During the same time periods, 101 adults sat outside their homes twice a day for 10 minutes, reported hog odor and physical symptoms, and measured their lung function. Conditional fixed-effects logistic and linear regression models were used to derive estimates of associations.
Results. The log odds (±1 standard error) of acute eye irritation following 10 minutes outdoors increased by 0.53 (±0.06) for every unit increase in odor, by 0.15 (±0.06) per 1 ppb of H2S, and by 0.36 (±0.11) per 10 µg/m3 of PM10. Odor and H2S were also associated with irritation and respiratory symptoms in the previous 12 hours. The log odds of difficulty breathing increased by 0.50 (±0.15) per unit of odor. A 10 µg/m3 increase in mean 12-hour PM2.5 was associated with increased log odds of wheezing (0.84 ± 0.29) and declines in forced expiratory volume in 1 second (-0.04 ± 0.02 L). A 10 EU/mg increase in endotoxin was associated with increased log odds of sore throat (0.10 ± 0.05), chest tightness (0.09 ± 0.04), and nausea (0.10 ± 0.05).
Conclusions. Pollutants measured near hog operations are related to acute physical symptoms in a longitudinal study using analyses that preclude confounding by time-invariant characteristics of individuals.

Schulz J, Friese A, Klees S, Tenhagen BA, Fetsch A, Rösler U, et al. Longitudinal study of the contamination of air and of soil surfaces in the vicinity of pig barns by livestock-associated methicillin-resistant *Staphylococcus aureus*. Appl Environ Microbiol. 2012 Aug;78(16):5666–71.
Link: http://aem.asm.org/content/78/16/5666.full

During 1 year, samples were taken on 4 days, one sample in each season, from pigs, the floor, and the air inside pig barns and from the ambient air and soil at different distances outside six commercial livestock-associated methicillin-resistant *Staphylococcus aureus* (LA-MRSA)-positive pig barns in the north and east of Germany. LA-MRSA was isolated from animals, floor, and air samples in the barn, showing a range of airborne LA-MRSA between 6 and 3,619 CFU/m(3) (median, 151 CFU/m(3)). Downwind of the barns, LA-MRSA was detected in low concentrations (11 to 14 CFU/m(3)) at distances of 50 and 150 m; all upwind air samples were negative. In contrast, LA-MRSA was found on soil surfaces at distances of 50, 150, and 300 m downwind from all barns, but no statistical differences could be observed between the proportions of positive soil surface samples at the three different distances. Upwind of the barns, positive soil surface samples were found only sporadically. Significantly more positive LA-MRSA samples were found in summer than in the other seasons both in air and soil samples upwind and downwind of the pig barns. spa typing was used to confirm the identity of LA-MRSA types found inside and outside the barns. The results show that there is regular airborne LA-MRSA transmission and deposition, which are strongly influenced by wind direction and season, of up to at least 300 m around positive pig barns. The described boot sampling method seems suitable to characterize the contamination of the vicinity of LA-MRSA-positive pig barns by the airborne route.

Wing S, Horton RA, Rose KM. Air pollution from industrial swine operations and blood pressure of neighboring residents. Environ Health Perspect. 2013 Jan;121(1):92–6.
Link: https://ehp.niehs.nih.gov/1205109/

Background. Industrial swine operations emit odorant chemicals including ammonia, hydrogen sulfide (H2S), and volatile organic compounds. Malodor and pollutant concentrations have been associated with self-reported stress and altered mood in prior studies.
Objectives: We conducted a repeated-measures study of air pollution, stress, and blood pressure in neighbors of swine operations.
Methods. For approximately 2 weeks, 101 nonsmoking adult volunteers living near industrial swine operations in 16 neighborhoods in eastern North Carolina sat outdoors for 10 min twice daily at preselected times. Afterward, they reported levels of hog odor on a 9-point scale and measured their blood pressure twice using an automated oscillometric device. During the same 2- to 3-week period, we measured ambient levels of H2S and PM10 at a central location in each neighborhood. Associations between systolic and diastolic blood pressure (SBP and DBP, respectively) and pollutant measures were estimated using fixed-effects (conditional) linear regression with adjustment for time of day.
Results. PM10 showed little association with blood pressure. DBP [β (SE)] increased 0.23 (0.08) mmHg per unit of reported hog odor during the 10 min outdoors and 0.12 (0.08) mmHg per 1-ppb increase of H2S concentration in the same hour. SBP increased 0.10 (0.12) mmHg per odor unit and 0.29 (0.12) mmHg per 1-ppb increase of H2S in the same hour. Reported stress was strongly associated with BP; adjustment for stress reduced the odor–DBP association, but the H2S–SBP association changed little.
Conclusions. Like noise and other repetitive environmental stressors, malodors may be associated with acute blood pressure increases that could contribute to development of chronic hypertension.