CONSIDERATIONS
FOR THE USE OF
MANURE IRRIGATION PRACTICES

Report from the Wisconsin Manure Irrigation Workgroup

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This informational report was developed by members of the Manure Irrigation Workgroup. The workgroup included invited participants representing a cross-section of interests concerned with the use of irrigation equipment to land-apply livestock manure or process wastewater by agricultural operations. Future public policy regarding manure irrigation would be made by state and local governments following appropriate public participation and input; this workgroup did not have that authority. This report is informational. The report is a group product, compiled and edited by Genskow and Larson with contributions and comments from all workgroup members and writing contributions from Borchardt, Craig, Baeten, Murphy, Struss, and Thiboldeaux. The report does not represent the views of any individual workgroup member, nor the views of any of the participating organizations.

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Please note that “Appendix C: Airborne Pathogens from Dairy Manure Aerial Irrigation and the Human Health Risk” is a stand-alone research publication authored by M. Borchardt and T. Burch. See recommended citation in Appendix C.

Table of Contents

Glossary and List of Acronyms

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ATCP 50	Chapter ATCP50 of Wisconsin Administrative Code, addressing Wisconsin's Soil and Water Resource Management Program
CAFO	Concentration Animal Feeding Operation
CUP	Conditional use permit
NMP	Nutrient management plan
NOAELl	No observable adverse effect level
NR 151	Chapter NR151 of Wisconsin Administrative Code, addressing Runoff Management
NR 213	Chapter NR213 of Wisconsin Administrative Code, addressing Lining Of Industrial Lagoons And Design Of Storage Structures
NR 214	Chapter NR214 of Wisconsin Administrative Code, addressing Land Treatment Of Industrial Liquid Wastes, By-Product Solids And Sludges
NR 243	Chapter NR243 of Wisconsin Administrative Code, addressing Animal Feeding Operations
NRCS	Natural Resources Conservation Service Conservation Practice
CPS 590	Standard Code 590
PI	Phosphorus Index
PSI	Pounds per square inch (pressure)
SWQMA	Surface Water Quality Management Area
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UWEX	University of Wisconsin-Extension
VMD	Volume median diameter (for droplet diameter sizing)
WDATCP	Wisconsin Department of Agriculture, Trade, and Consumer Protection
WDHS	Wisconsin Department of Health Services
WDNR	Wisconsin Department of Natural Resources
WPDES	Wisconsin Pollution Discharge Elimination System
µm	micrometer = 1x10^{-6} meter

Executive Summary

The Wisconsin Manure Irrigation Workgroup was convened in Spring 2013 by University of Wisconsin-Extension (UWEX) and University of Wisconsin-Madison (UW-Madison) College of Agricultural and Life Sciences at the request of Wisconsin Department of Natural Resources (WDNR) and Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP). The workgroup was asked to review a broad set of issues associated with manure irrigation and to develop guidance and recommendations for state agencies, local governments, and citizens seeking to understand this expanding technology. The workgroup has no formal authority to establish policy for any jurisdiction within Wisconsin. Any public policy action by local or state governments related to workgroup recommendations would involve appropriate public participation and input.

After hosting two public presentations and input sessions in May 2013, the workgroup met 16 times between July 2013 and September 2015. Throughout its duration, the workgroup maintained open channels for public input and comments through a website and email. Over this same time period, an independent but related study (funded by the WDNR and United States Department of Agriculture-Agricultural Research Service (USDA-ARS)) was being conducted to quantify the risk of illness associated with airborne pathogens from manure irrigation (summarized in Appendix C of this report). The timeline and results for that study influenced the timing of final conversations and recommendations from the workgroup.

The workgroup reviewed a range of issues for this report related to manure irrigation. Sections of the report identify the initial benefits and concerns around the practice that led to the workgroup formation, discussions of health and environmental risk, review of manure as a material, manure management, and existing rules and regulations associated with various aspects of manure irrigation. The report also provides descriptions for seven considerations for use of manure irrigation practices that drove workgroup discussion and provided information necessary for developing workgroup recommendations.

Decisions and recommendations made by the workgroup were based on a consensus seeking process. For many aspects of guidance and recommendations, the workgroup did achieve consensus. In particular, the workgroup reached consensus about recommendations for baseline conditions that should be in place if manure irrigation practices are used. The workgroup reached lower levels of agreement (near consensus or close-to-near consensus) for recommendations related to setback distances for different land uses under various combinations of conditions (such as wind speed, wind direction, etc.).
Consensus baseline recommendations for all uses of manure irrigation practices are that operators must:

- Follow all existing relevant state and local laws regarding animal waste and nutrient management
- Have and follow a NRCS CPS 590 Nutrient Management Plan
- Take appropriate steps to minimize drift
- Ensure no overspray of irrigated manure
- Have suitable means of supervising/controlling the equipment (e.g., active supervision, automatic sensors/controls, etc.)
- Have suitable means of determining relevant weather information (to include: wind speed, wind direction, and temperature)

- Have means of preventing contaminated backflow if equipment is connected to water sources
- Ensure that no human waste or septage is added to (or processed with) the manure.

Additional recommendations apply depending on whether and how the manure is processed. Those include issues related to time of day, wind speed, total number of applications per year, and equipment (such as nozzles that produce larger droplet sizes).

Recommendations for setback distances generally do not reflect consensus among all group members. Setback distance refers to distance from the edge of the area wetted by irrigated manure. For forests, adjacent agricultural lands, and road right-of-way wetted perimeter could be at the property line.. Minimum setback distances of 100 feet were recommended (at near consensus or close-to-near consensus) for property lines of public recreational areas, including property lines for schools or playgrounds, and distances ranging from as high as 750 feet to as low as 250 feet (with additional conditions) for dwellings and occupied buildings. In all cases, setback distances to an occupied building would take precedence over setback distance to a property line. The full set of baseline conditions and setback distances are described in Chapter 5, along with degree of consensus.

This report represents a compilation of science and knowledge vetted through the varied perspectives of workgroup members. The workgroup had limited resources and did not have the capacity to perform comprehensive reviews related to some emerging areas of science that have been identified as concerns for manure irrigation. For the issues discussed, the emphasis was placed on understanding additional risk incurred when land application of manure is conducted with irrigation practices in comparison to conventional manure application practices. As noted, this report does not establish policy for any jurisdiction in Wisconsin. It is intended to serve as a resource for citizens and elected officials engaged in discussions about appropriate next steps for their communities around the issue of manure irrigation.

1. Introduction

1.a Workgroup goals and objectives

Manure irrigation refers to the practice of applying livestock manure or process wastewater through irrigation equipment. It generally involves pumping the liquid manure from a storage area (such as a manure storage basin) through pipes or hoses to equipment conventionally used for irrigation—for example, “center pivots” or “travelling guns”—that are used to apply the liquid material to a field.

Manure irrigation as an agricultural practice is widespread in several states, but is less common in Wisconsin. Among Wisconsin’s largest livestock operations (CAFOs – or Concentrated Animal Feeding Operations), very few use the practice, and there is no estimate available for the number of smaller, non-CAFO operations that currently use manure irrigation practices (See Section 2c for more information about CAFO and non-CAFO users in Wisconsin). Yet, several factors are causing more farmers to consider manure irrigation as part of their overall manure management system.

Wisconsin’s Manure Irrigation Workgroup formed in 2013 to *review a broad set of issues associated with manure irrigation and to develop guidance and recommendations* for state agencies, local governments, and citizens seeking to understand this expanding technology. The workgroup has no formal authority and expects that any public policy action by local or state governments related to workgroup recommendations would involve appropriate public participation and input. The workgroup was convened by University of Wisconsin-Madison (UW-Madison) College of Agricultural and Life Sciences and University of Wisconsin-Extension (UWEX) at the request of Wisconsin Department of Natural Resources (WDNR) and Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) to provide an opportunity for diverse perspectives and interests to participate in the review process. Information in this report is intended to inform those decision-making processes.

The workgroup was asked to compile and review existing information, review new research, and produce written guidance and recommendations for the use of manure irrigation practices. Workgroup members (listed on the inside of the front cover) included researchers, state and local public health officials, staff from agricultural and environmental agencies, dairy farmers, conservation interests, and concerned stakeholders. As part of its review, the workgroup served in an advisory capacity to a separate independent research project led by two workgroup members and funded by WDNR and USDA-ARS. That study focused on quantifying risk of acute gastrointestinal illness associated with airborne pathogen transport from manure irrigation sites. Although independent efforts, the workgroup and research projects shared information and were mutually beneficial. Preliminary results from the study were presented to the workgroup over the course of several meetings in 2015 to help form the basis for workgroup recommendations. A summary of the study is included in Appendix C of this report.

The Manure Irrigation Workgroup process began in May 2013 with two public research symposia intended to help establish a common reference point for workgroup participants and other interested stakeholders. The symposia reviewed research and local knowledge related to benefits, concerns, and open questions associated with manure irrigation practices and solicited input. Presentations from the May 17, 2013 symposium are posted at the workgroup website *(http://fyi.uwex.edu/manureirrigation/).* The issues identified through those public forums provided an outline for workgroup discussions.

1.b Workgroup process and activities

The benefits and concerns identified by stakeholders (see Section 1c below) helped shape the agenda for the workgroup, and over its two-year duration, workgroup discussion touched on all of those issues. The workgroup met 16 times between July 2013 and September 2015. Agendas for individual meetings were set by the chair, often with suggestions and specific requests from workgroup members. There was no specific state funding allocated for workgroup support. Rather, workgroup members provided their time and in-kind support through their public agency and private organization resources. The workgroup maintained a website that included information about each meeting as well as background information and related reports. Throughout its duration, the workgroup maintained open channels for public input and comments through the website and email. All comments submitted were shared with the workgroup at the beginning of each meeting. Meetings were announced on the website and also through an email list open to anyone expressing an interest.

The workgroup operated under a set of ground rules established at the first meeting. These included agreements to focus on learning and problem solving, remain open to new information and perspectives, discuss difficult issues, and keep discussions focused. The workgroup agreed to seek consensus on workgroup decisions, and where consensus would not be possible, to note majority and minority perspectives. Most of the meetings involved discussing and vetting information from multiple perspectives. The final few meetings focused on understanding preliminary results of the Borchardt and Burch pathogen study (Appendix C) and making decisions about workgroup recommendations.

Additional details are available at the workgroup website: *(http://fyi.uwex.edu/manureirrigation/)*

1.c Initial concerns and benefits raised regarding Manure Irrigation

The May 2013 public symposia and subsequent comments shared with the workgroup identified potential benefits and defined concerns related to manure irrigation. Comments shared with the workgroup during and following those events represented strong and differing opinions on the relative merits and potential consequences associated with manure irrigation in Wisconsin. Comments and opinions included outrage over perceived risks to health and quality of life, advocacy for advantages of the practices over existing alternatives, and requests for cautious assessment. The central benefits and concerns related to those comments are summarized below.

Expressed concerns initially identified for the workgroup agenda

Concerns identified for the workgroup included questions related to the physical process of manure irrigation and the potential for negative consequences from drift, deposition, and volatilization of wastewater components. The workgroup sought to understand and address these concerns, which reflected several themes:

- **Public health risk from airborne pathogens and other contaminants.** Those sharing comments against manure irrigation practices expressed very strong concerns that wet and dry airborne materials from the application process could be transported to nearby and/or distant properties and cause harmful effects. Specific concerns included potential conveyance of pathogens, particulates, antibiotics, cleaning compounds, toxic gases associated with stored and land-spread manure wastes, endocrine disruptors, and antibiotic-resistant pathogenic bacteria. There was also concern that contaminants in aerosol form might be inhaled and carry toxins to the bloodstream more directly than if ingested. In addition to the health concerns for the general population, there were additional concerns over potential increased health risks to vulnerable populations such as the elderly and those with compromised immune systems.

- **Drift.** Public comments included concerns that irrigation practices could result in drift of wet manure material that could deposit on neighboring properties, surface waters, and crops in nearby fields. Organic and specialty farm interests raised concerns about the risk of losing organic certification and/or product marketability due to drift.

- **Odor and other quality of life concerns.** Reinforced by statements of people with homes near fields using manure irrigation, concerns were expressed about odor, respiratory health, poor air quality, increased airborne particulates, general contamination and potential constraints on the use and enjoyment of public and private property.

- **Surface water quality contamination.** Concerns were expressed about the potential for contamination of surface water related to runoff from precipitation events after manure irrigation application and about direct deposition of irrigated materials into waterways.

- **Groundwater quality contamination.** Concerns raised about groundwater quality included potential threats to wells and aquifers from irrigation applications where pathways to groundwater may be more direct such as on sandy soils or fractured bedrock areas. Concern about manure backflow into aquifers through irrigation water supplies was also mentioned.

- **Groundwater quantity.** Concerns also extended to groundwater quantity, specifically that manure irrigation may draw down groundwater levels due to the installation of irrigation systems and the need for additional water to dilute manure prior to application.

- **Implementation and compliance issues.** Concerns were also raised about the ability of farm managers to implement requirements associated with the use of manure irrigation as well as challenges for public agency staff in monitoring compliance with any required manure irrigation management practices.

<u>Potential benefits initially identified for the workgroup agenda</u>

In identifying an initial set of issues for the workgroup, those supporting the use of manure irrigation practices initially identified multiple potential benefits compared to other available options for manure transportation and application. The benefits group into three main issues.

- **Timing of manure application.** In contrast to trucks and tankers that move manure onto fields primarily in spring and fall, before planting and after harvest, manure irrigation allows for application to a growing crop when plant-nutrient uptake is highest. This in-season timing has the potential to reduce the volume of manure applied in the spring and fall (when risks of surface runoff may be higher) and shift application to drier summer months. Applying nutrients during the growing season may deliver nutrients more directly to the plant during peak uptake periods and decrease potential for nutrient loss to groundwater or surface water. The ability to apply smaller volumes per acre more often during the growing season may reduce the likelihood of ponding, macro-pore transport, and weather-related runoff risks. In-season application also increases the time period for planting of fall/winter cover crops which helps reduce the risk of nutrient runoff and losses below the crop root zone to groundwater.

- **Road safety and reduced road damage.** Piping liquid manure and process wastewater to a field and distributing through irrigation equipment reduces the numbers of trucks, tankers, and other heavy equipment that would otherwise haul that material on roads. Redirecting manure transport and distribution off of the roads would reduce road traffic from farm equipment, reduce road weight and damage on roads, and reduce the risk of traffic accidents and road spills.

- **Farm management and economic benefits.** Manure irrigation practices have the potential to allow farm managers to have more precise control over application rates and timing, lower distribution costs, and reduce soil compaction due to heavy equipment on fields in spring and fall. By allowing summer application on growing crops, it reduces the timing challenges of applying manure prior to planting in a late spring (related to weather, soil moisture, availability of custom manure haulers, and planting) or following fall crop harvest before frozen ground and snow covered conditions.

1.d Health and environmental risk – key concepts

As an introduction, several key concepts about risk and public health policy provide an important foundation for understanding potential implications of any management activities for public health and the environment. What follows are brief descriptions of risk perception, calculations of risk, individual behavior factors related to exposure, and acceptable exposure to pathogens. These concepts informed workgroup discussion and they set the stage for more detailed information used to evaluate the concerns and benefits presented throughout this report.

Closely related to these concepts is how to weigh their significance and consider public policy responses. Although not required by federal or state law, the precautionary principle as used in Europe often arises in public discussions around health and environmental risk. One version of this states, "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. The precautionary principle says we should attempt to anticipate and avoid damages before they occur or detect them early" (Wingspread 1998). It falls to legislative and administrative bodies at local, state, and federal levels to determine the appropriate balance of factors for their jurisdictions.

Risk perception

Daily activities present people with many situations that carry some probability or potential for harm, otherwise known as risk. Driving a car, walking down stairs, getting a medical x-ray, or eating certain foods all entail some chance of negative impact to an individual's health or safety. The amount of actual risk involved in an activity depends upon many factors specific to the situation. For a specific activity an individual may have some fear or dread corresponding to their knowledge of a risk. Dread may increase or decrease based on ability to observe or control a perceived hazard. However, an individual's perception of a hazard may not correspond to quantifiable estimates of risk. Risk, in an environmental sense, is defined by the USEPA as "the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor."

Calculation of risk

Risk can be calculated using quantifiable measurements of hazards combined with estimates of behavior or situations that bring people into contact with hazards. The calculation of human health risk in environmental situations involves two main elements: (1) the presence of a possibly harmful chemical, physical, or microbial agent in the environment at a concentration sufficient to cause harm, and (2) an exposure to that harmful substance. The calculation of risk involves the assignment of a probability to each of these main elements. It is important to understand that in terms of the probability for harm, if one of these elements is absent, the risk is interrupted. As an example, a chemical contaminant might be present in shallow groundwater in an urban area. If the people living in that area do not obtain their drinking water from that contaminated source, then there is no exposure to the contaminated source, and no corresponding risk. Environmental laws may still require reducing or eliminating the contaminant due to the potential of exposure from other pathways or ecological effects.

Individual behaviors that affect exposure

Individual behaviors can impact a person's exposure to a contaminant. For example, people breathe different amounts of air each day, drink a range of volumes of water, eat different foods, and spend time in different environments. Public health standards and guidelines for environmental contaminants include considerations for potential harm to the most sensitive members of the population. The standards and guidelines for exposure media such as soil, food, water, and air are adjusted based upon the exposure expected for various populations. We minimize our risk of exposure to pathogens by monitoring and controlling their presence where possible, and more broadly by sanitary practices that interrupt exposure pathways. Examples include hand washing, sanitation practices for food preparation, avoiding swallowing lake water while swimming, and properly cooking meat.

The harmfulness of an environmental agent is typically developed from a dose-response study. These studies expose a population to a range of contaminant exposure levels, or doses, and measure the effect (response) in that population. Dose response studies can also be constructed following acute or chronic exposure to a contaminant. The measured response can be defined in many ways including number of illnesses, effects on reproduction, effects on a body organ or organ system, or mortality. Over the range of exposures administered to the population, there will be some high dose or concentration above which all of the population is affected. There will usually be some dose or concentration that is above zero, but below which no effects are measured, also known as a no observable adverse effect level (NOAEL). Between these extremes there is an intermediate probability that any individual within the population will be affected at a particular exposure level.

The dose-response study is a key tool used to determine acceptable exposures to an environmental agent. Many types of contaminants are widespread in the environment, and may be from both natural and human-introduced sources. The effects of some agents are difficult to measure at very low concentrations. However, it is generally accepted that contaminant concentrations levels less than the NOAEL, are below the threshold needed to produce a measured human health effect. The graphed curve of a dose-response study allows for the estimation of these NOAELs (see Figure 1d-1). There is always some uncertainty surrounding the extrapolation of a dose-response study conducted with experimental animals to humans. For this reason, an NOAEL determined experimentally on animals is generally used as a starting place to calculate an acceptable exposure for humans that is much more stringent. For most chemical contaminants, chronic exposure is considered acceptable if it results in no more than one-in-one hundred thousand to one-in-one million (105 to 106) extra illnesses in the population over the span of one's lifetime. In many cases, the accepted approach of extrapolating from the experimental evidence may result in an environmental guideline or standard that lacks biological relevance. In other words, the established standard may be based on a calculation of infinitesimal risk. However, this approach is useful in satisfying the Precautionary Principle as it applies to public health policy.

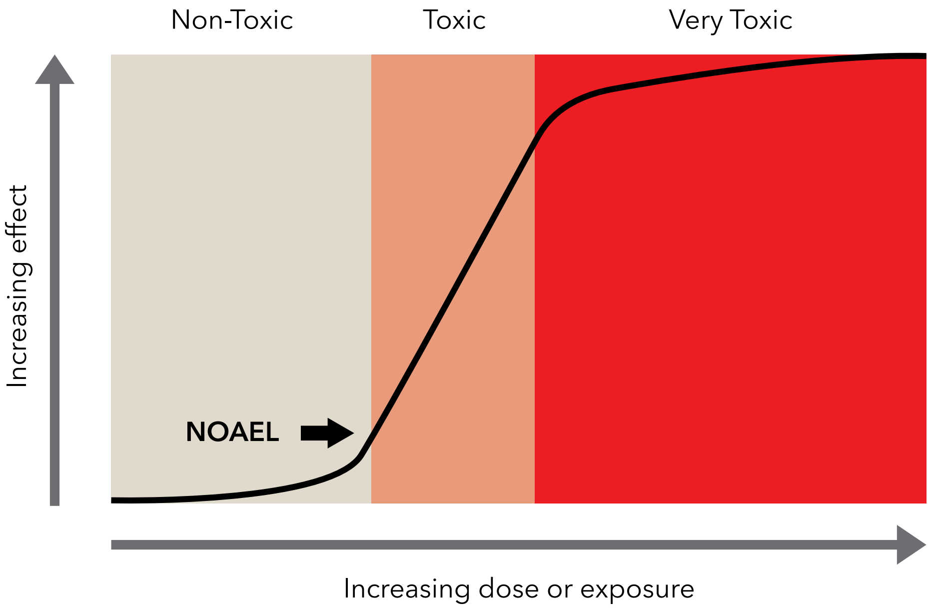


Figure 1d-1. A simple Dose-Response curve, illustrating the concept of increasing probability of effect with increasing exposure, with a threshold no observable adverse effect level (NOAEL) or non-toxic exposure range, and a saturated or very toxic exposure range. Figure modified from Osman 2011.

Acceptable exposure to pathogens

Exposure to a pathogen is a hazard that does not always result in disease. The risk of infection (ingesting or inhaling a certain amount of that pathogen that is necessary to cause infection in the body) is a function of factors discussed previously: 1) the presence of the potentially harmful microbial agent in the environment at a concentration sufficient to cause harm, and 2) a completed exposure pathway. The hazard from exposure to a pathogen depends not only on the probability of infection, but also the probability of developing illness from that infection, the severity of illness, duration of illness, and any potential complications.

Public health standards are based on acceptable levels of illness for different types of exposure and activity. For example, standards have been established for acceptable concentrations of fecal-related microbes in recreational surface water and drinking water in order to minimize exposure, infection, and illness. For swimming and recreational contact in surface waters, USEPA recommends concentrations of indicator bacteria (E. coli and Enterococci) that are estimated to result in 32 illnesses per 1,000 people who ingest water with that concentration of the microbes present. For drinking water standards, acceptable concentrations are much lower so that one in 10,000 who ingest water with that concentration are estimated to become ill. Actual individual infection rates would vary with such things as individual immune status. Recreational waters and drinking water are sampled regularly to ensure concentrations are below those threshold levels.

These key concepts around health and environmental risk are discussed throughout this report. Chapter 3 (and Section 3e in particular) provides a more detailed discussion of pathogen exposure associated with manure irrigation, drawing from the results of the research project summarized in Appendix C. The research examines issues related to the distance of pathogen drift from manure irrigation, and their viability as they are transported in the air.

1.e Organization of the report

The remainder of this report is organized into four chapters addressing the key issues explored by the workgroup. Chapter 2 provides background information about manure, manure management, and state and local regulations relevant to manure irrigation. Chapter 3 summarizes information compiled and discussed by the workgroup related to the central concerns and benefits identified at the outset of the review process. There are sub sections in Chapter 3 for droplet drift, odor, water quality, air quality, airborne pathogens, timing related to nutrient application and road concerns, and farm management and economic issues. Chapter 4 describes scenarios where manure irrigation practices might be experienced in a realistic setting. Chapter 5 presents the workgroup response and recommendations regarding use of manure irrigation in Wisconsin.

References for Chapter 1:

United States Environmental Protection Agency (USEPA). Basic Information on Water Quality Criteria. Website: *https://www.epa.gov/wqc/basic-information-water-quality-criteria*

Osman KA. 2011. Pesticides and Human Health. *Ch. 11 in* Stoycheva M., *ed.* Pesticides in the Modern World: Effects of Pesticides Exposure. ISBN 978-953-307-454-2.

Wingspread Statement. 1998. cited in an essay by Schettler et al. in McCally M. (ed.) 2002. Life Support: The Environment and Human Health. Cambridge, MA:MIT Press. The full statement is also available at: *http://www.sehn.org/wing.html*

2. Manure and Manure Application

2.a Manure

Manure is produced from livestock as feed is degraded and then excreted. Manure contains water and solid materials comprised of organic matter, nutrients, and microorganisms among other components not removed during the animal digestion process. The concentration and form of these constituents can vary significantly based on the feed and the animal itself. Therefore, the characteristics of manure are constantly changing over time and from animal to animal. Although the content of manure is variable, numerous documents provide averages and ranges for many of the components; these include MWPS 18-1 Manure Characteristics, UWEX A2809 Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin, and ASABE Standard 384.2 Manure Production and Characteristics, listed in the references for this section.

Manure is commonly characterized by commercial laboratory analysis for total solids (TS) or dry matter (DM), nitrogen (N), phosphorus (P), and potassium (K). Additional manure analysis for specialized applications is available on a more limited basis. TS is a key characteristic because it often dictates mechanical requirements for handling, storage, and land application of manure. Generally manure TS as excreted directly from the animal are highest for poultry, followed by beef, then dairy, then swine (TS in poultry > beef > dairy > swine), although exceptions can occur. Average values for TS and nutrient content in manure is evaluated through samples submitted across the state (see Tables A-1 and A-2 in Appendix A).

Manure has long been used by Wisconsin farmers as a source of essential nutrients for crop production. Nutrient content (N, P, K, etc.) determines the amount of manure necessary to optimize crop production and minimize losses to the environment. Manure application rates are adjusted in nutrient management planning to account for the movement of nutrients in an integrated livestock and crop system. The overall goal of nutrient management planning is to apply manure nutrients to the field at a rate and time that corresponds to crop nutrient uptake optimizing yields and limiting nutrient losses. Nutrient management guidance and regulations for Wisconsin are well documented in numerous publications (including guidance in UWEX A2809 Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin and NRCS CPS 590) and are discussed in more detail in Section 2c.

Microorganisms naturally present in the animal gut (pathogenic and non-pathogenic) are also present in manure. The profile and concentration of these microorganisms can vary based on a number of factors including but not limited to animal type, herd and individual animal characteristics, and animal diet. Many microorganisms are beneficial, non-pathogenic, and do not pose a threat to the hosts. However, some microorganisms are pathogenic and may pose a health risk to other animals of the same species or may be transmitted from animals to humans (also known as zoonotic pathogens), posing a threat to human health. For example, most strains of Escherichia coli (E. coli) are harmless to humans, but strains such as enterohaemorrhagic E. coli (EHEC), which includes E. coli 0157:H7, can cause illness in humans. As with the other manure constituents, the content of pathogens in the manure can change depending upon the health of the animals or the handling and processing of the manure. It is difficult to predict what pathogens are present in manure, and whether those pathogens are present in infectious concentrations. Table 2a-1 lists several pathogens found in livestock manure and their prevalence.

Table 2a-1: Pathogens in livestock manure and manure slurries

	Occurrence (% of positive manure samples)*			
Pathogen	Cattle	Poultry	Swine	Infective Doses
Bacteria				
Salmonella spp.	0.5 - 18	0 - 95	7.2 - 100	100 -1,000 cells
E. coli 0157:H7	3.3 - 28	0	0.1 - 70	5 -10 cells
Campylobacter spp.	5 - 38	57 - 69	14 - 98	< 500 cells
Yersinia enterocolitica	-	-	0 - 65	10,000,000 cells
Listeria spp.	0-100	8**	5.9 - 20	<10,000 cells
Protozoa				
Cryptosporidium spp.	0.6 - 23	6 - 27	0 - 45	10 -1,000 oocysts
Giardia	0.2 - 46	-	3.3 - 18	10-25 cysts

Source: From USEPA 2013, Page 14, Table 3-1. **"Occurrence, infective doses, and diseases caused by some of the pathogens present in manure and manure slurries from cattle, poultry, and swine."** (note: original table includes additional information and references.)
** Percentage of manure samples testing positive for the pathogen. Range of minimum and maximum percentage as reported in the literature. ** Based on a single study. Pathogen not detected for species in cells with hyphen (-)*

Manure may also include other materials produced by the animal (e.g. hormones) or not removed through the animal's digestion process (e.g. antibiotics). These materials are often considered to be emerging contaminants because little is known about their environmental fate and impact. Therefore they are topics of active research which has yet to establish clear relationships. Some studies have examined correlations between emerging contaminants from livestock operations and human health impacts but many mechanisms are not well understood.

Farmstead by-products added to manure

Although the textbook definition of manure is the material excreted by the animal, livestock and poultry facilities commonly include other by-products from the farmstead as manure is collected and stored. By-products commonly include animal urine and bedding but can also include farmstead runoff (from animal or feed storage areas), cleaning waste from milking facilities or other animal housing areas, spoiled feed and other spoiled products, runoff from animal sprinklers and other excess water sources. This can also include animal mortalities when composting or processing is involved.

Additional products and treatments

Some facilities may also take additional products from outside the farm facility to add to processing systems (described in Section 2b below). Producers may add these products to increase efficiency or for operational feasibility (e.g., for anaerobic digesters or composting), to increase their nutrient content for land application, or for revenue from tipping fees. Many are added to manure mixes for composting to achieve the characteristics needed for degradation by aerobic microorganisms (e.g., carbon-to-nitrogen ratio, moisture, or porosity). Some products are also added to anaerobic digesters to increase the quantity or the methane content of the biogas produced during anaerobic degradation by microorganisms. As both of these systems are biological and use microorganisms to degrade organic feedstocks, products accepted for these purposes must be non-toxic to the microorganisms within the system for the system to remain viable and active. The types of waste accepted for these systems in Wisconsin are outlined in Table 2a-2 below. For additional information about content of material in manure processing, see USEPA 2013.

Table 2a-2: Acceptable amendments for composting and digestion

Process	Amendments or Feedstocks Added to Process
Composting	Food waste, yard clippings, sawdust, wood chips
Anaerobic Digestion	Food waste, food processing waste, fryer grease, grease trap waste from food manufacture, paunch manure, blood and sludge from animal/meat processors, leachate from paunch manure dewatering, lime slurry, whey permeate, process wastewater from dairy and vegetable processors, sweet corn silage leachate

Source: WDNR

As part of the Wisconsin Pollution Discharge Elimination System (WPDES) water quality permitting process for CAFOs in Wisconsin, WDNR adds conditions for manure content (See Section 2c below). Permitted livestock facilities are required to specify in their nutrient management plan the additional off-farm wastes that they accept. If a facility accepts waste from an outside source, the waste must then be handled according to whichever facility (source or recipient) has the stricter standards—i.e., either that of the agricultural facility or those of the facility that produced the additional waste material. Therefore if a livestock facility were to accept any material deemed to be a highly hazardous regulated waste, then that facility must follow the more strict rules attached to that waste. If a facility were to accept septage waste, they must follow the regulations outlined for pathogen control and vector attraction requirements for septage. If a facility accepts industrial waste, the content of that waste must be approved by the WDNR wastewater program regardless of the volume it accepts, even if it is below the 10% exemption pursuant to Wisconsin Administrative Code chapter NR 214.17 (as is required for proper tracking of industrial waste disposal for all permitted facilities that engage in manure pit/digester disposal).

Although each request is unique, a typical WDNR plan approval condition required for a CAFO to accept industrial wastewater into a digester would include the sample language for appropriate substrates included in the sidebar (below). Biofuel wastes, and other wastes not exclusively from food processing, are to be tested upon initial acceptance and annually thereafter for parameters in ch. NR 217 and meet the criteria for exceptional quality sludge (see Table 2a-3).

Table 2a-3. Maximum allowable concentrations of industrial wastes not exclusively from food processing

Parameter	Maximum Concentration
Arsenic	41 mg/kg
Mercury	17 mg/kg
Lead	300 mg/kg
Cadmium	39 mg/kg
Molybdenum	40 mg/kg
Selenium	100 mg/kg
Copper	1500 mg/kg
Nickel	420 mg/kg
Zinc	2800 mg/kg

Source: WDNR

References for Section 2a:

American Society of Agricultural and Biological Engineers (ASABE) Standard 384.2 "Manure Production and Characteristics." *http://www.asabe.org/publications.aspx*

Midwest Plan Service (MWPS) 18-1 "Manure Characteristics." Published by Iowa State University. *http://www.maeap.org/uploads/files/Livestock/MidWest-Plan-Service-Charts.pdf*

United States Environmental Protection Agency (USEPA). 2013. "Literature Review of Contaminants in Livestock and Poultry Manure and Implications for Water Quality", Office of Water (4304T), EPA 820-R-13-002, July 2013. *http://water.epa.gov/scitech/cec/upload/Literature-Review-of-Contaminants-in-Livestock-and-Poultry-Manure-and-Implications-for-Water-Quality.pdf*

University of Wisconsin Extension (UWEX) A2809 "Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin." *http://learningstore.uwex.edu/assets/pdfs/A2809.pdf.*

SIDE BAR: Sample language included in a WPDES permit for accepting additional material as part of manure processing.

Approved Substrates: Substrates shall be limited to the types and sources in the following table, and shall not contain septage, or chemical or physical contaminants that will adversely affect the digester effluent as a material for land application. Substrates may include mixtures co-mingled from different generators, but not waste from unspecified generators, and no waste that is subject to regulation as a hazardous waste.

Approved Substrate Type	Substrate Source
food processing & preparation by-products *	vegetable food preparation, distribution & processing; & dairy food preparation, distribution & processing
dissolved air floatation (DAF) sludge, blood, offal & other animal wastes	meat slaughtering & meat packing operations; & other meat preparation, distribution & processing, including rendering
glycerin from biodiesel manufacture, & thin stillage from ethanol manufacture	biofuels manufacturing

* Examples of approved food processing and preparation by-products, include the following: cranberry mash; vegetable cuttings; cheese whey; fryer grease; and grease trap waste from food manufacture and food services (segregated from human waste). [Source WDNR]

2.b Manure Management

Each livestock facility has an individualized arrangement of components that combine to create its manure management system. Manure handling systems typically have four major components: (1) collection, (2) processing/treatment, (3) storage, and (4) transfer and land application (Figure 2b-1). Although not all manure handling systems have all four components, almost all (aside from grazing systems) include manure collection and land application. Adding processing or storage into manure management systems has been a result of cost, regulation, environmental impact, or general operational efficiency changes. Manure storage components have been integrated into almost all larger livestock facilities and also for many medium and small sized facilities. Some larger livestock operations have also included (or are considering) the use of additional treatment components.

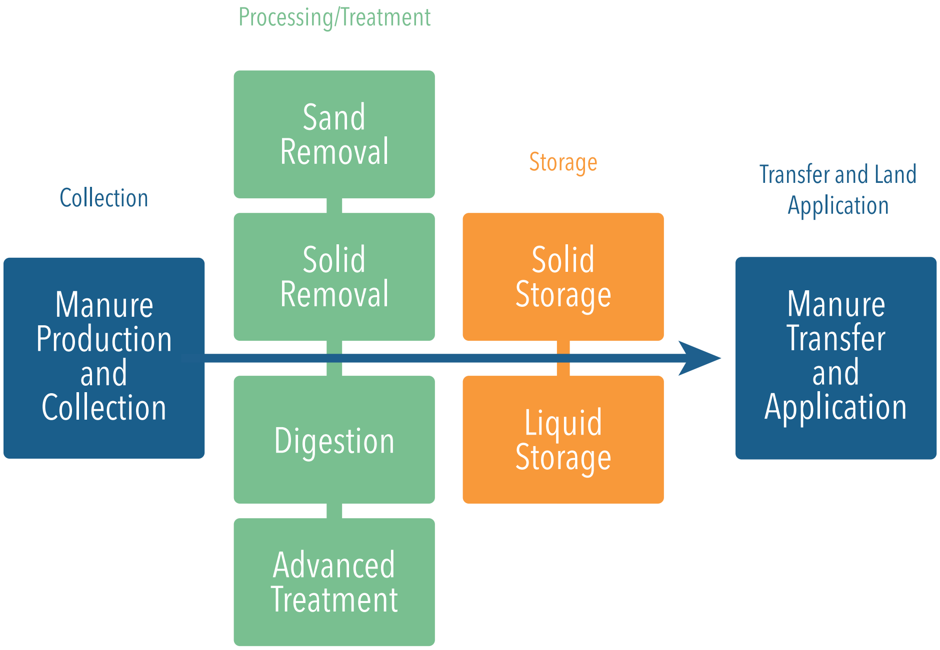


Figure 2b-1: Manure handling system components

Each of the four manure system components have multiple technology and management options that may alter manure consistency, management flexibilities, costs, and environmental impacts among others. It is critical for effective operation that all components of a manure management system are compatible. A brief overview of some of the more common manure system components (and compatibility with irrigation equipment) is provided below. More information on the tradeoffs and operational impacts of manure system component selection are discussed in Chapter 4.

Component 1: Collection

Manure collection includes the gathering and transfer of manure within a housing facility to other system components. The specific manure collection system has relatively little impact on manure irrigation.

Component 2: Processing/treatment

Manure processing systems are used to treat or alter the physical handling characteristics of manure to allow for increased management options and/or reduce negative impacts. Some manure processing systems that are in operation today include solid-liquid separation (most common), anaerobic digestion (less common), and advanced treatment (least common).

- **Solid-liquid separation.** Solid-liquid separation is the settling or mechanical separation of manure solids from manure liquids resulting in two products with different characteristics than the original product. Manure must have a low total solids content in order to be pumped and land applied as liquid. It is recommended that manure contain below 10% total solids content to enable use of a traditional manure pump. Total solids must be even lower for material to pass through irrigation nozzles without clogging. For traveling gun systems the solids are recommended to be below 5%, and below 3% for center pivot systems (for which the irrigation nozzles are smaller). Solid-liquid separation is commonly achieved through passive settling systems such as manure basins, sometimes with numerous basins in series, or by using mechanical systems. Mechanical systems for separation include screw presses, screens in different configurations, and others which commonly use screens for separation of liquids and solids. Separation systems change the total solids content in the manures' liquid and solid forms as well as the nutrient density, pathogen content, nutrient availability to plants and other aspects. In general, the separation results in the liquid stream having an increased nitrogen-to-phosphorus ratio and the solid material having a lower ratio.

- **Anaerobic digestion.** Anaerobic digestion is a controlled biological degradation process which occurs in an environment without oxygen. This degradation occurs naturally by microorganisms which already exist in manure. Anaerobic digestion systems convert carbon within the manure to methane which is captured and combusted, commonly to generate electricity. During the digestion process, manure is heated and degraded changing manure characteristics, although the manure still remains and must be managed after the digestion process. Some of the major changes to manure following digestion include the reduction in pathogen concentrations. Significant reductions (>80%) have been shown to occur, although in cases where there are high initial concentrations of pathogens, digested manure may still retain pathogens at concentrations that could contribute to human health risk (Burch et al, 2016). In addition, anaerobic digestion systems have fluctuations in performance, and pathogen reduction efficiency may change over time. The temperature at which a digester is maintained is another important factor in reducing pathogen concentrations. Generally, mesophilic digesters operate between 90-110 °F and thermophilic digesters between 120-140 °F. Digestion systems have also been shown to mineralize nutrients (Wright et al, 2004) and reduce odors, although odor reductions are difficult to quantify. While anaerobic digestion systems have many potential benefits, they also require significant capital investment.

- **Advanced treatment.** Advanced treatment refers to the use of additional systems to further separate or reduce nutrients, pathogens, and odors from livestock manure and process wastewater. Advanced treatment systems can be used to sterilize manure (manure pasteurizers) or can be used to purify the liquid fraction of manure to meet discharge standards for water quality. Options for advanced treatment include membrane systems, biological treatment systems, reverse osmosis, and others. These systems require high initial capital costs and significant ongoing operating costs (including high energy demand), which are typically greater than the current land application costs incurred by many facilities. Advanced treatment systems are highly variable in their design and performance, and the costs associated with the systems have reduced their implementation, although they are present at some livestock facilities around the country, including in Wisconsin. Manure pasteurizers are used more commonly in many European countries and are installed specifically to reduce pathogen concentrations in manure to reduce impacts during land application.

- **Composting.** Although designed for solid manure management and not compatible with manure irrigation, composting is another process option for livestock manure. Information about composting systems is readily available from multiple sources.

Component 3: Storage

Manure storage is commonly integrated into manure systems to accommodate operational issues with manure handling and to increase flexibilities in application timing. Storage enables producers to apply manure at times which result in the least environmental impact (such as runoff and leaching) including when the ground is not frozen, soils are not saturated, and there is no precipitation forecast. Installation of manure storage systems is highly regulated and involves strict standards for design, operation, and maintenance, including a nutrient management plan (see Section 2c below for more details). A liquid manure storage system is necessary for use of manure irrigation due to the need for a large volume of manure for pumping during application periods, particularly for center pivot systems.

Component 4: Transfer and application methods

Many manure application methods are available to apply manure to cropland. Most facilities use a combination of manure application technologies to allow them to meet environmental, operational, regulatory, and economic constraints. Commonly, manure has been hauled to fields from a storage area and applied to land with spreaders and tankers (see Figure 2b-2). The volume capacities of these range from approximately 3,000-10,000 gallons per tanker load. Permanent and non-permanent transfer lines are also used for moving manure to the field. Permanent lines are buried beneath the soil surface while non-permanent lines (typically flexible hoses) are laid out for each manure application period (generally one or two times per year). Pumping manure through transfer lines reduces the total number of truck loads and the number of miles trucks travel on roads. Permanent lines have a significant capital cost which makes them infeasible for many operations. Use of manure irrigation systems may involve a shift in manure hauling practices from road vehicles to pumping systems. However, pumping systems can also be used with other application methods, and it is common to pump manure without the use of irrigation systems. Any permanent pipelines for manure irrigation would require regular monitoring to ensure the lines do not leak. In addition, if the lines connect to water systems there must be back flow prevention to ensure no manure can contaminate those water sources.

Other common field application methods include surface broadcast of manure (where manure is spread from heights up to 10 feet above the ground using a splash plate instead of a nozzle) and injection systems (where manure is injected into the ground and covered with soil) (See Figure 2b-2). These methods can be used with tanker hauling equipment as well as the pumping techniques described above. Many facilities with liquid/slurry manure systems use a variety of techniques to apply manure. The choice is influenced by field constraints (e.g., slope, soil type), weather and soil conditions (particularly for fields with a high moisture content), environmentally sensitive features, time of year, cropping system, and cost.

Irrigation with a traveling gun might occur when manure cannot be applied with tractors or tankers, when manure storage systems are reaching capacity and there is need to avoid overtopping, and when crops would benefit from numerous nutrient applications or need additional water during the growing season. Center pivot irrigation systems might be used to decrease compaction, apply greater volumes of more dilute manure, reduce irrigation water needs, and apply nutrients to crops throughout the growing season. Additional information about farm management issues associated with manure irrigation is presented in Sections 3f, 3g, and Chapter 4.

References for Section 2b:

Burch, T.R., S.K. Spencer, S.S. Borchardt, R.A. Larson, A. Alkan-Ozkaynak, M.A. Borchardt. 2016. Inactivation of dairy manure-borne pathogens by anaerobic digestion. Presented at Annual Conference of the Wisconsin Chapter of American Water Resources Association. March 2016.

Wright, P., S. Inglis, J. Ma, C. Gooch, B. Aldrich, A. Meister, & N. Scott. 2004. Comparison of Five Anaerobic Digestion Systems on Dairy Farms. 2004 ASAE/CSAE Annual International Meeting, Ottawa, Ontario, Canada. Paper No. 044032.

Figure 2b-2. Manure application equipment

1. manure injection, 2. broadcast spread with a tanker, 3. traveling gun and reel, 4. operating traveling gun, 5. center pivot with drop nozzle, 6. center pivot end gun

2.c Existing rules, regulations, and practices related to manure irrigation

Prevalence of Manure Irrigation in Wisconsin

The current prevalence of manure irrigation in Wisconsin is largely unknown. The existing statewide rules that directly regulate manure irrigation only apply to CAFOs that are permitted by the WDNR through the Wisconsin Pollutant Discharge Elimination System (WPDES) process. Smaller non-CAFO farms (not operating under a WPDES permit) have fewer regulations and are not required to report their use of manure irrigation practices. Information presented below addresses statewide rules for all farms, additional rules for CAFOs, and local rules in Wisconsin regarding manure irrigation.

In early 2014, the WDNR distributed a survey to all WPDES-permitted facilities asking whether the farm is currently using manure irrigation, plans on using manure irrigation within the next two years, or is not using manure irrigation and does not intend to do so within the next two years. The survey was sent to approximately 250 farms across the state and had responses from 69 farms, for a 28% response rate. Of the respondents: 12 farms indicated they had or currently use manure irrigation, 10 farms planned on using manure irrigation within the next two years, and 47 farms were not using manure irrigation and do not intend to use the technology over the next two years.

Since the survey was completed, the WDNR has required CAFO facilities to update their nutrient management plan (NMP) to include additional information related to manure irrigation. WDNR indicates that these same requirements will apply to those farms who anticipate using manure irrigation. Required updates to the CAFO NMP include information related to fields being used for manure irrigation, including required setback distances and soil types, characteristics of the manure or process wastewater that would be applied through manure irrigation, irrigation equipment design, operation practices, field monitoring, and other pertinent information. As of March 2016, seven CAFO farms in the state had successfully applied and were approved by the WDNR to use manure irrigation, and four were pending. Table 2c-1 identifies the CAFOs that are currently permitted and using manure irrigation or for which a decision is pending.

Table 2c-1. Wisconsin CAFOs Approved for Manure Irrigation

Farm	County	Equipment	Treatment
Central Sands Dairy	Juneau	Center Pivot	Manure digester
Green Valley Dairy	Shawano	Center Pivot	Manure digester
Holsum Elm & Irish Dairies	Calumet	Center Pivot (mobile)	Manure digester
Maple Leaf Dairy	Manitowoc	Center Pivot	Manure digester
Pagels Ponderosa	Kewaunee	Center Pivot (mobile)	Manure digester
Robinway Dairy LLC	Manitowoc	Center Pivot	Reverse osmosis
Rosenholm Dairy LLP	Buffalo	Traveling Gun	Solids separation with aerobic treatment for liquid manure
Dallman East River Dairy^	Calumet	Center Pivot	
Ocooch Dairy^	Vernon	Traveling Gun	
Ostrowski Farms^	Marathon	Center Pivot	
UW Arlington Research Station^	Columbia	Traveling Gun	

^Approval pending or temporarily revoked
[Source: WDNR, as of March 2016]

Current Statewide Wisconsin Rules for All Farms

Current Wisconsin rules and regulations that affect the use of manure irrigation include chapters NR 151, NR214, and NR243, Wisconsin Administrative Code and Natural Resources Conservation Service Conservation Practice Standard 590 (NRCS CPS 590), sometimes called the "NRCS 590 standard" or a "590 NMP." Non-CAFO farms do not have to meet NR 214 or NR 243 requirements. However, these farms do have to meet Wisconsin's NR 151 performance standards that require having and implementing a NMP. As a side note, Wisconsin Department of Agriculture Trade and Consumer Protection (WDATCP) tracks NMPs filed with the state, and as of 2015, approximately 31% of total cropland acres have official plans on file (WDATCP 2015). Through chapter ATCP 50 Wisconsin Admin Code, NMPs must be consistent with the 2005 version of the NRCS CPS 590. Most Wisconsin counties also have manure storage ordinances and/or farms that participate in Wisconsin's Farmland Preservation Program. These ordinances or tax credit programs require having and implementing a NMP consistent with the NRCS CPS 590. Table 2c-2 summarizes the setback distances a farm with a NRCS CPS 590 NMP must follow when applying manure or process wastewater regardless of the application method. NRCS adopted a new NRCS CPS 590 Nutrient Management Standard in December 2015. There are additional application restrictions included within this new standard. WDATCP is currently in the rule promulgation process to include this new standard.

Table 2c-2. Current manure application setback distances for farms with NRCS CPS 590 NMPs

Restrictive Feature	2005 Setback	Code Reference
Community Public Water Supply Well	50 feet[1]	NRCS CPS 590 V.A.2.(3) mechanical applications prohibited within 50′, V.B.[2]
Non-Community Water Supply Well	50 feet[1]	NRCS CPS 590 V.A.2.(3) mechanical applications prohibited
Inhabited Dwelling	50 feet[1]	NRCS CPS 590 V.A.2.(3) mechanical applications prohibited
Depth to Groundwater & Bedrock	12 inches & 20 inches	NRCS CPS 590 V.B.[2]
Direct Conduit to Groundwater	200 feet	NRCS CPS 590 V.A.2.(3) incorporation[3]
Navigable Waters & Conduits	300 or 1,000 feet	NRCS CPS 590 V.A.2.b. Perennial streams (continuous flow) winter prohibition[4]
Wetland	None	
Dallman East River Dairy^	Calumet	Center Pivot
Ocooch Dairy^	Vernon	Traveling Gun
Ostrowski Farms^	Marathon	Center Pivot
UW Arlington Research Station^	Columbia	Traveling Gun

Source: WDATCP

[1] Maintain 50 feet setbacks from drinking water wells

[2] To minimize N leaching to groundwater on high permeability soils, or soils with less than 20 inches to bedrock, or soils with less than 12 inches to apparent water table, or within 1,000 feet of a municipal well NRCS CPS 590 requires:
- No fall commercial N applications except for establishment of fall-seeded crops. Commercial N application rates, where allowed, shall not exceed 30 pounds of available N per acre.
- On irrigated fields split or delayed N application to apply a majority of crop N requirement after crop establishment. Or, use a nitrification inhibitor with ammonium forms of N. Note: "Instinct N" inhibitor label prohibits using irrigation equipment to apply the product to fields
- For summer or fall manure applications limit rates to 90 or 120 lbs. of available N rate per acre depending on timing and crop.

[3] Maintain 200 feet setbacks from upslope areas contributing runoff to direct conduits to groundwater (wells, sinkholes, fractured bedrock at the surface, tile inlets), unless effectively incorporated within 72 hours. Note: manure irrigation may not meet effective incorporation criteria due to manure solids content/application rate

[4] When frozen or snow-covered soils prevent effective incorporation at the time of application, implement the following: (1) Do not apply nutrients within the *Surface Water Quality Management Area (SWQMA) being 1,000 feet from the high-water mark of the pond or lake or wit in 300′ of streams* except for manure deposited through winter gleaning/pasturing of plant residue. (2) Do not apply nutrients to locally identified areas delineated in a conservation plan as contributing nutrients to direct conduits to groundwater or surface water as a result of runoff. (3) Do not exceed the P removal of the following growing season's crop when applying manure. Liquid manure applications are limited to 7,000 gallons per acre until spring or summer. (4) Do not apply nutrients on slopes greater than 9%, except for manure on slopes up to 12% where cropland is contoured or contour strip cropped.

To minimize entry of nutrients to surface water and groundwater, NRCS CPS 590 requires application restrictions listed below.

- Ensuring manure nutrient applications are consistent with UW publication A2809, "Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin."

- Applying manure nutrients using either the soil test P or P-Index strategy

- Documenting methods, timing, form and rates of application using calibrated application equipment to achieve the planned application rates

- Meeting specific practices when applying manure nutrients in a SWQMA (i.e., incorporation, cover crops, residue, buffers)

- No manure application on the following features: surface waters, established concentrated flow channels (grass waterways), non-harvested permanent vegetative buffers, non-farmed wetlands, wells and sinkholes

- No manure ponding, discharge to drain tiles or runoff from application fields

- No manure application on saturated soils within a SWQMA

- No manure application on fields that exceed the tolerable soil loss

Additional Statewide Rules for CAFOs

CAFO farms operating under a WPDES permit are subject to additional requirements included in chapters NR 214 and NR 243, Wis. Adm. Code. Since NR 243.14(1)(a) adopts nutrient budgeting, soil test recommendations, application practices and restrictions contained in NRCS CPS 590, the requirements from the NRCS CPS 590, at a minimum, must also be followed by a CAFO. Other Wisconsin Administrative Codes, such as NR 151 and NR 214, do not restrict the specific practice of manure irrigation but rather regulate it as a method of surface application. Table 2c-3 identifies the setback distances a CAFO must follow when applying manure or process wastewater through an irrigation system.

Table 2c-3. Current manure irrigation setback distances for Wisconsin CAFOs

Restrictive Feature	Setback	Code Reference
Community Public Water Supply Well	1,000 feet	NR 214.14(1)(a)
Non-Community Water Supply Well	250 feet	NR 214.14(1)(a)
Inhabited Dwelling	500 feet*	NR 214.14(1)(b)
Depth to Groundwater & Bedrock	5 feet	NR 214.14(1)(c)
Direct Conduit to Groundwater	100 feet	NR 243.14(2)(b)8
Navigable Waters & Conduits	25-100 feet	NR 243.14(4)(a)
Wetland	25 feet	NR 243.14(4)(a)

*Distance may be reduced with the written consent of any affected owners and occupants.
Source: WNDR

Additional restrictions and limitations that do not include explicit numerical setback distances include:

- Ponding or runoff is prohibited on the application site – NR 214.14(2)(a) & NR 243.14(2)(b)1 & (2).

- Spray nozzles shall be arranged so that application will be evenly distributed over the acreage being loaded – NR 214.14(2)(d).

- The average hydraulic application rate may not exceed 10,000 gallons per acre per day – NR 214.14(3)(d).

- The irrigation system shall be operated in a load/rest cycle – NR 214.12(5)(a).

- The soil at each individual spray irrigation field shall be tested annually for available nitrogen, available phosphorus, available potassium and pH – NR 214.14(4)(c).

- Manure or process wastewater may not cause the fecal contamination of water in a well – NR 243.14(2)(b)3.

- Manure or process wastewater may not be applied to saturated soils – NR 243.14(2)(b)5.

- Manure or process wastewater may not be surface applied when precipitation capable of producing runoff is forecast within 24 hours of the time of planned application – NR 243.14(2)(b)13.

- Surface application of liquid manure on frozen or snow covered ground (>1 inch) is prohibited – NR 243.14(7)(a) & (b).

Other sections of NR 214 and NR 243 give the WDNR the authority to require additional monitoring and restrictions if deemed necessary. These requirements can include:

- The department may require reduced hydraulic application rates or grass buffer strips, or both, around the perimeter of the site to absorb runoff during rainfall events – NR 214(2)(g).

- The department may restrict spray irrigation during times of the year when the cover crop is dormant or not actively taking up water and nutrients – NR 214.14(3)(g).

- The department may require the discharge be monitored for BOD5, total suspended solids, forms of nitrogen, chloride, metals or any other pollutant than may be present – NR 214.14(4)(b).

- The department may require the installation of a groundwater monitoring well system – NR 214.21(a).

- The department may require the permittee to implement practices in addition to or that are more stringent than the requirements specified in section NR 243.14 when necessary – NR 243.14(10).

Current Local Wisconsin Rules

Some Town and County governments in Wisconsin have adopted local ordinances that explicitly prohibit manure irrigation or require specific conditions for its use. Those municipalities have based their local ordinances on threats to public health and/or have deemed manure irrigation to be a public nuisance. Local governments requiring a Conditional Use Permit (CUP) to operate a manure irrigation system set specific conditions to obtain a permit which can include types of equipment, timing of application, wind conditions, opportunities for public hearings, and more. The City of Algoma in Kewaunee County bans all spreading, spraying, and storing liquid manure (solids content less than 12%) within city limits as a public nuisance affecting health; this prohibition includes the use of manure irrigation. Table 2c-4 contains a list of Wisconsin Towns and Counties that have adopted a local ordinance specific to manure irrigation. Other local governments have also considered manure irrigation ordinances.

Table 2c-4. Local Municipalities with a Manure Irrigation Ordinance

Local Government*	County	Prohibited or Conditional Use Permit (CUP)	Ordinance Category	URL **(web address at end of Chapter 2)**
Adams County	Adams	Conditional Use Permit	Public Health	Link here
Bayfield County	Bayfield	Prohibited	Public Nuisance	Link here
Town of Brussels	Door	Prohibited		no link (on file with DATCP Ordinance No 32)
Town of Gardner	Door	Prohibited		Link here
Town of Liberty Grove	Door	Prohibited (Center Pivot)	Public Nuisance	Link here
Town of Sevastopol	Door	Prohibited	Public Nuisance	Link here
Town of Sturgeon Bay	Door	Prohibited		Link here
Town of Marshfield	Fond du Lac	Prohibited	Public Nuisance	Link here
Town of Rosendale	Fond du Lac	Prohibited	Public Nuisance	Link here
Town of Decatur	Green	Prohibited (Center pivot)	Public Nuisance	Link here

Table continues on next page.

Table 2c-4. Continued.

Local Government*	County	Prohibited or Conditional Use Permit (CUP)	Ordinance Category	URL **(web address at end of Chapter 2)**
Town of Sylvester	Green	Prohibited (Center Pivot)	Public Nuisance	Link here
Town of Lincoln	Kewaunee	Prohibited	Public Nuisance	Link here
Town of West Kewaunee	Kewaunee	Prohibited	Public Nuisance	Link here
City of Algoma	Kewaunee	Prohibited	Public Nuisance Affecting Health	Link here
Town of Bradford	Rock	Conditional Use Permit		
Town of Fulton	Rock	Conditional Use Permit (Center Pivot) and Prohibited (Traveling Gun and End Gun on Center Pivot)		Link here
Town of Harmony	Rock	Prohibited	Public Nuisance	Link here
Town of Johnstown	Rock	Conditional Use Permit	Public Nuisance	Link here
Town of Richmond	Walworth	Conditional Use Permit	Public Health	Link here
Town of Utica	Winnebago	Conditional Use Permit		Link here
Town of Saratoga	Wood	Prohibited	Public Nuisance	Link here

* For additional information regarding these ordinances please consult with the local government and/or their legal counsel

If a local government proposes a livestock ordinance for water quality protection (per Wisconsin Statutes section NR 92.15) that exceeds agricultural performance standards and prohibitions or related conservation practices or technical standards in ATCP 50, they need approval from either WDNR or WDATCP. That approval would indicate the regulations are necessary to achieve water quality standards under Wisconsin Statutes section 281.15. An approval from WDNR or WDATCP is not necessary if the livestock ordinance addresses cropping practices that do not directly relate to a livestock operation. Thus far, no local government in Wisconsin that has enacted a livestock ordinance that restricts or prohibits manure irrigation focused on water quality.

Local and state public health departments generally play a secondary role in these issues and have no direct regulatory authority over agriculture, except broadly in certain situations. State of Wisconsin Right-to-Farm laws (Wisconsin Statutes section 823.08) are intended to prevent inhibition of continual agricultural operations based solely on private nuisance—noise, odor, aesthetics, etc., leading to conflict over use and enjoyment of property. Exceptions to Wisconsin's Right-to-Farm Law require the determination of a public health hazard based on established health standards and guidelines. Agricultural operations may present a nuisance, for example odor, without rising to the threshold of a health hazard. Under Wisconsin law, the local health officer has the authority to identify and order the abatement of public health hazards. Health hazards most commonly identified around agricultural operations are related to wastewater spills, runoff, and ground- and surface-water impacts. In common practice, when there is a spill or runoff incident, other regulatory agencies will have a prominent role, and the focus of the local health officer will be to ensure that local residents have a source of safe clean household water.

Manure Irrigation Requirements in Other States

Other states have experience using manure irrigation in agricultural operations. A brief compilation of information gathered in 2012-2013 by WDNR staff from neighboring states and others that have used the practice is included in Appendix B. Each summary includes general information about the extent of manure irrigation, the type of public complaints documented by the agency that regulates animal feeding operations, and any setback distances or special regulations for the practice. The summaries in Appendix B are not intended to be comprehensive and conditions may have changed since they were compiled.

References for Section 2c:

WDATCP. 2015. Wisconsin Nutrient Management Update & Quality Assurance Team Review of 2015's Nutrient Management Plans. [*http://datcp.wi.gov/uploads/Farms/pdf/NMUpdate2015.pdf*]

Direct Web Addresses for Table 2c-4 (Local Municipalities with a Manure Irrigation Ordinance)

Adams County: http://www.adamscountylwcd.net/Ordinance_Spray_Irrigation.pdf

Bayfield County: http://www.bayfieldcounty.org/documentcenter/view/3591

Town of Brussels: not listed

Town of Gardner: http://www.greenbaypressgazette.com/story/news/local/door-co/news/2014/12/12 gardner-town-board-bans-center-pivot-manure-spraying/20332065/

Town of Liberty Grove: http://libertygrove.org/uploads/documents/Ord 15-2.pdf

Town of Sevastopol: http://www.townofsevastopol.com/uploads/ckfiles/files/Manure Liquid Animal & Ag Wastewater 10-23-14.pdf

Town of Sturgeon Bay: http://www.greenbaypressgazette.com/story/news/local/door-co/news/2014/11/07 town-sturgeon-bay-passes-manure-spraying-law/18677625/

Town of Marshfield: http://townmarshfield.com/Files/Ordinances/Public_Nuisance_Manure.pdf

Town of Rosendale: http://sustainruralwisconsin.net/wp-content/uploads/2012/09/Ordinance-Amendment-Center-Pivots-Town-of-Rosendale-07-17-2012.pdf

Town of Decatur: http://townofdecatur.com/wp-content/uploads/2016/03/manure-ordinance-rev-2-16-16-for website.pdf

Town of Sylvester: https://greencdf.org/wp-content/uploads/2016/02/Sylvester-Center-Pivot-Irrigation-Ordinance-Final.docx

Town of Lincoln: http://s3.documentcloud.org/documents/1302564/lincoln-center-pivot-manure-irrigation-ban.pdf

Town of West Kewaunee: http://www.greenbaypressgazette.com/story/news/local/kewaunee-county/2015/02/19 first-town-ordinance-county-ban-manure-spraying-passed/23686005/

City of Algoma: https://assets.documentcloud.org/documents/1302253/algoma-manure-spreading-ban.pdf

Town of Bradford: not listed

Town of Fulton: http://ecode360.com/search/FU2213?query=irrigation

Town of Harmony: http://townofharmony.com/municipal-code

Town of Johnstown: https://drive.google.com/viewerng/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnx0b3dub2Zqb2huc3Rvd24xfGd4OjEzNmE1NDI3NGQ5ODBlYzA

Town of Richmond: http://www.codepublishing.com/wi/richmond/

Town of Utica: http://townofutica.org/wp-content/uploads/2015/09/Zoning-Ordinance-2010..2013-2014.pdf

Town of Saratoga: http://www.saratogawisconsin.org/dbfiles/center pivot.pdf

3. Considerations for Practice

As discussed in the Introduction to this report, the workgroup focused on several key considerations associated with the practice of manure irrigation. Sections 3a-3e address expressed concerns initially identified for the workgroup agenda. Each section presents the issues, concerns, current practice, and remaining uncertainties. Each section also includes a summary table identifying practices and conditions that may limit or exacerbate aspects of each concern. Sections 3f-3g describe management issues and potential benefits associated with the practice.

As a way to visualize the considerations for practice associated with manure irrigation, Figure 3-1 provides a conceptual illustration of the elements of fate and transport of irrigated manure and agricultural wastewater and includes representations of the environmental and public health issues involved. During irrigation manure is applied on the soil surfaces and moves to the soil root zone of crop plants. The figure identifies potential sensitive areas to be avoided by misapplication or wind drift of manure irrigation. These include surface water, neighboring houses, and wellheads. The figure also illustrates that the viability of microbes in the irrigated manure is affected by environmental conditions. There are also concerns about any application of liquid manure that could enter groundwater via fractured bedrock or other direct conduits. Each of these features are discussed in the context of relative differences of manure irrigation compared to available alternative methods for manure application.

3.a Non-Aerosolized Droplet Drift

Droplet Drift – Definitions

Droplet drift refers to the aerial movement of liquid material outside the intended application area. Drift is different from the direct application of liquid outside the designated application area due to overspray. Overspray occurs when the irrigation system is not correctly managed and liquid is applied directly past intended boundaries (e.g., the crop field). Overspray can be avoided with correct system design and management and should not occur with properly operating systems. Droplet drift is dependent on a number of factors including equipment, system operation, weather, and spray characteristics. However, the primary drivers of drift are wind velocity and direction, droplet size and density, and application height (Grisso et al. 2000; Zhu et al. 1994; Hewitt et al. 2002). Wind has been shown to be the most significant factor in drift, where increasing wind can increase drift (Molle et al. 2012). Droplet size determines the rate at which the droplets fall to the ground, also affecting drift. Droplets are classified by size in reference to the Volume Median Diameter (VMD), which indicates the diameter in which half of the spray droplets by volume have diameters greater than the median and half less. The difference between liquid droplets and aerosolized particles is largely dependent upon the diameter of the droplet.

For the purposes of this discussion, particles with a diameter less than 100 µm are considered to be aerosolized particles (for comparison a dollar bill has a thickness of 110 µm).

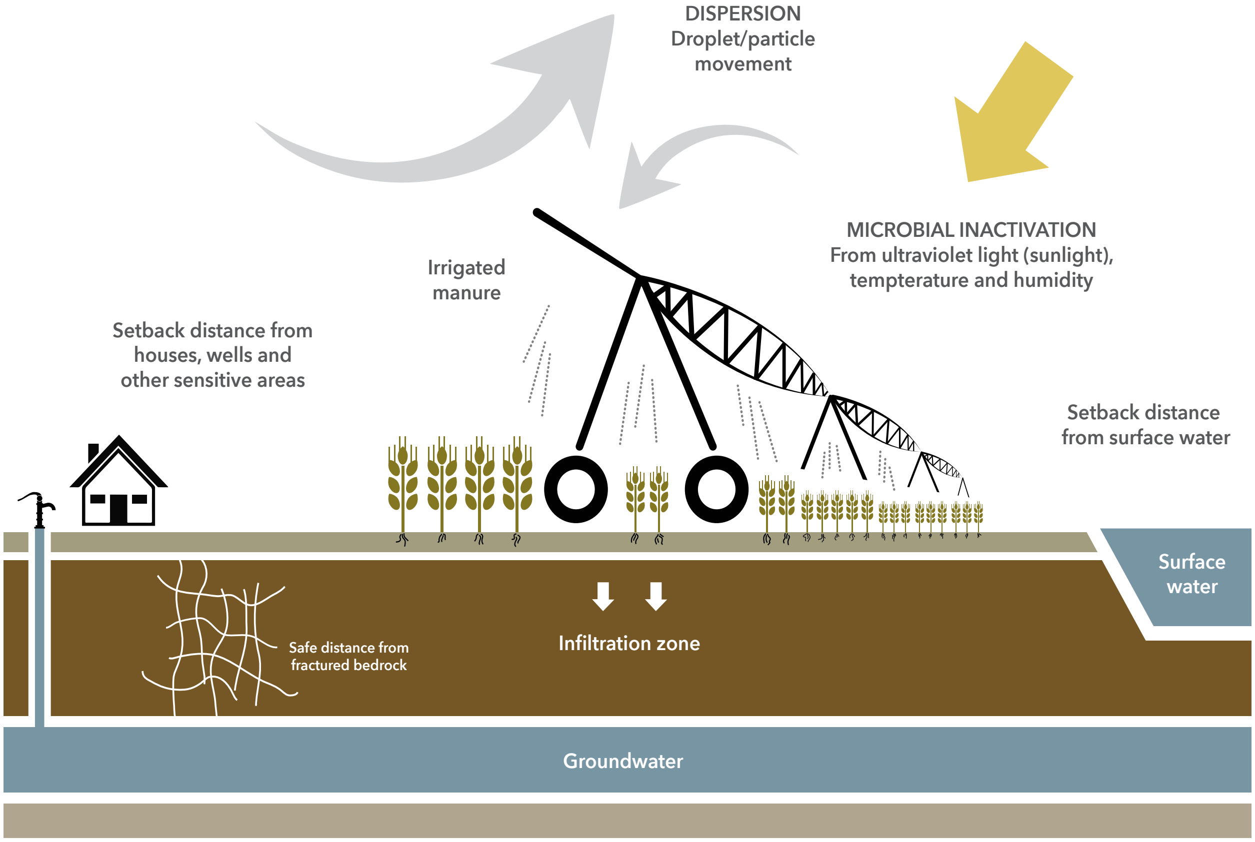


Figure 3-1. Highlighted Issues Associated with Manure Irrigation Practice

Droplet Drift – Issues of Concern

Droplet drift can occur during application for all types of liquid manure application methods. However, methods that release manure above the crop height or at increasing heights above the soil surface are more subject to drift (as compared to injection or broadcast applications). Droplet drift is a concern when it results in manure transport beyond the intended application area. This might include drift to surface waters, well head areas, residences, public areas, or ready–to-eat crops. Droplet drift can be understood as a physical event, but the risk associated with drift is dependent upon the distance traveled, the sensitivity of the deposition area, weather conditions, and the concentration and viability of any microbes or other contaminants contained in the drifted material. In Wisconsin, concerns have been raised about drift of liquid manure onto surrounding lands if the crops are grown for human consumption, or are public or private property where any of the contents in manure are unwanted.

Droplet Drift – Current Practices and Regulation

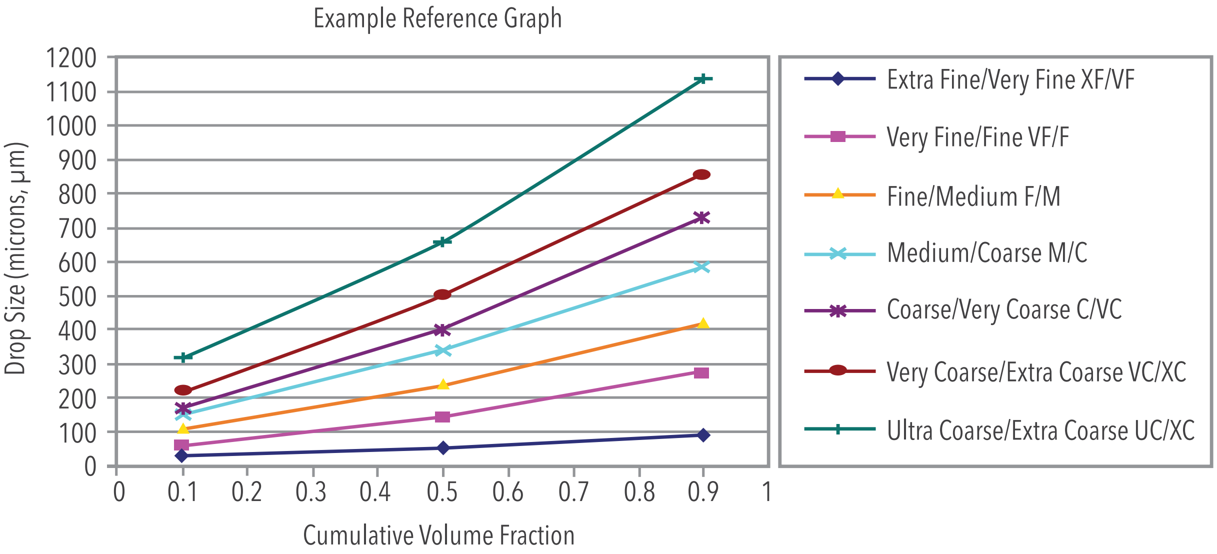
Wisconsin law prohibits pesticide overspray and significant pesticide drift (ATCP 29.50(2)), and Wisconsin's technical standards for irrigation water management specify that overspray should not reach public roads (WI NRCS Code 449). Managing manure application to reduce droplet drift (distinct from overspray) is important for multiple application methods (including surface broadcast methods), but may not be relevant for methods that do not surface apply manure (e.g., direct injection). Conventional application methods do not have regulations regarding droplet drift when applying manure, however setback distances outlined in Section 2c apply for all types of manure applications (See Section 2c and Table 2c-1 for information on setbacks).

- **Siting (location and application considerations).** Drift concerns are magnified if the end location where drift droplets land creates a risk. A recommended practice to limit the potential impacts of any droplet drift that may occur is to apply manure to fields with adjacent lands that are owned by the applicator or for which permission has been granted by the owner. Risk of negative impact can also be reduced significantly by applying manure when the wind is blowing away from populated areas or property boundaries. Installing barriers, such as vegetated wind breaks, can also reduce drift as particles can be trapped in the vegetation reducing potential impact to locations past the property boundaries.

- **Weather.** Wind speed is the dominant factor in the distance of droplet drift (Molle et al. 2012). There is a general agreement that irrigation application with wind speeds above 10 mph significantly increases drift (Grisso et al. 2000; Thistle 2004). When applying manure through irrigation systems, selecting times when temperatures are increasing will promote upward movement decreasing the impact of drift. Periods of inversion, where the weather conditions will trap particles and droplets near the ground, can result in increased distances of drift. However, application of larger droplets limits the impact of these weather factors (see below for information on increasing droplet sizes). If combined with low humidity, high air temperatures can result in increased evaporation of droplets or contribute to decreasing their size, which could increase drift (Thistle 2004). High relative humidity can also contribute to drift potential in smaller particles as it increases the distance to evaporation (Grisso et al. 2000). However, research indicates that larger particles (> 200 μm) do not experience a drift effect for relative humidity values from 10-80% (Grisso et al. 2000). Overall, maximizing droplet size in manure irrigation systems is important to minimize drift.

- **Equipment.** Regardless of the application method, an increase in manure application height will generally increase the distance droplets can drift. Droplets have farther to fall when released higher from the ground, and as height above the ground increases, wind also increases, further affecting potential for drift (Grisso et al. 2000). Typical/conventional land application methods can release manure below the soil depth using injection (where droplet drift is essentially zero), or directly at soil level, or above the ground height with low and high mounted spray booms and splash plates. Spray booms and splash plates located on tankers applying manure to land can range from surface height application to greater than 10 feet in the air depending upon the application equipment. Center pivot irrigation systems have a wide variety of application heights that extend above or below the 12-14 foot tall structures. The applicator can adjust the release height from just above the ground by using drop nozzles or raise to 20+ feet in the air by using impact sprinklers mounted at the top of the structures and end guns which release manure past the end of the boom. Many drop nozzles release manure 8 feet above the soil surface in order to remain above a full-grown corn crop. Traveling gun equipment projects liquid material through a spray arc from the fixed nozzle height above most other application methods.

As noted, larger droplet sizes also reduce droplet drift. Droplets with a VMD less than 200 μm are more prone to drift as they have insufficient weight to overcome air resistance, even when winds are below 10mph (Wilson nd.; Grisso et al. 2000; Grover et al. 1978; Byass & Lake 1977; Bouse et al. 1990). Droplet size is a factor of the nozzle selected and the operating water pressure of the system, where larger nozzle sizes and lower pressures increase droplet size (and decrease drift). Many low-drift nozzles are available which produce VMD droplet sizes between 300- 600 μm (Grisso et al. 2000). For any commercially available nozzle, the droplet size is reported at various operating pressures according to droplet size classifications in ASAE S572.1, Spray Nozzle Classification by Droplet Spectra, Appendix A. Droplet drift is reduced by using droplet classifications of medium/coarse (VMD≈350 μm), course/very coarse, extra coarse, and ultra-coarse. See Figure 3a-1 for an illustration of droplet size ranges in each classification.



Source:.ANSI/ASAE (2013) S572.1, Figure 1. Used with permission.

Figure 3a-1 Illustration of distribution of droplet size ranges for classifications

Droplet Drift – Unknowns and Remaining uncertainties

There is wide-reaching peer reviewed literature concerning droplet drift and mitigation of that drift. However, most droplet drift studies have been conducted on irrigation systems used for water and pesticide application, and there is no available research specific to drift associated with manure irrigation. Despite this, conventional drift research does provide relevant information since the manure used in these systems is very dilute (<5% solids) resulting in similar characteristics to water (e.g., similar density and viscosity). It is reasonable to assume that the low-solids characteristics of manure-derived liquids used in irrigation systems will behave similarly to the liquids in the referenced studies. The physical characteristics of liquid manures may change with a solids content greater than 5%, but that threshold is above what is feasible for operation of a center pivot systems and unlikely in traveling gun systems. In addition, in many other applications smaller droplet sizes are required for adequate coverage upon deposition; that is not critical in manure application, and the droplet sizes are commonly much larger and less prone to drift than those used in the reference studies.

Based on available information, Table 3a-1 provides a compilation of practices expected to limit or exacerbate drift under various conditions and types of irrigation equipment.

Table 3a-1. Droplet Drip Issues for Manure Irrigation Practice

	Practices or conditions expected to limit Drift	Practices or conditions that exacerbate risk of Drift
Siting	Edge of field barriers (e.g., trees) as wind block To minimize potential impact from drift, limit irrigated use to areas adjacent to own fields	Irrigated use adjacent to fields not owned by the farm may increase potential impacts if drift occurs
Weather	Winds < 4mph High temperature High relative humidity Standard atmospheric conditions	Winds > 10mph Wind in the direction of surrounding residences, other property lines, or sensitive vegetation Low temperature Low relative humidity (increased rate of evaporation increasing drift) Periods of inversion

Table continues on next page.

Table 3a-1. Continued.

	Practices or conditions expected to limit Drift	Practices or conditions that exacerbate risk of Drift
Equipment: Center Pivot	Drop nozzles which lower the nozzle height below the boom structure. Note that nozzle heights are generally fixed for an entire season. Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse	Application from the top of a center pivot using impact sprinklers. Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, extra fine
Equipment: Traveling Gun	Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse	Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, extra fine

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3.b Odor

Odor – Definition and Issues of Concern

Odor is the human perception of how something smells based upon the chemical reactions it imparts on the olfactory senses in the nose and is a significant concern for use of manure irrigation systems. Although highly variable from person to person, humans have the ability to perceive thousands of different odors, and many of those can have a profound influence on an individual's state of mind and sense of wellbeing. Exposure to odor can result in mental, physical, health, and social impacts as a result of the human responses it invokes (Stowell et al, 2007). Odor impacts range from diminished quality of life or stress for neighboring residents to economic loss from reduced land values or loss of clientele for businesses. Issues identified in Wisconsin include disruption of family gatherings, inability to enjoy the outdoors on hot humid days, potential negative impact on property value, and a negative impact to tourism. Concerns about odors can equal or surpass other concerns related to agricultural operations including water quality, traffic, noise and dust. Personal experiences shared with the workgroup and reports documenting significant negative odor and related quality of life impacts in Wisconsin and other states (e.g., NRDC 2001, Plains Justice 2010) reinforce the critical importance of odor issues and associated management practices.

Quantifying manure odors is challenging due to the fact that over 300 different compounds can contribute to their composition. In addition, no one indicator, such as ammonia or hydrogen sulfide, corresponds directly to a perceived odor. The degree to which manure odors present a nuisance depends on the type of waste, duration of storage, the chemical and biological conditions under which it is stored, processing or treatment, proximity to those affected by the odor, and local weather conditions. Manure application systems that actively aerosolize manure liquids (such as irrigation systems) can be expected to increase chemical volatilization and intensity of the corresponding odors, although potentially for a shorter duration (Krantz et al, 2007).

By changing the number and timing of applications in a given area throughout the growing season, irrigation systems have the potential to increase the frequency of odor incidents. Odor levels can be managed or mitigated with processing and storage techniques including digestion or solid separation among others. Odor mitigation practices can be used with all forms of land application.

Odor - Current Practice and Regulations

Wisconsin Right-to-Farm legislation protects farms from nuisance complaints and litigation associated with objectionable odors resulting from the normal course of agricultural activities in the absence of associated health or safety hazards (Wisconsin Statute 823.08); see discussion in Section 2c. State agencies have little authority to require farms to change their practices or control odor levels. Many farms recognize the potential negative impacts of agricultural odors and take voluntary steps to reduce odor impacts through manure treatment and timing and method of application.

The Livestock Facility Siting Rule (ATCP 51) establishes a state standard that relies on a predictive model to estimate odor generated by manure storage, housing and animal lots. The odor standard accounts for the role of separation distance and odor control practices in reducing the impact of odors on neighboring properties. In local jurisdictions that have adopted a siting ordinance, livestock operations may need a passing odor score to obtain a siting permit. While the standard currently does not address the temporary effects of odor from the field application of manure, it does allow operators to develop an optional odor management plan identifying practices that can reduce conflicts associated with dust and odor.

- **Siting (location and application considerations).** Siting is the most critical component of odor abatement since preventing odors from reaching a receptor eliminates odor impact. Operators of irrigation systems can limit odor impacts by applying manure when winds are blowing away from receptors and avoid periods when neighbors may be outside such as weekends and holidays (Auvermann et al, 2002). Edge of field odor barriers (such as trees) may reduce the odor transport toward receptors.

- **Weather.** When odors can be dispersed, their impact is reduced. Available guidance recommends operating systems when the air is warming (such as early morning to afternoon) and when winds are above 5 mph, both of which will increase dispersion (Auvermann et al, 2002).

- **Waste Characteristics.** Reducing the odor content of the manure through processing and storage will reduce the odor impacts when the manure is applied. Anaerobic digestion and solids separation are two processing techniques which can reduce odors (composting is a manure processing technique that also reduces odors but would not apply to manure with a high liquid content). Storage in aerobic conditions or a treatment lagoon will result in degradation of organic matter and odor causing compounds reducing the odor impact upon application. A number of biological and chemical additives also have the potential to reduce odors when added to manure storage systems, however actual performance of additives can vary significantly. Managers can also reduce the impact by excluding fresh manure from storage two weeks prior to land application, and by applying manure in mid-summer or fall after the manure storage has become active. When land applying, dilution of manure has been shown to significantly reduce odors. A 2:1 dilution is recommended for processed manures and a 15:1 dilution is recommended for raw unprocessed manure slurries (Auvermann et al, 2002). It is also recommended that additions of highly odorous materials should be avoided to reduce odor impacts.

- **Equipment.** Using drop nozzles which are below the canopy will reduce odor transport. Application from atop an irrigation boom using impact sprinklers and end guns will increase the odor transport. Smaller droplets sizes have greater surface area per unit volume of manure and will therefore increase odor (MWPS 18-3). It is recommended to select equipment and operating pressures which result in droplets sizes greater than 150 µm (MWPS 18-3), corresponding to droplet classifications of coarse, very coarse, extremely coarse, or ultra-coarse (See Figure 3a-1).

Odor – Unknowns and remaining uncertainties

As noted, quantifying odor and predicting individual reaction to odor both present challenges. Variability in individual response leads to differential effects on those exposed to odorants. Given these uncertainties, Table 3b-1 provides a compilation of practices expected to limit or exacerbate impacts from odor under various conditions and types of irrigation equipment.

Table 3b-1. Odor Issues for Manure Irrigation Practice

	Practices or conditions expected to limit Impact from Odor	Practices or conditions that exacerbate risk of Impact from Odor
Siting	Consideration of neighbors (see Livestock Siting guidance) Physical separation between source and receptor, such as edge of field barriers (e.g., trees) as a wind block	Near populated areas/public gathering areas Application on weekends or holidays
Weather	Winds > 5mph When temperatures are rising	Winds < 5mph (stable conditions) Wind in the direction of populated areas or residences Periods of inversion

Table continues on next page.

Table 3b-1. Continued.

	Practices or conditions expected to limit Impact from Odor	Practices or conditions that exacerbate risk of Impact from Odor
Waste Characteristics	Waste treatment (Aerobic treatment or anaerobic digestion or treatment lagoons) Additives demonstrated to reduce odor Dilution with treated waste water or fresh water No new manure additions for 2 weeks prior to application Application in mid-summer or fall after lagoon has been active	Addition of highly odorous materials Application in spring or winter when lagoon is not active
Equipment: Center Pivot	Drop nozzles which lower the nozzle height below the boom structure. Greater reductions if below the canopy. Note that nozzle heights are generally fixed for an entire season. Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse	Application from the top of a center pivot using impact sprinklers. Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, or extra fine
Equipment: Traveling Gun	Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse	Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, or extra fine

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3.c Water Quality

Water Quality – Issues of Concern

Concerns about nutrients and microorganisms from crop fields entering surface or groundwater are present with all forms of manure application, including manure irrigation. As discussed in Section 2c, Wisconsin has numerous rules and regulations for manure management intended to protect water quality. Regardless of the type of manure application methods used, if the process is not carefully managed, there are several pathways that can lead to surface water or groundwater contamination. These include situations in which:

- Application rates and/or frequency exceed established crop nutrient needs/uptake periods
- Application rates and/or frequency exceed soil infiltration or soil available water capacity and result in:
  - ponding and surface runoff to surface waters, drain tile inlets or wells
  - losses to subsurface drain tiles that discharge to surface waters
  - losses below crop root zone depth and possibly to groundwater (can occur on highly permeable soils or cracked clay soils)
  - losses to groundwater via bedrock fractures
- Application onto established or recently harvested fields with clay soils and visible cracks or macropores in late summer or early fall that result in losses to subsurface drain tiles that discharge to surface waters or bypass of crop root zone to groundwater.
- Application on highly permeable soils in late summer or fall months to meet following spring crop nutrient requirements that result in nutrient losses below crop root zone depth and then groundwater.
- Aerial drift of applied manure occurs within or beyond the field boundary due to windy conditions that reaches surface waters or nearby drinking water wells.

Surface water and groundwater contamination are more likely to occur when manure nutrients are applied on saturated soils, prior to major rain events, soils with no growing crop, high volume rates per application, and low solids manure. For surface and groundwater protection, irrigation methods have specific management concerns related to drift management, equipment selection and maintenance, timing, source, and rate factors.

In general, manure nutrient application via irrigation can increase the number of applications with low application rates, on growing crops with lower soil moisture and help achieve surface and groundwater quality benefits on multiple soil types and crops. Compared with other manure application methods (which typically apply manure or process wastewater weeks or months in advance of growing season and crop uptake), manure irrigation allows farms to make multiple, lower rate applications during the growing season (May-Oct) on established crops during periods of peak nutrient uptake and periods with lower rainfall intensity and runoff potential. This flexibility helps maximize liquid manure or process wastewater storage capacity, opportunities for more double cropping/use of cover crops, which can further reduce the risk for causing pollution of surface or groundwater.

It is important to note that potential runoff incidents from over-application or application when field conditions promote runoff and the associated compliance (and related enforcement) with water quality regulations were major concerns raised about the practice. A Canadian report on manure traveling gun systems from the late 1990s (LWPPP, nd), identified runoff events associated with unsupervised applications and/or applications when soil conditions led to runoff. Similarly, concerns about non-compliance with water quality permits issued to CAFOs have been documented in multiple states, including Wisconsin (e.g., SRAP 2015). These concerns underscore the importance of application management to reduce runoff from all manure application systems and effective systems to ensure compliance.

Water Quality – Current Practices and Regulation

See section 2c of report for current Wisconsin rules and regulations (state and local) related to using manure irrigation. As a brief recap, it is assumed in this document that all farms, at a minimum, have developed and are following a nutrient management plan consistent with the NRCS CPS 590 to minimize nutrient entry to surface and groundwaters and account for application method, rate, source, timing and placement. WPDES permitted facilities that land apply industrial wastewater and confined animal feeding operations that use irrigation equipment to apply liquid manure or process wastewater must meet more restrictive land application requirements found within Wisconsin Administrative Code chapters NR 214 and NR 243. Such restrictions help further minimize the risk for pollution (via surface runoff, leaching or drift) to surface or groundwaters beyond the NRCS CPS 590.

Water Quality – Unknowns and Remaining Uncertainties

Nutrients and microbial organisms (including pathogens) associated with manure or process wastewater can be transported to surface water or groundwater through runoff, discharges, infiltration and atmospheric deposition. The key factors related to the fate and transport of liquid manure or process wastewater pathogens via drift or via runoff to surface or groundwater are not well understood and need additional research. Chapters 3 and 8 of a July 2013 literature review by USEPA provide a detailed overview of manure pathogen types, pathogen survival and transport factors and management measures (USEPA 2013).

While nutrient management practices and systems do not focus specifically on controlling manure pathogens, they do address many of the potential pathways (e.g., erosion, runoff and infiltration) for microbial transport to surface or groundwater. Manure irrigation, when compared to other forms of manure application, allows for flexibility in manure management with respect to application rate, timing, frequency and placement, which, in turn, can help reduce the risk for pathogen transport and loss to surface or groundwater. As presented in Section 3e and Appendix C, the factors influencing pathogen survival (fate) include temperature, ultraviolet (UV) radiation, moisture, pH, nutrient availability, ammonia concentration in the medium and competition for nutrients (see also Rogers and Haines, 2005). Ultraviolet light exposure promotes pathogen die off. Irrigating manure or process wastewater during daylight hours within the crop growing season (May-Oct) helps promote greater die off of pathogens through exposure to UV light and desiccation, limiting potential impact on surface water or groundwater.

Based on available information, Table 3c-1 provides a compilation of practices expected to limit or exacerbate water quality issues under various conditions and types of irrigation equipment.

*Table 3c-1. Water Quality Issues for Manure Irrigation Practices**

	Practices or conditions expected to limit Water Quality Impacts	Practices or conditions that exacerbate risk of Water Quality Impacts
Siting	· No application within 1,000 feet from municipal wells and 250 feet from private wells · No application within 100 feet from surface waters (perennial or intermittent streams), conduits to surface waters, groundwater conduits and wetlands (closer may be acceptable). · No application within 100 feet from concentrated flow channels, conduits to navigable waters, intermittent or perennial streams, wetlands, or other surface water features (closer may be acceptable). · No application on soils less than 5 feet depth to groundwater or bedrock on frozen or snow covered ground. · No application on soils less than 5 feet depth to groundwater or bedrock during growing season when outside peak crop nutrient uptake period · 100 foot setbacks from tile inlets and field depressional areas leading to tiles or groundwater conduits.	· Application in intermittent or perennial streams, wetlands, or other surface water features. · Application onto wells or other groundwater conduits. · Application onto tile inlets and field depressional areas leading to tiles or groundwater conduits. · Application on soils with less than 5 feet to groundwater or bedrock on frozen or snow covered ground. · Application > 15,000 gal/acre and no avoidance field areas that are tiled or contain numerous soil cracks/macropores. · Manure discharge through tiles to surface waters during or after application; no cease of application after tile discharges; no containment and clean up; no reporting of spills to WDNR. · Piping connection between manure supply lines and wells providing dilution water without a backflow preventer.

Table continues on next page.

Table 3c-1. Continued.

	Practices or conditions expected to limit Water Quality Impacts	Practices or conditions that exacerbate risk of Water Quality Impacts
Siting	· No tile line discharges to surface waters. If discharge, cease application and immediately contain and clean up discharges; report manure spill to WDNR. · Avoidance of field areas that are tiled or contain numerous soil cracks/macropores (minimal applications may be acceptable)	
Weather	· Daytime applications for UV exposure and pathogen destruction. · No application if rainfall amount that could cause surface runoff is forecast within 24 hours of application. · Consider soil moisture conditions with rainfall forecast.	· Majority of applications made during nighttime hours; no consideration for UV exposure and pathogen destruction. · Application during or prior to rainfall.
Waste Characteristics	· To minimize pathogen content: · Digested manure using thermophilic temperature ranges (> 135 degrees) or Reverse Osmosis system wastewater (most effective). · Digested manure using mesophilic temperature range (100-135 F) (can be effective). · Separated or Raw Manure with periodic field and weather monitoring (can be effective).	· Operating to increase ammonia can contribute to increased regional atmospheric deposition on surface waters.
Equipment: Center Pivot (with or without end gun)	· Effective monitoring of environmental conditions, irrigation equipment, downwind/downgradient areas for drift, ponding and runoff from field and setback distances. · Application does not cause ponding, drift or runoff from field into surface waters, wells, tile lines or other groundwater conduits.	· No monitoring of environmental conditions, irrigation equipment, downwind/down-gradient areas for drift, ponding and runoff from field, setbacks. · Drift or runoff from field into surface water, wells; discharges to tile lines or onto other groundwater conduits.
Equipment: Traveling Gun		

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3.d Air Quality

Air Quality – Issues of Concern

Application of all manure regardless of method has the potential to negatively impact air quality in terms of (1) nuisance odors, (2) hazardous air pollutants, primarily ammonia and hydrogen sulfide, (3) greenhouse gas emissions (methane, carbon dioxide, and nitrous oxide), and (4) particulate matter. The hazardous air pollutants potentially present at concentrations to be of concern to humans from direct inhalation from manure systems are ammonia (see Table 3d-1) and hydrogen sulfide (see Table 3d-2). Other hazardous compounds such as amines, aldehydes, and organic acids are typically present at lower concentrations where the main effects are contributions to odor.

Formaldehydes have been a source of concern as they are used in foot baths at livestock facilities, but a study conducted by the Vermont Department of Health found no difference in the level of formaldehydes in manure at facilities that used formaldehyde footbaths and those that did not. It also found that farms using formaldehyde footbaths did not impact indoor or outdoor concentrations, even during land application (Vermont Department of Health 2012). Although at sufficient concentrations, **ammonia** can cause respiratory issues or death, at lower concentrations measured around livestock operations the primary concern is regional air quality and not effects from direct inhalation. **Hydrogen sulfide** may be present around livestock operations at nuisance levels, and it can be an acute hazard in confined spaces; more rarely is hydrogen sulfide identified as a public health hazard around agricultural operations (Minnesota Department of Health 2009; Plains Justice 2010). Hazards associated with hydrogen sulfide are typically near the manure storage or other confined spaces on the farmstead, not by fields. **Methane** and **carbon dioxide** emissions are released from manure during its degradation in storage, during application, and from the soils following application. These greenhouse gases are a concern for global climate change, however the concentrations do not pose direct concerns to human when field applied. Manure-related respirable particulate matter can form directly from bio-aerosols generated from agricultural activities, or can form indirectly on a regional scale from atmospheric reactions involving **ammonia** released from a variety of sources, including agricultural practices (Harper et al. 2009; Hristov 2009). **Particulate matter** at dangerous levels can cause respiratory illness, lung inflammation, and issues related to respiratory disease (Laden et al. 2006; Venners et al. 2003; Danielsen et al. 2010).

It is expected that any type of irrigated manure application will increase air emissions as compared to direct injection. Techniques and equipment are available that would be expected to reduce air emissions relative to other aerial spray application methods (e.g., using drop nozzles to lower application height as compared to using impact guns that project above a center pivot boom), although many of these practices have not been evaluated in scientific studies. Earlier work done by regulatory and advisory workgroups in Wisconsin have addressed air emissions in greater detail. That work recommended best practices to reduce air quality impacts at the various stages of livestock waste production, storage, transport, and land application (see WDNR 2010 and NRCS document in references). Irrigation application of liquid manure was not listed among the best practices to reduce air emissions.

Table 3d-1: Ammonia toxicity progression (Michigan Department of Environmental Quality 2006)

Property	Concentration in air (ppm)
Detectable odor	0.04-53
Eye, nose irritation	50-100
Strong cough	50-100
Airway dysfunction	150
Lethal in 30 minutes	2,500-4,500
Immediately lethal	5,000-10,000

Table 3d-2: Hydrogen sulfide toxicity progression (ATSDR 2006)

Property	Concentration in air (ppm)
Typical background level	0.0002
Odor threshold (AIHA 1989)	0.001-0.008
Offensive odor, headache	0.3
Very offensive odor	3-5
Asthmatics affected	2
Human flatus	3-18
Olfactory paralysis	150

Table continues on next page.

Table 3d-2: continued

Property	Concentration in air (ppm)
Central nervous system depression, loss of consciousness, neurological problems may persist	>500
Lung paralysis, collapse, death	>600-1,000 (concentrations in actual events are uncertain)

Air Quality – Current Practices and Regulation

The primary goals of reducing air quality impacts focuses on reduced emissions from the four negative impact categories: (1) nuisance odors, (2) hazardous air pollutants, primarily ammonia and hydrogen sulfide, (3) greenhouse gas emissions (methane, carbon dioxide, and nitrous oxide), and (4) particulate matter. Tradeoffs associated with selecting a manure application system based on emissions mitigation can complicate efforts to reduce emissions across all four categories.

Reducing ammonia emissions is important both in preserving the economic value of nitrogen and for avoiding the release of nitrogen into the atmosphere where it can contribute to the atmospheric formation of oxides of nitrogen, ammonium nitrate, and fine particulate matter [PM2.5] (Harper et al. 2009; Hristov 2009). Injection of manure is a best practice for reducing ammonia emissions (Rotz 2004), followed by incorporation. According to some literature which ranks manure application methods in order of typical nitrogen losses, manure irrigation is listed as the method with the highest average N loss (Rotz 2004). However, more recent field studies have suggested that losses of ammonia are similar to other application methods (which is likely due to the dilute nature of manure applied through irrigation systems) (Misselbrook et al. 2004). As irrigation requires lower manure dry matter content than other application methods, it may increase the infiltration of manure which results in less ammonia losses to volatilization (Meisinger and Jokela 2000).

Federal and Wisconsin regulations directly impacting agricultural air quality and emissions from production areas or from land application do not currently exist. Reductions in greenhouse gases are not currently regulated at agricultural facilities and practices to reduce them remain voluntary. OSHA regulates air quality occupational health standards for farm workers at livestock facilities which have at least ten employees for ammonia, carbon dioxide, hydrogen sulfide, methane, PM 2.5, and formaldehyde (see Table 3d-3). Greenhouse gas emissions and the global warming potential resulting from manure irrigation have not been measured. As compared to injection methods, there may be a reduction in N2O emissions, but it can be assumed that carbon dioxide (CO2) would likely increase using irrigation systems.

Table 3d-3: OSHA Occupational Standard and Wisconsin Ambient Air Standard

Air Contaminate	OSHA Occupational Standards			Ambient Air Standard [expressed as 24 hour average] (µg/m3)
	8-hr Time Weighted Average	Ceiling (ppm)	Additional Notes	
Ammonia	50 ppm	--	--	418*
Carbon Dioxide	5,000 ppm	--	--	na
Hydrogen Sulfide	--	20	50 ppm acceptable maximum peak above ceiling conc. for 10 minutes once if no other measured exposure occurs	335*
Methane	--	--	No exposure limits, simple asphyxiate, oxygen levels must be maintained above 19.5%	na
$PM_{2.5}$	5 mg/m^3 (particulate not otherwise regulated)			35 (primary and secondary)**
Formaldehyde	0.75 ppm			na

* *Wisconsin Administrative Code Chapter NR 445.07 Table A;*
** *USEPA National Ambient Air Quality Standard*

- **Siting (location and application considerations).** Although air quality impacts are likely to be regional in nature, edge of field barriers can be used to reduce particle transport and potentially reduce impacts.

- **Weather.** Low wind speed may actually reduce emissions during and following manure application. It has been found that increasing wind speeds up to 5.6 mph increases ammonia emissions from manure (Rotz 2004). As temperature is directly related to manure emission rates, applying manure in lower temperatures will reduce emission losses. Similar to odor, periods of inversion should be avoided since dispersion is limited during these times. Higher temperatures and low humidity may promote evaporation and increase emissions and should therefore be avoided.

- **Waste Characteristics.** To minimize potential for air quality impacts, operators should avoid additions of materials that will result in higher concentrations of chemicals or compounds that are of concern to air quality since increased concentrations typically lead to increased emissions. For example, an increase in ammonium or ammonia content will increase ammonia losses when applied. If using irrigation practices, diluting manure with fresh water can reduce ammonia emissions during land application (MWPS 18-3). Integrating recovery systems to remove components of concern is recommended to reduce the impact to air quality (e.g., ammonia recovery systems prior to land application).

- **Equipment.** Drop nozzles below the vegetative canopy are expected to reduce air quality impacts as the vegetated canopy may capture some of the compounds of concern. Applying manure from the top of the pivot increases the path length of the droplet, which may increase emissions and increase potential for a negative impact on air quality.

Air Quality – Unknowns and Remaining Uncertainties

Researchers have not actually measured many of the air quality parameters in Table 3d-3 for manure irrigation, and much of the information represents data collected on other manure application methods including surface broadcast, surface broadcast with incorporation, or injection. The mechanisms and trends behind emissions from other systems can be used to understand and predict the impacts from manure irrigation. However, it should be noted that this information has not been measured directly in manure irrigation systems, and (aside from noted studies) models have not been calibrated for manure irrigation. It is also important to understand that there are many tradeoffs between the emissions from these practices, and it is difficult to put importance over one impact versus the other.

Based on available information, Table 3d-4 provides a compilation of practices expected to limit or exacerbate regional air quality impacts under various conditions and types of irrigation equipment.

Table 3d-4 Air Quality –Regional Air Quality Issues for Manure Irrigation Practices

	Practices or conditions expected to limit Regional Air Quality Impacts	Practices or conditions that exacerbate risk of Regional Air Quality Impacts
Siting	Edge of field barriers or other plant surfaces (for adsorption)	
Weather [3]	Low wind < 5 mph Low temperature	High > 5 mph High temperature Inversion periods Winds toward populated areas and residences
Waste Characteristics [2]	Low initial ammonia concentration or ammonia recovery technologies	Additions of material with high nitrogen or sulfur content.
Equipment: Center Pivot [1]	Drop nozzles which lower the nozzle height below the boom structure. Note that nozzle heights are generally fixed for an entire season. Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse.	Application from the top of a center pivot. Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, or extra fine.
Equipment: Traveling Gun	Nozzle selection and operating pressure which result in droplet classification of coarse, very coarse, extremely coarse, or ultra-coarse.	Nozzle selection and operating pressure which result in droplet classification of medium, fine, very fine, or extra fine.

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3.e Airborne Pathogens

Airborne Pathogens – Definition and Issue of concern

Application of liquid dairy manure by traveling gun or center pivot irrigation systems is becoming more common in Wisconsin. A primary concern raised about these practices by stakeholders is that manure irrigation could increase the risk of airborne pathogen transmission to humans and livestock. The concern stemmed from the potential increase in airborne droplets and more frequent application compared to other application methods. To address the issue of airborne pathogen transmission, this section summarizes a Wisconsin study on dairy manure irrigation and human health risks (Borchardt and Burch 2016, included as Appendix C). Much of the text in this section of the report is extracted from Appendix C (with permission); other parts are paraphrased for brevity.

The study summarized here is a Quantitative Microbial Risk Assessment (QMRA) developed using data collected from several Wisconsin farms employing manure irrigation practices. The Wisconsin study had two primary objectives:

1. Identify weather variables (e.g., wind speed, solar radiation, and relative humidity) most important for airborne pathogen transport during manure irrigation.
2. Use microbial risk assessment to estimate the risk of illness for people exposed to airborne pathogens downwind from manure irrigation sites.

Appendix C includes the research study details and a summary of previous research on health risks associated with airborne fecal pathogens. Based on assumptions outlined below and in Appendix C, the study quantifies risk of acute gastrointestinal illness from pathogens at different downwind distances.

Airborne Pathogens – An Overview of QMRA Study

Conceptual Model of Pathogen Transport, Inactivation, and Exposure in Air. Airborne transport of pathogens from irrigated manure to humans depends on four processes (Figure 3e-1). Following release from the irrigation nozzle, manure droplets are deposited on the ground due to gravity, while aerosols are transported downwind. During transport, the aerosolized pathogens disperse in the atmosphere (reducing their concentration) and are inactivated (i.e., killed). The rate of inactivation can occur quickly and depends on temperature, relative humidity, and ultraviolet light from sunshine. For example, a representative inactivation rate during daytime conditions is 0.07 per second (Teltsch et al. 1980), which corresponds to a half-life of 10 seconds. This means that the initial pathogen concentration in the aerosol is reduced by half for every 10 seconds of exposure to environmental conditions. However, while inactivation occurs quickly during the day, it can be much slower during nighttime conditions (Teltsch et al. 1980; Paez-Rubio and Peccia 2005). Human exposure to pathogens that survive airborne transport can occur through four routes: 1) inhalation, with some fraction of the inhaled aerosols being swallowed and reaching the gastrointestinal system; 2) deposition of the pathogens onto food or crops that are then eaten; 3) deposition of pathogens onto inanimate surfaces, followed by hand-to-mouth transmission; and 4) contact with vectors (e.g., pets or insects) that cause secondary, indirect transmission. Following exposure, the pathogens may result in infection and/or illness depending on the host's immune system.

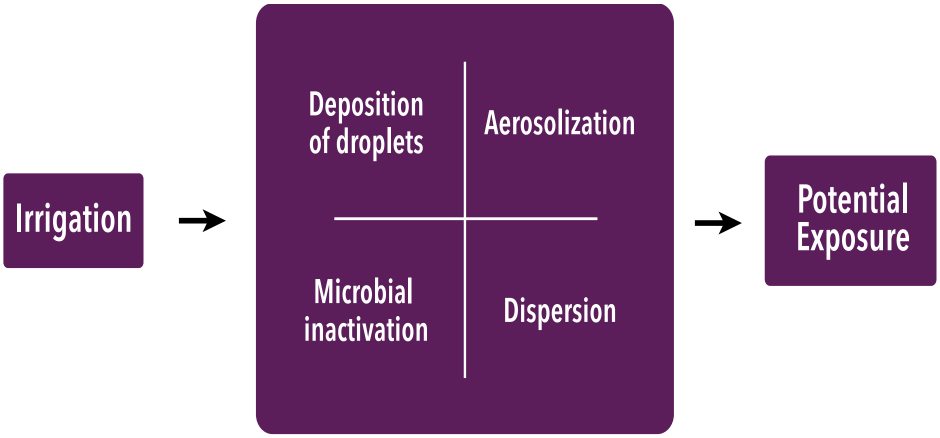

Figure 3e-1 Conceptual model of pathogen airborne transport and human exposure during manure irrigation.

[note: Also Figure C-1 in Appendix C]

Finally, it is important to recognize that the pathogen content of dairy manure can be highly variable from herd to herd and in the same herd over time. Thus, exposure to dairy manure does not always result in exposure to pathogens. On the other hand, the absence of pathogens in a specific dairy herd at a specific point in time does not equate to the universal absence of health risk from that herd over time.

Risk assessment study methods.

For the study, risk was defined as the probability of acute gastrointestinal illness (AGI) due to airborne transmission of pathogenic bacteria from irrigated manure to humans. It considered the most immediate exposure route described above – inhalation followed by ingestion – at distances up to 1,000 feet from the irrigation wetted perimeter. Unlike similar studies previously conducted, risk estimates were based on empirical field data for 21 full-scale dairy manure irrigation events from three dairy farms. Note, using AGI as the risk outcome errors towards higher risk estimates because the more severe illnesses that can result from these pathogens (e.g., septicemia, hemolytic uremic syndrome) are less likely to happen than AGI.

Because the pathogens of interest were rarely found in the manure at the study farms, two non-pathogenic bacteria that were always present in manure were used as surrogates to represent airborne transmission of pathogens. The surrogates measured in the study were selected to show a range of risk associated with losses through transport. Bovine Bacteroides had the highest detection frequencies in the downwind air and is used in the analysis to represent pathogens with high potential for survival during transport. Gram negative bacteria had the lowest detection frequencies in the downwind air and is used in the analysis to represent pathogens with lower potential for survival during transport. Air concentrations of both surrogates decreased with distance from the manure irrigated wetted perimeter.

Risk from exposure was considered for three pathogens, C. jejuni, EHEC, and Salmonella spp., because these pathogens are common on U.S. dairy operations (USDA 2003; USDA 2011). The risk assessment accounted for variation in people's susceptibility to infection by relying on millions of combinations of age, time spent outdoors, inhalation rate, and inhalation volume drawn randomly from statistical distributions for these parameters (see Figure C-4).

The risk assessment also accounted for variability in pathogen content of dairy manure by modeling two different values for pathogen prevalence in the manure influent. For the three pathogens considered, the first value was a typical prevalence for dairy operations of 39%, 40%, and 90% for EHEC, Salmonella spp., and C. jejuni, respectively (USDA 2003; USDA 2011). The second value was conservative as it assumed 100% prevalence for each pathogens considered. The combination of two surrogates and two pathogen prevalence values yielded four risk scenarios that circumscribe the range of risk estimates obtained in this study.

In addition to the QMRA, researchers also developed empirical models to investigate the relationship between measured concentrations of airborne microorganisms and environmental factors measured during each field trial. These factors included distance, wind speed, relative humidity, sunlight, temperature, and concentrations of microorganisms in source manure.

Study Findings.

Median risk estimates varied between roughly 1 in 100,000 and 1 in 100 depending on different combinations of pathogen prevalence and the surrogate used to represent airborne transmission of pathogens. Though wide, this range is considerably narrower and somewhat higher than most risk estimates from previous similar studies. It also largely falls between acceptable risk thresholds for drinking water (1 infection per 10,000 people per year) and recreational water (32 illnesses per 1,000 swimmers per event). Finally, it must be recognized that these risk estimates represent single exposure events. If individual fields are irrigated multiple times in a season, then the cumulative risk over that season will be higher. That cumulative risk can be estimated as the product of the single exposure risk and the number of exposure events per season.

Overall, the most important factor for interpreting risk estimates was pathogen prevalence in the source manure. However, if a pathogen is present, then results suggest that distance and wind speed were the most important environmental factors related to measured airborne microorganism concentrations.

Implications for Siting (location and application considerations).

Anticipated risks related to airborne pathogens vary based on distance from a manure irrigation source. Understanding this variation is essential for informing recommendations of setback distances between manure irrigation and neighboring receptors such as residences, schools, gardens, surface water, and well heads. It is also important for those making decisions to determine their acceptable risk threshold and the combination of pathogen prevalence and surrogate used for risk determination.

The most important weather variable in determining downwind microbe concentrations is wind speed. Other factors, such as solar irradiance and dispersion interact with wind speed and distance to affect downwind concentrations of active microbes. Prevalence, initial concentration of pathogens in the source manure, and distance downwind from the source are also critical non-weather factors.

In general, this analysis shows that four actions provide the biggest payoff in reducing the risk of airborne disease transmission from dairy manure irrigation: 1) improvements in herd health to reduce pathogen prevalence in manure; 2) treatment to reduce or eliminate manure pathogens; 3) irrigate in low wind speed conditions to reduce downwind transport; and 4) maximize the distance between irrigated manure and people.

<u>Airborne Pathogens – Unknowns and remaining uncertainties.</u>

Additional information about unknowns and remaining uncertainties is presented in the more complete study summary in Appendix C. The discussion of study limitations and data interpretation is especially important for understanding this study.

Table 3e-2. Airborne Pathogen Issues for Manure Irrigation Practices

	Practices or conditions to limit airborne pathogen risk	Practices or conditions that exacerbate airborne pathogen risk
Siting	Edge of field barriers Maximize separation distance to inhabited dwellings/public spaces Avoid irrigating when wind direction is towards inhabited dwellings	Irrigating near households with young children, elderly people, or people that have compromised immune systems Irrigating near an inhabited dwelling
Weather	Applications during: · Low wind velocities · Warm temperatures · Bright sunshine · Low humidity	Applications during: · High wind velocities · Cool temperatures · Overcast periods · Nighttime · High humidity · Inversion periods
Waste Characteristics	Good herd health Maintaining low pathogen level in applied material through: · Anaerobic digestion · Storage for 30 to 90 days in manure lagoon · Aeration of lagoon effluent · Pasteurization · Advanced treatment Pathogen analysis before application	High initial levels of pathogens in applied material. Higher potential from: · Fresh manure or manure stored for < 30 days · Calf manure
Equipment: Center Pivot	Drop nozzles which lower the nozzle height below the boom structure. Note that nozzle heights are generally fixed for an entire season. Low pressure Large droplet sizes	Application from the top of a center pivot using impact sprinklers. High pressure Small droplet sizes
Equipment: Traveling Gun	Large droplet sizes	Small droplet sizes

References for 3e. Airborne Pathogens

All references for this section are found in Appendix C.

3.f Timing of application for nutrient benefits, road safety, and road damage

Over time, the equipment used by farmers and custom manure applicators for nutrient land application and hauling have increased in size and weight. Increased vehicle size and traffic volume from livestock operations during manure land application has raised questions about public safety and the negative impacts on quality of life when trucks and/or large farm equipment is operating frequently. A related issue of concern to local governments is the negative impacts that large farm equipment can have on local road systems, as revealed by the Wisconsin DOT *Implements of Husbandry* report.

Manure handling is changing

As discussed in Chapter 2, livestock manure characteristics and handling techniques have changed in recent decades. At the same time the livestock housing systems consolidate low solids agricultural by-products other than manure which contributes to a more liquid manure mix. A general increase in farm size has further accelerated the trend toward use of high-volume liquid manure storage systems. As noted, the reduction in winter spreading of manure has further condensed the calendar windows for applying livestock manure to the land.

As discussed in Chapter 3, solids separation is commonly practiced on larger dairy farms. Separated manure allows the liquid fraction to be handled using a variety of application techniques (often at a higher application rate per acre due to the reduced nutrient content). The separated solid fraction of the manure can be partially recycled as animal bedding or land applied. In addition, the reduction of water from separated solids increases nutrient density and allows hauling to greater distances and nutrient application onto fields that may not have previously received manure.

The majority of livestock manure hauled in the state of Wisconsin is less than 11% dry matter. Transportation of liquid or slurry manure is primarily by tanker wagons pulled by farm tractors or semi-truck tankers. A common strategy when developing a manure application plan is to minimize hauling distances from the livestock production site to reduce hauling costs.

A significant portion of Wisconsin's manure is transported by professional nutrient applicators. These contractors move from farm to farm with specialized manure agitation/loading equipment and utilize a fleet of transport vehicle and non-permanent drag hose lines to efficiently haul and land-apply manure. With the shift to professional land application of manure by nutrient applicators, there has been improved capacity for conformance with nutrient management plans and environmental restrictions. An unintended negative consequence is that a limited number of haulers are available to provide service to numerous farms during the short spring and fall land application windows typically available in Wisconsin.

Timing Issues

Much of Wisconsin's livestock manure is applied during relatively short time periods in the spring before planting (which can be complicated by late thaws or extended wet periods) and in the fall, after harvest when applications can be complicated by late harvest, extended wet periods, or early snow or freezing. Livestock manure can also be applied in late spring/summer months on alfalfa or after harvest of winter wheat crops. Yet, those narrow spring and fall time periods of intensive action concentrate risks related to rural road safety problems (congestion and accidents involving farm vehicles), the potential for application mistakes and spills, and nuisance concerns related to odor and operation of agricultural equipment (noise, lights, dust, etc.). As noted in other parts of the report, the timing of application also affects nutrient uptake, nitrogen leaching, and other runoff or water quality factors.

Fields need to be dry prior to planting and once planted cannot have manure applied by vehicles, limiting the time period for application. Applying manure after alfalfa cutting is an exception, but may be limited to a short period after cutting because of regrowth, rain occurring after harvest, and soil moisture. Similarly, fall application is limited by when crops are harvested from the field and when the ground freezes and snow accumulates on the surface. Figure 3f-1 illustrates annual time periods when the majority of manure is applied to crop fields. Within the manure application periods are additional crop planting and harvesting operations that limit manure application.

With manure irrigation, the time period for applications increases to include the summer months during the growing season. This allows:

- The timing of application to be more selective based on weather and soil conditions.
- Applications to be divided over several dispersed time intervals during the crop growing season reducing the risk of nutrient and bacteria surface runoff or loss/entry into groundwater (e.g., potentially four applications of 0.2 inches each rather than a single application of 0.8 inches).
- Application to occur in drier soil conditions which allows nutrients, microorganisms, and water to be absorbed in the upper soil layer reducing losses. De-nitrification does not occur when soil moisture is below 50-55%, thereby reducing nitrous oxide (a greenhouse gas) production.
- Application to occur on growing crops which allows
  - Roots to absorb applied nutrients and water, potentially increasing plant yields and reducing the risk of nutrient leaching to groundwater.
  - Plant structure to reduce the risk of surface runoff.
  - Reductions in groundwater use during dry conditions.
- Applications to the surface of plants and soil allowing for pathogen inactivation from desiccation and solar radiation
- Improvement in nitrogen use efficiency (reduction in nitrogen loss) as nitrogen is applied when roots are actively growing and drawing nitrogen from the soil unlike traditional application where substantial nitrogen leaching can occur in the late winter and spring (Masarik et al 2014).

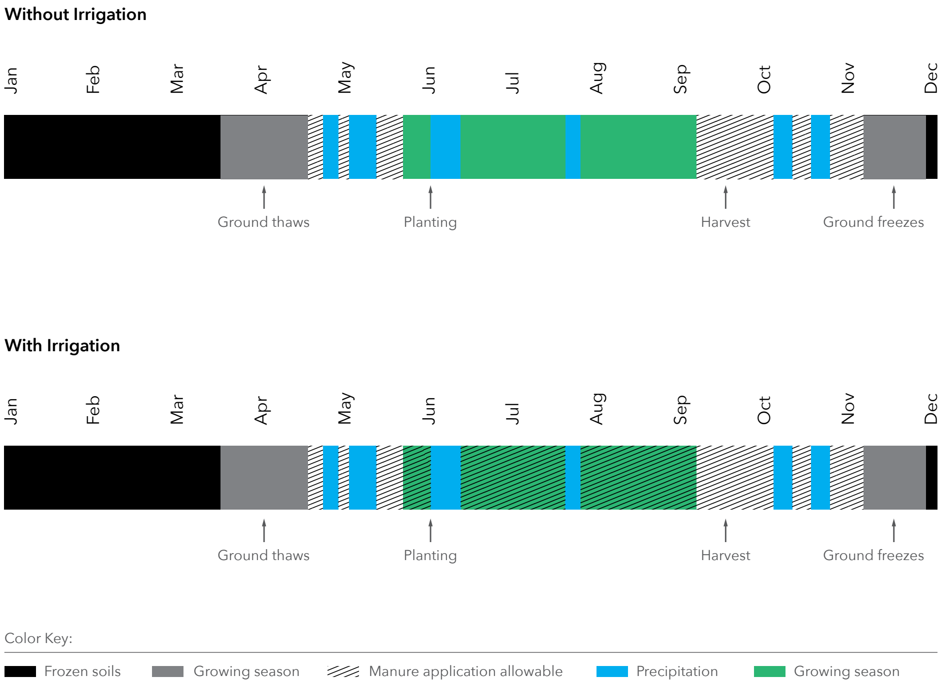

Figure 3f-1. Annual Timeline showing potential land-application periods for manure with and without irrigation

Manure hauling affects road safety, and increases road wear and maintenance

The network of township roads that typically surround livestock operations were built using state/federal grant funds. Historically, Town leaders took advantage of these incentives to surface most of the town roads in Wisconsin to reduce dust and annual maintenance costs inherent to un-surfaced roads (routine grading to maintain a level road surface). At the time these roads were constructed, they were not designed to accommodate the changes in traffic volume and vehicle loads associated with contemporary manure application. Township roads tend to be narrower than county roads, with narrower shoulders and portions of many were constructed on less than ideal subgrade materials. Results and recommendations included in the *Implements of Husbandry* study will likely affect how town roads are used for manure hauling.

As outlined in that report, to address safety concerns and to minimize road damage, many livestock operations have worked with local governments to implement manure hauling best management practices. Examples include temporarily converting local roads to one-ways. The one-way traffic pattern prevents smaller vehicles from having to move far right to when encountering large equipment on a two-way road. The one-way traffic pattern also allows heavy tanker equipment to travel down the center of the road, which allows for better weight distribution to the road surface and reduces the chance for break up along the edge of the road.

Interest in using permanent and mobile piping for distributing manure is also increasing (see Chapter 2). Part of the interest can be attributed to new road vehicle weight and size limitations included in recent Implements of Husbandry legislation (2013 Wisconsin Act 377). As an alternative to hauling manure to fields, some livestock operations have installed permanent underground pipe systems to convey manure liquids to centralized field locations. Those piping systems allow for application using irrigation equipment or pump/drag hose systems. The underground pipe systems have a significant initial capital cost but can significantly reduce vehicle traffic associated with hauling and applying manure.

References

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Wisconsin Department of Transportation (WDOT). 2013. Implements of Husbandry Study: Phase I Report to the Secretary of the Wisconsin Department of Transportation (January 2013); Phase II Report to the Secretary of the Wisconsin Department of Transportation (July 2013); Phase II Addendum Report to the Secretary of the Wisconsin Department of Transportation (September 2013). Reports available at http://wisconsindot.gov/Pages/dmv/agri-eq-veh/study.aspx

3.g Additional farm management and economic issues

Manure irrigation offers options for livestock operations that can improve overall farm management and influence farm economics. Decisions by farm managers to use available technology and practices involve considerations for cost, convenience, impacts to existing farm operations and management, and conservation and stewardship objectives. Livestock operations have multiple reasons for considering manure irrigation as part of their overall farm system. These include the potential for the following:

- Better control over the timing of manure applications to allow for application during the summer growing season.
- Improved accuracy of nutrient application and potential nutrient efficiency and crop benefits from delivering nutrients when plants are growing.
- Flexibility to modify application rates based on crop development and nutrient status (within the overall constraints of a nutrient management plan).
- Reduced soil compaction (or risk of soil compaction) due to field traffic of manure application equipment.
- Improved crop yields with nutrient and water delivery.
- Shifting manure distribution toward piped systems and away from tankers/trailers on roads.
- Reduced traffic and road concerns (for the farmer/operator as well as other drivers and neighbors).
- Reduced cost of application of nutrients (reduced fuel usage and costs).
- Reduced demand on custom manure applicators when weather, crop, and soil

conditions result in shortened acceptable periods of time to apply nutrients in Spring and Fall.

- Increased likelihood manure storage structures will remain at lower levels throughout the growing season and will not enter the winter season with manure remaining, reducing the risk of overtopping.
- Capturing manure management benefits as part of investments in irrigation systems installed as protection against drought.

Understanding costs associated with manure irrigation compared to other available practices is helpful for understanding farm management decisions. As discussed in section 2b, livestock operations use a variety of methods for collecting, processing, transporting, and field-applying manure. Decisions about any one part of a manure management system are interdependent with decisions about the other parts of that system. Any options for field application are limited by spreading restrictions, agronomic application rates, weather, and soil conditions.

<u>General cost considerations</u>

Section 2b identified four main components associated with manure management and hauling. General costs associated with different component options are outlined below.

- **Manure processing/treatment:** As noted in section 2b, costs associated with installing manure processing systems can be highly variable as can the maintenance and operational costs of different systems. Digester systems and cost of manure processing equipment to remove fiber and segregate nutrients can cost millions of dollars. Nutrient segregation systems can allow for greater control of nutrient content in the liquid manure applied through manure irrigation systems, which may be especially useful for applying small doses of nutrients at specific times in the plant growing cycle through center pivot systems. Nutrient segregation systems begin with removal of fiber, and can then progress with additional investment to remove phosphorus, and with more investment removal of nitrogen (ammonia) and pathogens. Nutrient segregation will result in concentrated nutrient sources which can be transported to fields further from the animal operations and applied in a manner similar to how commercial fertilizers are used.

- **Manure transport through piping systems:** Installing pipes for transporting liquid manure from storage structures to fields eliminates the need to transport the material in trucks. Estimated cost of installing and permitting pipelines to irrigation systems can range from approximately >$110,000/mile - $150,000/mile.

- **Traveling gun systems:** As described in section 2b, travelling guns are highly mobile pieces of equipment that can be moved easily from field to field. Hoses attached to traveling guns can connect to either piping systems, tanker trucks, or directly to storage facilities. Traveling guns also require low solids content (from 4 to 7% solids). Costs to purchase and use traveling guns are relatively low.

- **Center pivot systems:** Cost of center pivot irrigation systems are approximately $1,000/acre or more (add reference/source). Inclusion of special nozzles (including drop-nozzles that lower the discharge point closer to the ground), remote web-based management technologies for controlling pivot rotation speed and flow rates for individual nozzles increase costs. As noted in section 2c, use of center pivot systems requires low solids content in order for the nozzles to function. Older center pivot equipment may not be fitted for the drop nozzles and rotators recommended for use.

Operational cost estimates for transport and application

Several estimates regarding operational cost associated with differing management aspects of manure irrigation practices are provided below. Manure irrigation is one component of manure management and application for an operation. Costs associated with other practices and technologies for transporting and applying manure to fields are included for context and comparison.

Fuel costs

- $3.50/gal
- pumps/tractors/trucks use 5 gallons/hour or 5 miles/gallon

Application rates

- vary between 10,000-20,000 gallons/acre of unprocessed manure (note: 27,000 gal/acre is approximately 1 inch of liquid/acre)

Hosing application

- Pumping capacity 650-1,000 gal/minute.
- Each additional mile from source requires additional pump.
- Ability to place hose/pipe under roads.
- Requires 3-person crew to run system plus an additional person per pump. Field setup requires additional tractor, hose trailers and 1hr down time for each hose set for a 20-40 acres.
- Application is observed continuously to prevent runoff.

Trucking application

- Often in combination with hosing application where nutrients are trucked to field, emptied into a tank, and from tank to hosing application. This complicates the application with trucks lining roads waiting for hose application delays.
- When applied directly to fields the following apply: soil compaction concerns; tractor and equipment needed to incorporate manure into the soil; mud tracked on to roads when leaving fields; and application rates more variable depending on soil type/conditions, topography, truck speed and load.
- 5-20 trucks running at a time depending on distances hauled which can range up to 30 miles one way.
- Average truck tank holds 5600 gallons and takes three minutes to fill or empty.
- Primarily applied in spring prior to planting or fall post crop harvesting. Can also be applied in season on alfalfa crop within a 5 day period after cutting (with limitations by soil moisture and soil compaction concerns).

Center Pivot Irrigation

- 45 acre pivot, 30 hp electric nutrient pumps, 10 hp pivot motor 0.5 gal/hr. pump capacity 450 gal/minute.
- Ability to apply spring, summer, and/or fall, on growing crops with multiple applications (application rates consistent with nutrient management plan and crop utilization).
- Depending on the level of dilution from solid separation and nutrient segregation technology, volumes may vary from 40,000-150,000 gals/acre (1.5 – 5.5 inches of liquid per acre) applied through numerous applications throughout the seasons. Tables A-1 and A-2 in Appendix A presents estimates of nutrient content of manure.

4. Scenarios

The individual situations in which manure irrigation might be used as a land application practice would determine the extent of potential risks and benefits. The scenarios below are intended to illustrate how the addition of manure irrigation might change producers' management practices and how those changes may affect their neighbors. Three simplified scenarios below represent three different farm sizes: 150-cow, 600-cow, and 2,500-cow operations. All three operations use a mix of manure irrigation and conventional application methods. For each scenario, tables reflect increasing percentages of manure that could be applied with irrigation technology relative to conventional methods. Scenario assumptions are identified, and each scenario highlights differences in manure hauling, potential reduction in tanker trips for neighbors, reduced tanker road mileage, and the producer's cost impacts for hauling.

4.a Three Dairies

Assumptions for all three scenarios

The following assumption apply to all three scenarios and throughout this section of the report:

- Animals: Milking cows are 1,400 pound milking cows (and the farm includes no support animals)
- Manure production: 18.7 gallons of manure per 1,000 pounds of cow per day
- Manure solids content: all manure is considered to be 5% solids content to allow for irrigation (center pivot systems require additional solids removal as outlined)
- Total manure volumes: Manure production values are multiplied by 1.8 to account for additional wastes produced on the farm (e.g. urine, milking parlor wash water)
- Manure hauling frequency: 150-cow farm hauls throughout the year; the 600-cow and 2,500-cow operations haul primarily in spring and fall
- Average hauling distance: 150 cow farm is 0.9 miles, 600 cow farm is 1.5 miles, and a 2,500 cow farm is 3.8 miles (note: consistent with a recent manure survey conducted in Wisconsin)
- Tanker volume: A tanker holds 8,000 gallons of manure
- Cost of land application: Tanker land application is $0.015/gallon and irrigation application is $0.0075

  Note: capital costs are significant for center pivot systems
  - center pivot systems commonly cost upwards of $1,000 per acre
  - permanent buried manure lines range $110,000-$150,000 per mile
  - non-permanent drag hose lines $6,000-$13,000 per mile depending upon hose-line diameter
  - manure pumping systems also require pumps at approximately $50,000 each (roughly one pump per linear mile)

Dairy with 150 cows

This 150 milking cow dairy produces 3,927 gallons of manure per day (1,433,355 gallons annually), and 7,069 gallons of total manure and other agricultural by-products combined (2,580,039 gallons annually). If applied every 4 days (roughly 89 times per year) that is 28,990 gallons per application. That would translate to three tanker loads driving 0.9 miles to the field and back every 4 days for the entire year (or approximately 6 tanker trucks per week). If this dairy decided to integrate a traveling gun system to haul some of the manure, it would affect the truck traffic and application costs depending on the amount applied with a traveling gun system (see Table 4a-1).

Table 4a-1: Differences associated with shifting 0-50% of manure application to irrigation for the 150-cow dairy

	Annual Percent of Manure Applied by Traveling Gun				
	0%	10%	20%	30%	50%
Annual Manure Volume Applied by a Tanker (gallons)	2,580,039	2,322,035	2,064,031	1,806,027	1,290,020
Annual Manure Volume Applied by a Traveling Gun (gallons)	0	258,004	516,008	774,012	1,290,020
Annual Manure Tanker Trips	323	290	258	226	161
Annual Total Tanker Distance Traveled (miles)	583	524	466	408	291
Application Cost ($)	$38,701	$36,766	$34,831	$32,895	$29,025

It is highly unlikely that a producer would use a center pivot manure irrigation system at a small dairy. Use of a center pivot system for manure irrigation requires manure storage (only 25% of smaller farms use storage) and solids removal processing, which is beyond the investment capabilities of this size farm.

Dairy with 600 cows

This 600 milking cow dairy produces 15,708 gallons of manure per day (~5.7 million gallons annually), and 28,274 gallons of total manure and other agricultural by-products combined (~10 million gallons annually). If applied on average 15 times per year that is ~700,000 gallons per application period. That would translate to 645 tanker loads driving 1.5 miles to the field and back both during the spring and fall each year.

If this dairy decided to integrate a traveling gun or center pivot irrigation system to haul manure it would affect the truck traffic and economics according to the amount applied with the irrigation system, Table 4a-2.

Table 4a-2: Differences associated with shifting 0-50% of manure application to irrigation for the 600-cow dairy

	Annual Percent of Manure Applied by Traveling Gun				
	0%	10%	20%	30%	50%
Annual Manure Volume Applied by a Tanker (gallons)	10,320,156	9,288,140	8,256,125	7,224,109	5,160,078
Annual Manure Volume Applied by a Traveling Gun or Center Pivot (gallons)	0	1,032,016	2,064,031	3,096,047	5,160,078
Annual Manure Tanker Trips	1,290	1,161	1,032	903	645
Annual Total Tanker Distance Traveled (miles)	9,821	8,839	7,857	6,875	4,910
Application Cost ($)	$154,802	$147,062	$139,322	$131,582	$116,102

Dairy with 2,500 cows

The 2,500 milking cow dairy produces 65,450 gallons of manure per day (~24 million gallons annually), and 117,810 gallons of total manure and other agricultural by-products combined (~43 million gallons annually). If applied on average 2 times per year that is ~2 million gallons per application period. That would translate to almost 450 tanker loads driving 3.8 miles to the field and back for two different application periods in the year if all manure was applied through tankers. The annual cost to haul the manure is ~$645,000

If this dairy decided to integrate a traveling gun or center pivot irrigation system to haul manure it would affect the truck traffic and economics according to the amount applied with the irrigation system, Table 4a-3.

Table 4a-3: Differences associated with shifting 0-50% of manure application to irrigation for the 2,500-cow dairy

	Annual Percent of Manure Applied by Traveling Gun				
	0%	10%	20%	30%	50%
Annual Manure Volume Applied by a Tanker (gallons)	43,000,650	38,700,585	34,400,520	30,100,455	21,500,325
Annual Manure Volume Applied by a Traveling Gun or Center Pivot (gallons)	0	4,300,065	8,600,130	12,900,195	21,500,325
Annual Manure Tanker Trips	5,375	4,838	4,300	3,763	2,688
Annual Total Tanker Distance Traveled (miles)	40,920	36,828	32,736	28,644	20,460
Application Cost ($)	$645,010	$612,759	$580,509	$548,258	$483,757

4.b Implications for Manure Distribution, Application and Transport

Potential Impacts to Manure Distribution – with 600 Cow Example

Manure application rates are generally limited by phosphorus allowances in nutrient management plans (depending on phosphorus soil test levels and cropping systems) or by volume limits (limited by infiltration to prevent runoff). Using a manure irrigation system requires low solids content and some degree of processing that can separate the nutrients for management. Regardless of the processing method used, the total amount of nutrients involved does not change. Operators must apply, recycle, or export (including off site sales) nutrients.

Using the previous scenario for 600 cows, these cows produce 10,320,156 gallons of total manure each year. Assuming a 1,200 acre land base and even distribution, that results in a manure application rate of 8,600 gallons per acre per year. Separating that manure through processing for use in a manure center pivot irrigation system allows a producer to fractionate that manure into two forms. For example 8,000,000 gallons of manure could contain half of the nutrients (now more dilute), and the remaining 2,320,156 gallons would contain the other half of the nutrients (now very concentrated and closer to a solid); this will change options for land application rate. A producer could apply 13,333 gallons per acre each year in two separate applications to half of the fields of the more dilute liquid, and 3,287 gallons per acre one time per year to the other half of the acres available. Different manure technologies and management systems would control the separation of nutrients and thereby control the land application. Some manure application to certain fields each year may be eliminated or reduced (e.g., fields with high runoff risk or proximity to other sensitive areas) and other lower risk fields could receive more of a diluted manure.

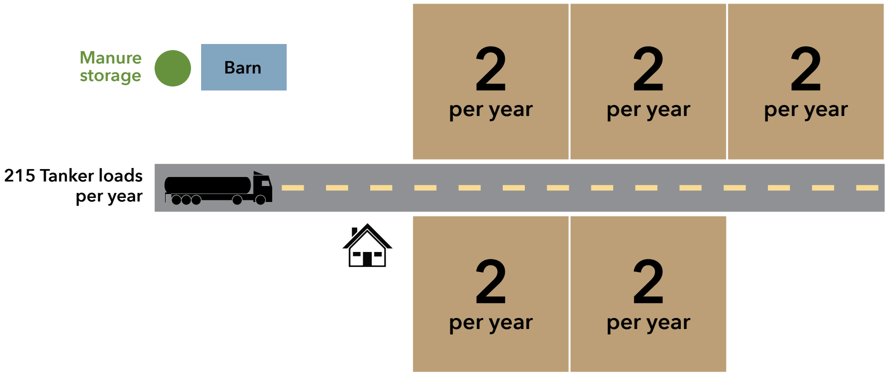
Potential Impacts to Application and Transport– with 600 Cow Example

Assume the same 600 cow dairy in the example above hauls a portion of their manure to five fields that are each 40 acres (square parcels 1,320 feet by 1,320 feet). If using a conventional manure application system, assuming a tanker hauling 8,000 gallons of manure per trip and an application rate of 8,600 gallons per acre, then 215 truck-tanker loads per year would be required to transport the manure to these five fields. These tankers would concentrate manure application during two periods each year, one manure application during spring and an application during the fall.

As illustrated in Figure 4b-1, manure irrigation would change the transport situation. If one center pivot system was added on one of these fields, each field would still receive the same amount of manure nutrients (as dictated by a nutrient management plan). As solids separation is required to reach the low solids content necessary for irrigation systems, the volume of manure applied to each field would change. Looking at the same five fields, the field with the center pivot system would receive four applications per year of more dilute liquid manure (fewer nutrients per gallon). Two of the five fields would now receive one application of solid manure each year (spring or fall) with higher nutrient density. Two fields would have no change in manure application and would receive one application in the spring and one in the fall. In this scenario, a manure pipeline would be used to transport the liquid manure to the center pivot, reducing 86 tanker loads for a total of 129 tankers per year (assuming the total manure volume remains constant before and after separation and a solid spreader holds the same volume as the liquid tanker).

This example simply illustrates one way of many that manure could be redistributed with the addition of manure irrigation. Although manure transport and application are altered, the total nutrients applied will not change. Additionally, as highlighted by the circle around the house in Figure 4b-1, different setbacks apply (as with a dwelling) when using manure irrigation systems, which influence system placement. Recommendations for setbacks and other operational guidelines are described in the next section.

Manure Applications with Conventional Methods



Manure Applications with Conventional Methods & Irrigation

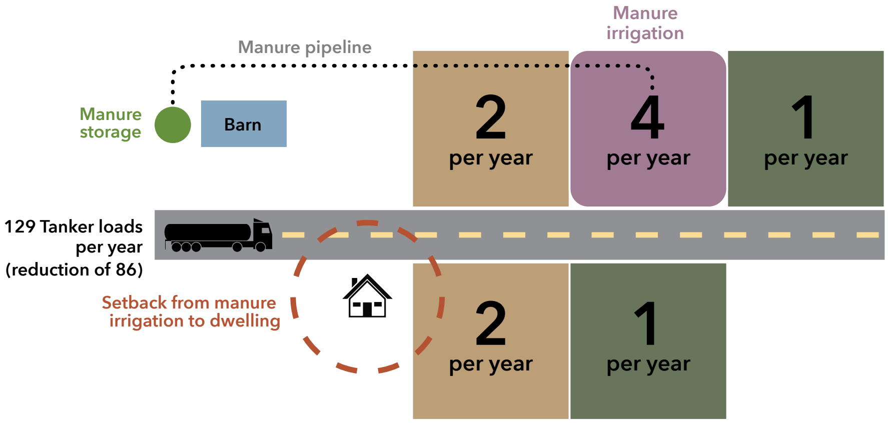


Figure 4b-1 Differences in field application of manure with irrigation and without

5. Workgroup Response and Recommendations

The Manure Irrigation Workgroup formed to review a broad set of issues associated with manure irrigation and to develop guidance and recommendations for state agencies, local governments, and citizens seeking to understand this expanding technology. As outlined in Chapter 1 of this report, the workgroup met over approximately two-and-a-half years to fulfill its charge. The group primarily reviewed and vetted information and held lengthy discussions around issues of public health, risk, dairy and livestock management, rural land use conflict, and the set of issues in Chapter 3. The opportunity for the workgroup to engage with and include researchers conducting the QMRA study (Appendix C) offered unique insights into the issues involved as well as the strengths and limitations of that study. Although much of the information compiled for this report is based in well-established science, research on a number of issues specifically associated with manure irrigation is incomplete or inconclusive. This includes research regarding environmental fate and transport of hormones and the potential for antibiotic resistance associated with livestock management. While the group did not have access to resources to conduct new studies, all of those issues were discussed to some extent. Section 5a below revisits the main issues identified for the workgroup agenda at the outset of this process, and Section 5b presents recommendations based on areas of agreement among workgroup members.

5.a Responses to expressed concerns and potential benefits

1. Public health risk from airborne pathogens and other contaminants

There are public health risks related to the use of manure irrigation. Although not all of these risks were quantified, research revealed that manure irrigation practices can be managed to reduce these risks associated with the most pathogenic microbes found in manure below common thresholds used for public health. The study found that reducing the pathogen prevalence in manure and limiting exposure pathways were also effective in reducing health risks associated with acute gastrointestinal illness. Risk of exposure can be minimized by applying setback distances as reported in the study, but also by applying manure at low wind speeds, using physical barriers, or applying manure closer to the ground, among other actions. Reducing prevalence can be accomplished through herd health management or destruction of pathogens using processing systems (e.g., anaerobic digestion or pasteurization) or by applying manure when environmental conditions result in microbial inactivation.

The research summary in Appendix C provides risk estimates at specific setback distances for a given pathogen prevalence and concentration. Throughout, the study team emphasized that whenever they faced a choice regarding input for the analytical model (see Figure C-4 in Appendix C), they chose the option that would be more conservative toward public health. For example, for each of the millions of simulations behind the QMRA results, the study assumed a person would remain at a constant distance from the wetted perimeter (e.g., 100 feet, 500 feet, etc.) for the entire time they were outdoors; for cumulative risk exposure (Figure C-9, Appendix C), the analysis assumed constant exposure and constant distance, which are both additional conservative assumptions. Therefore the study results modeling 100 percent pathogen prevalence can be viewed as a conservative worst-case scenario; use of practices to reduce prevalence and concentrations of pathogens can reduce public health risk below this threshold.

Uncertainties about transport and exposure for other contaminants remain and are likely associated with operation management. The QMRA study did not (and could not) include every pathogen and contaminant potentially present in livestock manure, however it did analyze pathogens commonly found in dairy manure (see Table C-1 in Appendix C and Table 2a-1 in the report). The study broke new ground in quantifying risk from manure irrigation (both in measurement and analysis), and it helped narrow the band of calculated risk estimates compared to any previous research. Those results and the multiple conservative assumptions were important elements of workgroup discussion and influenced the recommendations below. Additional factors expected to limit or exacerbate airborne pathogen risk are listed in Table 3e-2.

2. Drift

Drift of irrigated manure could occur with sufficient wind and droplet sizes prone to drift. Several management actions can be taken to minimize and prevent drift. A more detailed discussion of drift is included in Section 3a, including a list of conditions expected to limit drift or exacerbate risk of drift in Table 3a-1.

3. Odor and other quality of life concerns

Concerns about odor and negative impacts to quality of life from manure irrigation practices were among the strongest expressed to the workgroup and will undoubtedly be central to future public policy discussions around this issue. Odor and factors expected to limit or exacerbate its impact are discussed in some detail in Section 3b. Broader quality of life issues were raised in multiple workgroup discussions and presentations, but given the many individual experiences and perspectives that are encompassed by quality of life along with landscape and community variations across Wisconsin, the workgroup found it difficult to discuss the issue objectively or reach consensus.

Certainly concerns about severe personal hardship resonated with workgroup members, including testimonials shared with the workgroup about effects of nearby manure irrigation on adjacent homeowners. The reports mentioned in Section 3b illustrate those concerns. One of the very challenging points in discussing potential setback distances from dwellings or occupied buildings centered around whether the distances could be reduced (under various conditions) with permission of the owner or the building occupants. The question raised concerns about inequities and power imbalances, including if the occupant was a residential owner or renter and their status relative to neighboring landowners and the community. Although many quality of life issues are not addressed explicitly, the issues surrounding quality of life were discussed throughout the process and the recommendations below are intended to minimize or eliminate negative quality of life impacts if manure irrigation practices are used.

4. Surface water quality contamination

Interactions between manure irrigation and surface water quality are discussed in Section 3c. As with all forms of manure application, if not managed correctly, manure irrigation could lead to surface water contamination from runoff. Yet, manure irrigation, when compared to conventional manure application methods, also has the potential to reduce risk of surface water contamination by opening a longer time frame for applying manure to avoid application periods when increased runoff is expected, increasing infiltration due to the dilute nature of the manure, and reducing application volumes applied during each application period. As noted in Section 3c, it also has potential for over-application if used without supervision.

5. Groundwater quality contamination

Similar to surface water, if not managed correctly in sensitive areas, manure irrigation applications could lead to groundwater contamination. However, a series of smaller/lower-rate applications using manure irrigation systems during the growing season and at times of peak crop need can increase nutrient uptake by plants and provide more effective holding capacity in the upper soil surface layers, both of which would reduce the potential for leaching of nutrients and other contaminants to groundwater. Interactions between manure irrigation and groundwater quality are discussed in Section 3c.

6. Groundwater quantity concerns

At the outset of workgroup activities, concerns were raised that manure irrigation would lead to increased pumping of groundwater to dilute manure for irrigation or simply to take advantage of irrigation equipment. The workgroup did not determine if manure irrigation would have a negative impact on groundwater quantity due to additional pumping for dilution of manure during application. However, the practice may reduce groundwater use if liquid manure could be applied to crops in a system which would otherwise use groundwater.

7. Implementation and compliance issues

Concerns about the ability of farmers to implement required actions and the capacity for regulators to monitor compliance are common and well-justified. Those concerns are reinforced and magnified by broadly circulated real examples of non-compliance that have led to harm. Implementation issues were discussed throughout manure irrigation workgroup meetings, including interactions with a nationally recognized speaker on the issue at an April 2014 workgroup meeting. Ongoing conversations in Wisconsin around challenges of monitoring, compliance, and enforcement associated with livestock agriculture have been a consistent part of the context for workgroup meetings and were an important factor in developing recommendations.

These concerns are expected to continue, and they highlight the importance of effective working relationships among those using manure irrigation, their neighbors and communities, and those working with producers on both voluntary and regulatory programs.

8. Timing of manure application

The ability to apply manure nutrients to a growing crop at a time when the crop is most likely to use the nutrients is a clear benefit from manure irrigation practices. This flexibility allows for application during summer months instead of typical application in spring or fall. Application throughout the season may reduce nutrient losses as more nutrients may be used by the crop leaving less available for potential loss to the environment. In addition, using manure irrigation may interrupt common routes affecting nutrient losses to the environment during spring and fall application periods. More information about timing issues is included in Section 3f.

9. Road safety and reduced road damage

Shifting manure transport from practices requiring road use into piped distribution systems reduces the number of manure vehicle trips on the roads. In addition, the reduction of manure related traffic during common manure hauling periods may further reduce road damage as those periods correspond to times when the weather can increase risk for damage. More information about this issue is available from the Implements of Husbandry Report mentioned in Section 3f. Given the geographic distribution of fields used for manure application by a single livestock operation, implementing manure irrigation will not eliminate the use of manure tankers and trucks. However, as illustrated in Section 4, it can reduce the amount of manure transported on the roads. It should be noted that piped distribution systems can be used with other manure application methods (separate from manure irrigation), and the benefits could be achieved with other application systems.

10. Farm management and economic benefits

Manure irrigation increases flexibility for manure management. In combination with other system components for manure processing and storage, producers using manure irrigation practices can manage nutrients more precisely to meet crop needs over time. Although those system components involve high initial capital costs, multiple dilute applications of manure through manure irrigation methods may reduce individual application costs, compared to conventional methods. Additional information about these components is included in Sections 2a and 2b, and more about the farm management and economic benefits associated with manure irrigation is found in Section 3g and Chapter 4.

5b. Recommendations

Consistent with the original ground-rules established by the workgroup, all decisions were consensus seeking. Consensus was defined as unanimous agreement among workgroup members that they could "live with" whatever item was being presented for a decision. When consensus was not possible, the group also used "near consensus" to establish a very high level of agreement (one or two not agreeing), "close to near consensus" (a few not agreeing), and "no agreement" when there was broad disagreement. Leading up to the final meeting, the workgroup had reached multiple consensus agreements around baseline conditions for the use of manure irrigation. As the most challenging issues around setback distances were presented for decisions at the final workgroup meeting, the group relied on the near consensus, close to near consensus, and no agreement measures.

When items were discussed and presented for a decision, those who could not agree with the set of conditions being discussed were asked what, if anything, could change their position. If something could be adjusted, the adjusted conditions would be presented until those adjustments led other people to change from agreement to disagreement, all the while seeking the highest level of agreement possible. Because of the workgroup charge to better understand issues related to manure irrigation and to provide information and recommendations to other stakeholders for their own decision-making, this summary is reporting on general levels of agreement among diverse workgroup perspectives rather than vote counts.

Consensus Baseline Recommendations

As stated throughout this report, the recommendations proposed by the workgroup are intended to inform decisions by state bodies and local governments. They carry no authority. Rather, they represent the deliberations and perspectives of a diverse set of interests and experts who invested their time to review these issues in an effort to understand the balance of potential benefits and concerns about manure irrigation.

All manure irrigation applications. In all cases, if manure irrigation practices are to be used, operators must:

- Follow all existing relevant state and local laws regarding animal waste and nutrient management
- Have and follow a NRCS CPS 590 NMP
- Take appropriate steps to minimize drift
- Ensure no overspray of irrigated manure
- Have suitable means of supervising/controlling the equipment (e.g., active supervision, automatic sensors/controls, etc.)
- Have suitable means of determining relevant weather information (to include: wind speed, wind direction, and temperature)
- Have means of preventing contaminated backflow if equipment is connected to water sources.
- Ensure that no human waste or septage is added to (or processed with) the manure.
- Wind-speed will be determined as a 15-minute mean measurement on the field.
- Drop nozzles on the center pivot.
- Nozzles and operating pressures selected to provide "coarse" or larger droplet sizes (based on ANSI/ASAE classifications, see Figure 3a-1)).
- Apply all materials and abide by all setbacks in accordance with an approved NRCS CPS 590 NMP

- No more than 8 irrigation applications to any given field per growing season (potential to increase if manure is treated using accepted pathogen reduction technologies*).

*Treated refers to additional manure processing, including but not limited to:

- Digestion meeting NRCS Standard 366 – Anaerobic Digester, combined with solids separation to 2% solids or less.
- Digestion with a Hydraulic Retention Time (HRT) ≥ 25 days at 100°F or a HRT ≥ 5 days at 140°F.
- Pasteurization to reduce bacterial levels by a minimum of 75%.
- Aeration to 2 mg/l oxygen concentration.
- Flocculation using polymers to 1% solids or less.
- The workgroup recognized that if acceptable testing and sampling protocols were to be developed in the future, then testing that demonstrated acceptable results at time of application could substitute for treatment.

Note: There were several discussions about the similarities between traveling gun and end gun mounted to a center pivot boom, but no decisions made regarding recommendations for end gun use.

Recommendations for Setback Distances

Given the many factors involved, the workgroup did not reach full consensus on recommendations for setback distances from various land uses and property types. In one case, the group did reach consensus, and for several situations, the group reached near consensus or close to near consensus. These areas of agreement around setback distances assume that all baseline recommendations listed above would be in place in addition to the setback distances. If a dwelling or occupied building is present, then setback distance to a dwelling/occupied building would take priority over distance to a property line. As noted above, during the discussion various conditions were added or removed in attempts to reach higher levels of agreement. When consensus was not reached, it was either because the conditions had become too restrictive or not restrictive enough from the perspective of workgroup members.

Before presenting further recommendations, it is important to clarify two terms used as part of the recommendations: wetted perimeter and setback distance. **The wetted perimeter** is the outer edge of the area receiving liquid manure through irrigation equipment. Figure 5-1 shows an illustration of the wetted perimeter for traveling gun and center pivot equipment. For a center pivot using an end-gun for field corners, the wetted perimeter would be a square rather than a circle. **The setback distance** is the minimum distance between the wetted perimeter of irrigation and the item or land use in question. Figure 5-2 illustrates the setback distance between the outside of a house and the wetted perimeter for a traveling gun application.

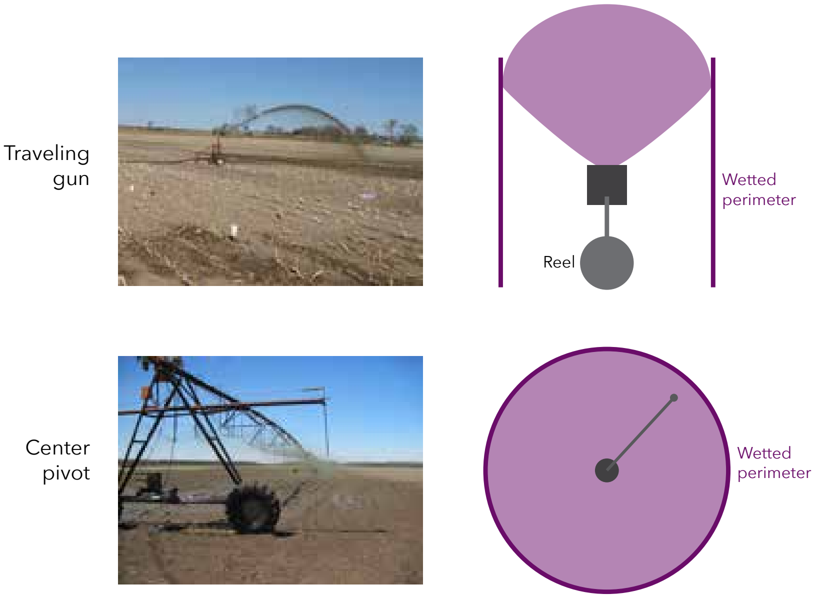


Figure 5-1. Wetted perimeter

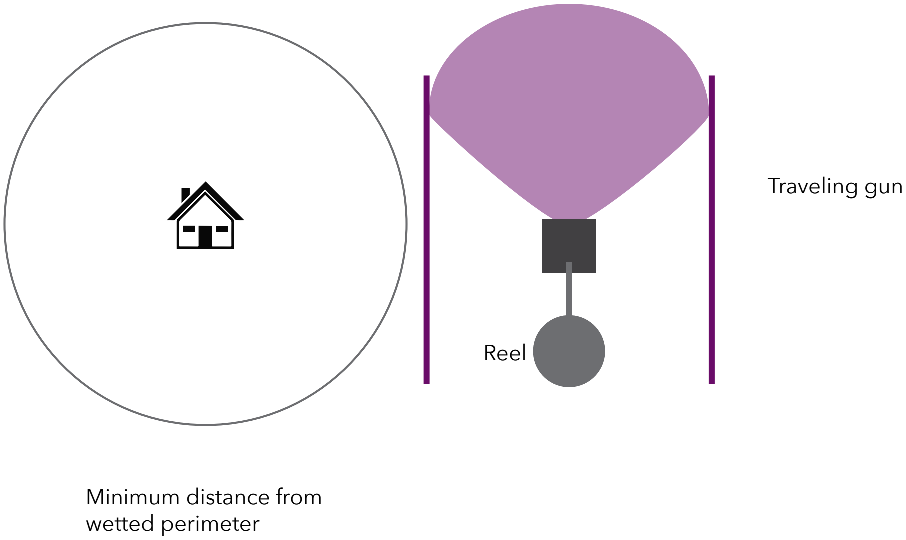


Figure 5-2. Setback distance

Setback: Forests

For application near **the property line for public forest land with no recreational access,** (e.g., county or state lands without forest recreation or trails), there was **consensus** for a setback distance of **0 feet,** with no additional conditions.

For application near **the property line for private forest land,** there was **near consensus** for a setback distance of **0 feet,** with no additional conditions. The differences between the two had to do with potential inadvertent recreational contact for private lands.

0 feet: public forests with no recreational access (Consensus)

0 feet: private forests (Near consensus)

Figure 5-3a: Forests

Setback: Adjacent agricultural lands

For application near **the property line for pasture land (that is used as pasture),** there was **near consensus** for a setback distance of **0 feet,** with no additional conditions. There was **no agreement** for any additional restrictions near pastureland.

For application near **the property line for cropland owned by others,** there was **near consensus** for a setback distance of **0 feet,** under the condition that the adjacent cropland was not used to produce organic or raw consumed crops. There was **close to near agreement** for setback distances of 0 feet and 50 feet regardless of the crop grown on adjacent cropland.

0 feet: pastures (Near consensus)

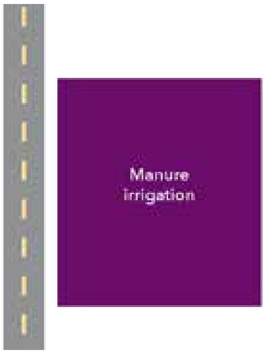
0 feet: crops if not organic or raw consumed (Near consensus)

0 feet: any crop (Close to near consensus)

Figure 5-3b: Adjacent agricultural lands

Setback: Road right of way

For application near **the property line for a road Right-of-Way,** for all types of roads, ranging from rural roads to interstate highways, there was **near consensus** for a setback distance of **0 feet,** with no additional conditions.

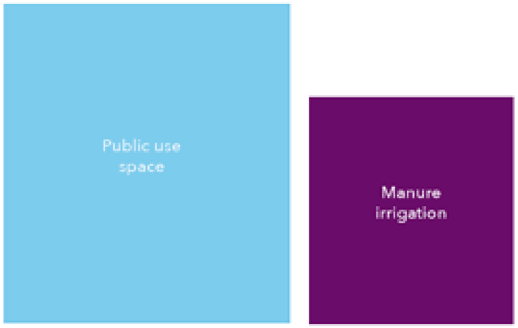


0 feet: all types of roads and highways (Near consensus)

Figure 5-3c: Road right of way line

Setback: Property line for public recreational area, school, or playground

For application near **the property line for a school, playground, or public recreation area,** there was **near consensus** for a setback distance of **100 feet, under the following conditions:** wind-speed ≤ 10 mph, wind direction parallel or away from the property line. There was **no agreement** for other conditions at 100 feet or for distances < 100 feet or > 100 feet under various conditions



100 feet: if wind-speed ≤ 10 mph AND wind blowing parallel or away from property line (Near Consensus)

Figure 5-3d: Property line for public recreational area, school, or playground

Setback: Dwelling or occupied building

The workgroup reached some level of agreement for setback distances of 750, 500, and 250 feet from dwellings and occupied buildings, when applications occur during daylight hours and assuming that all baseline recommendations are in place.

500-750 feet: depending on wind speed and direction conditions (Near consensus)

250 feet: with additional conditions (Close to near consensus)

Figure 5-3b: Adjacent agricultural lands

At 750 feet from wetted perimeter to building, the group reached **near consensus** for each of the following sets of conditions (independent of one another):

- 750 feet with no wind-speed restrictions regardless of wind direction (near consensus)
- 750 feet with wind-speed ≤ 10 mph regardless of wind direction (near consensus)
- 750 feet with wind-speed ≤ 15 mph regardless of wind direction (near consensus)

At 500 feet from wetted perimeter to building, the group reached **near consensus** for each of the following sets of conditions (independent of one another):

- no wind-speed restrictions if wind direction is parallel to or away from the building (near consensus)
- wind-speed ≤10 mph regardless of wind direction (near consensus)

At 250 feet from wetted perimeter to building, the workgroup **did not reach consensus or near consensus** for any combination of practices. **At 250 feet** from wetted perimeter to building, there was **close to near consensus** on each of the following sets of conditions (independent of one another):

- Manure is treated to reduce pathogens (or tested to document pathogen levels similar to those resulting from other practices described previously), wind speed ≤ 10 mph, wind direction is parallel to or away from building (close to near consensus).
- Permission is granted by the building occupant (close to near consensus).
- Permission granted by the building occupant and wind speed ≤ 10 mph regardless of wind direction (close to near consensus).

The workgroup did not reach any level of agreement on recommendations for conditions at distances less than 250 feet to dwellings/occupied buildings. In other words, there was broad disagreement about any distance of less than 250 feet to a dwelling or occupied building.

Recommendations for Manure Irrigation during night-time hours:

Workgroup discussions around night-time use of manure irrigation practices raised both potential benefits and potential concerns. Benefits centered around potential for lower wind-speeds and therefore less drift. It was also thought that potential benefits included less impact to neighbors for odor and pathogen inhalation as they are less likely to be outdoors during these times. Concerns included loss of potential for microbial inactivation from ultraviolet light, and the possibility that a wind speed of zero could prevent microbial inactivation from dispersion. There were also concerns about the logistics of monitoring night-time application to ensure proper system function, proper system monitoring, and proper application to intended areas as suggested in the baseline recommendations.

For application during night-time hours (if all consensus baseline recommendations are in place), the workgroup reached **near consensus** for allowing night-time application using the same setbacks as daytime application, under the following conditions: manure is treated or tested following accepted protocol, the wind speed is ≥ 2 mph and ≤ 10 mph, and wind direction is parallel or away from the building or property line.

The group reached **close to near consensus** for allowing night-time application using the same setbacks as daytime application, under the following conditions (independent of one another):

- manure is treated or tested following accepted protocol and the wind speed is ≥ 2 mph and ≤ 10 mph; or
- manure is treated or tested following accepted protocol, the wind speed is ≥ 4 mph and ≤ 10 mph, and wind direction is parallel or away from the building or property line.

There was **no agreement** that night-time application should be allowed with only treatment, and there was re-affirmation of a previous baseline recommendation consensus decision that untreated manure should not be applied at night using irrigation practices, where untreated refers to manure considered raw or processes only through physical separation (see * above).

Other Issues and levels of agreement

There was **near consensus *against*** a proposal to recommend a 3-mile setback from any public recreation areas or commercial businesses for odor control, with provisions for reducing setback with permission of business owners.

For dwellings, several combinations of conditions were rejected by the workgroup. At 250 feet and 500 feet there was **no agreement** on the following sets of conditions:

- At both 500 feet and 250 feet, there was **no agreement** on allowing use with no restrictions for application at this distance.

- At both 500 feet and 250 feet, there was **no agreement** on requiring manure treatment or testing required for application via irrigation with no other conditions.
- At 500 feet, there was **no agreement** on requiring manure treatment or testing and wind-speed ≤ 10 mph with no other conditions
- At 500 feet, there was **no agreement** on requiring manure treatment or testing and wind-speed ≤ 15 mph with no other conditions
- At 250 feet, there was **no agreement** on a requirement for wind-speed ≤ 10 mph regardless of wind direction, with no other conditions.
- At 250 feet, there was **no agreement** on a requirement wind-speed ≤ 10 mph regardless of wind direction if manure treated or tested.
- At 250 feet, there was **no agreement** on a requirement for wind direction to be parallel to or away from building, with no other restrictions.

Beyond those areas of disagreement, the workgroup reached consensus or near consensus on multiple situations for which manure irrigation could be an appropriate tool for manure management. All of the recommendations were discussed and developed with the intention of informing local and state policy decisions by providing a measure of agreement among broad and diverse perspectives on the issue of manure irrigation. The workgroup consistently emphasized its lack of authority to act on the recommendations. Any additional public deliberation to occur in the context of decisions by elected and administrative officials at local and state levels. Workgroup discussions also emphasized the benefits and importance of good neighbor considerations, such as those for odor in Section 3b, along with all other recommendations when using manure irrigation practices.

Appendix A: Nutrient Content in Manure

Table A-1. Nitrogen and dry matter composition of dairy and swine manure samples analyzed in Wisconsin from 1998 to 2012.

		Maximum	75th percentile	50th percentile[†]	25th percentile	Minimum	Mean	Standard deviation of Mean	Standard Error of Mean	N[‡]
Dairy, liquid	Total N, lb/1,000 gal	108.8	18.2	14.5	10.3	0.2	14.1	6.6	0.2	1505
	NH4-N, lb/1,000 gal	55.7	10.0	8.5	6.5	1.1	8.7	4.2	0.2	289
	NH4-N/Total N, % *	130.4	64.5	58.3	45.8	7.8	56.9	13.6	0.8	289
	Dry Matter, %	4.0	3.4	2.5	1.6	0.1	2.4	1.1	0.0	1505
Dairy, slurry	Total N, lb/1,000 gal	283.1	27.5	23.1	20.4	1.7	24.2	8.9	0.2	1695
	NH4-N, lb/1,000 gal	36.8	13.7	11.1	9.5	0.1	11.3	4.5	0.3	217
	NH4/Total N, %	117.6	53.2	46.6	39.0	1.9	46.1	14.0	0.9	217
	Dry Matter, %	11.0	8.1	6.3	5.0	4.1	6.7	1.9	0.0	1695
Dairy, semi-solid	Total N, lb/1,000 gal	71.6	9.6	8.0	6.7	0.0	8.3	3.3	0.1	1196
	NH4-N, lb/1,000 gal	5.4	3.5	2.6	2.1	0.0	2.7	1.1	0.1	154
	NH4/Total N, %	83.3	48.0	38.7	28.6	0.0	37.6	15.8	1.3	154
	Dry Matter, %	20.0	17.5	15.3	13.4	11.1	15.4	2.5	0.1	1196
Dairy, solid	Total N, lb/1,000 gal	78.5	13.0	9.2	7.0	0.2	11.0	7.0	0.2	1709
	NH4-N, lb/1,000 gal	51.0	2.5	1.8	1.1	0.0	2.1	3.2	0.2	411
	NH4/Total N, %	820.9	32.1	23.1	16.5	0.0	26.0	43.2	2.1	411
	Dry Matter, %	99.4	41.3	29.4	23.9	20.1	36.7	18.8	0.5	1709
Swine-farrow, liquid	Total N, lb/1,000 gal	42.7	22.5	16.7	9.7	0.6	16.3	8.7	0.8	117
	NH4-N, lb/1,000 gal	32.6	19.1	16.4	10.3	2.5	15.3	6.2	1.0	42
	NH4/Total N, %	99.7	86.6	76.7	70.6	43.0	77.5	10.8	1.7	42
	Dry Matter, %	4.0	1.9	1.0	0.5	0.1	1.3	1.0	0.1	117

Table continued on following page.

Table A-1. continued

		Maximum	75th percentile	50th percentile†	25th percentile	Minimum	Mean	Standard deviation of Mean	Standard Error of Mean	N ‡
Swine-farrow, slurry		No data fewer than 25 samples								
Swine-finish-indoor, liquid	Total N, lb/1,000 gal	78.1	38.3	29.2	18.6	1.8	28.3	12.3	0.7	346
	NH4-N, lb/1,000 gal	42.8	28.4	22.5	13.9	2.5	21.6	9.8	1.1	74
	NH4/Total N, %	95.2	85.0	79.6	74.1	26.9	78.5	10.6	1.2	74
	Dry Matter, %	4.0	3.3	2.5	1.4	0.1	2.4	1.1	0.1	346
Swine-finish-indoor, slurry	Total N, lb/1,000 gal	89.1	57.8	52.5	45.7	22.9	52.1	9.9	0.5	405
	NH4-N, lb/1,000 gal	59.7	43.2	39.6	33.1	6.4	37.9	8.9	0.8	111
	NH4/Total N, %	89.3	76.8	72.4	68.5	13.9	70.4	11.6	1.1	111
	Dry Matter, %	11.0	8.1	6.3	5.1	4.1	6.7	1.9	0.1	405
Swine-finish-outdoor, liquid	Total N, lb/1,000 gal	51.5	27.4	16.4	6.9	0.9	18.1	12.7	0.9	180
	NH4-N, lb/1,000 gal	44.8	28.1	12.8	4.6	1.5	16.3	13.4	2.0	47
	NH4/Total N, %	96.1	85.8	76.0	65.5	25.5	73.7	15.8	2.3	47
	Dry Matter, %	4.0	2.4	1.3	0.4	0.1	1.5	1.2	0.1	180
Swine-finish-outdoor, slurry	Total N, lb/1,000 gal	74.6	62.1	54.1	46.1	19.7	53.1	12.6	1.4	78
	NH4-N, lb/1,000 gal	61.6	56.9	42.9	40.4	25.8	46.1	9.4	1.5	37
	NH4/Total N, %	91.7	85.6	78.6	73.6	63.2	79.0	7.2	1.2	37
	Dry Matter, %	11.0	8.0	6.9	5.5	4.1	6.8	1.7	0.2	78

(Source: C. Laboski. UW-Madison, Department of Soil Science.)

† The 50th percentile is the median. For data like this, the median is a better measure of central tendency than the mean because it is not influenced by unusually high or low values.

‡ N is the number of samples analyzed.

* NH_4-N/Total N is the percentage of total N that is NH_4-N. Not every sample had NH_4-N analyzed. This was calculated using only the samples where NH_4-N and Total N were analyzed.

Table A-2. Daily manure production and characteristics, as-excreted

Animal	Size (lbs)	(lb/day)	Total manure (ft3/day) (gal/day)	Water (%)	Density (lb/ft3)	Nutrient content (lb/day) (N) (P2O5) (K2O)
Dairy cattle	150	13	0.20 1.5	88	65	0.05 0.01 0.04
Dairy cattle	250	21	0.32 2.4	88	65	0.08 0.02 0.07
Heifer	750	65	1.0 7.8	88	65	0.23 0.07 0.22
Lactating cow	1,000	106	1.7 12.7	88	62	0.58 0.30 0.31
Lactating cow	1,400	148	2.4 17.7	88	62	0.82 0.42 0.48
Dry cow	1,000	82	1.30 9.7	88	62	0.36 0.11 0.28
Dry cow	1,400	115	1.82 13.6	88	62	0.50 0.20 0.40
Veal	250	9	0.14 1.1	96	62	0.04 0.03 0.06
Beef cattle Calf	450	26	0.42 3.1	92	63	0.14 0.10 0.11
High forage	750	62	1.0 7.5	92	62	0.41 0.14 0.25
High forage	1,100	92	1.4 11.0	92	62	0.61 0.21 0.36
High energy	750	54	0.87 6.5	92	62	0.38 0.14 0.22
High energy	1,100	80	1.26 9.5	92	62	0.54 0.21 0.32
Cow	1,000	63	1.00 7.5	88	63	0.31 0.19 0.26
Swine						
Nursery	25	2.7	0.04 0.3	89	62	0.02 0.01 0.01
Grow-Finish	150	9.5	0.15 1.2	89	62	0.08 0.05 0.04
Gestating	275	7.5	0.12 0.9	91	62	0.05 0.04 0.04
Lactating	375	22.5	0.36 2.7	90	63	0.18 0.13 0.14
Boar	350	7.2	0.12 0.9	91	62	0.05 0.04 0.04

Table continued on following page.

Table A-2. continued

Animal	Size (lbs)	(lb/day)	Total manure (ft3/day) (gal/day)	Water (%)	Density (lb/ft3)	Nutrient content (lb/day) (N) (P2O5) (K2O)
Sheep	100	4.0	0.06 0.4	75	63	0.04 0.02 0.04
Poultry Layer	4	0.26	0.004 0.031	75	65	0.0035 0.0027 0.0016
Broiler	2	0.18	0.003 0.021	74	63	0.0023 0.0014 0.0011
Turkey	20	0.90	0.014 0.108	75	63	0.0126 0.0108 0.0054
Duck	6	0.33	0.005 0.040	73	62	0.0046 0.0038 0.0028
Horse	1,000	50	0.80 5.98	78	63	0.28 0.11 0.23

(Source: Manure Characteristics MWPS-18 Manure Management Systems Series, December 2000)

Values are as-produced estimations and do not reflect any treatment. Values do not include bedding. The actual characteristics of manure can vary ± 30% from table values. Increase solids and nutrients by 4% for each 1% feed wasted above 5%

*Weights represent the average size of the animal during the stage of production.

Appendix B: Manure Irrigation Information from Other States

Wisconsin DNR staff contacted state agency staff that regulate animal feeding operations (AFOs) in other states. Contacts were made by email or telephone during 2012-2013. Each state contacted was asked about the extent of manure irrigation use in that state, extent of complaints received by the agency about the practice, and any regulations regarding setbacks or other requirements. The USEPA Region 5 office works with Wisconsin state agencies and local governments to implement regulatory and non-regulatory programs related to water quality and public and environmental health. Results are included below grouped by states within Wisconsin's same USEPA region and outside of that USEPA region.

<u>States in the same USEPA region as Wisconsin (Region 5):</u>

Illinois

- **Extent of Manure Irrigation Use:** Manure irrigation is limited to a few farms. Permanent pivots and mobile guns are used.
- **Complaints:** Complaints received by agency primarily focus on odor. Fecal drift does not appear to be a large issue.
- **Setbacks/Other Requirements:**
  - Dept. of Ag rule requires a 1/4 mile (1320 feet) setback from any residence for spray irrigation, except if the operation was doing it before 1997, they are exempt from the setback, or if they are spreading on frozen or snow-covered ground, they are exempt.
  - *Illinois Waste Management Plan Regulations*
    - Livestock waste applied within ¼ mile of any residence not part of the facility shall be injected or incorporated on the day of application. However, livestock management facilities and livestock waste handling facilities that have irrigation systems in operation prior to May 21, 1996, or existing facilities applying waste on frozen ground, are not subject to the provisions of this subsection (o) [510 ILCS 77/20 (f)(5)];
    - Livestock waste may not be applied within 200 feet of surface water unless the water is upgrade or there is adequate diking and waste will not be applied within 150 feet of potable water supply wells [510 ILCS 77/20(f)(6)];
    - Livestock waste may not be applied in a 10-year flood plain unless the injection or incorporation method of application is used [510 ILCS 77/20(f)(7)];
    - Livestock waste may not be applied in waterways. [510 ILCS 77/20(f) - for the purposes of this Part, a grassed area serving as a waterway may receive livestock waste through an irrigation system if there is no runoff, the distance from applied livestock waste to surface water is greater than 200 feet, the distance from applied livestock waste to potable water supply wells is greater than 150 feet; the distance from applied livestock waste to a non-potable well, an abandoned or plugged well, a drainage

well, or an injection well is greater than 100 feet; and precipitation is not expected within 24 hours

- **For more information:**
  - *http://web.extension.illinois.edu/clmt/pdf/rules_il-manure-plan-rules.pdf*
  - *http://web.extension.illinois.edu/sfmm/dairy.cfm*
  - *http://www.epa.state.il.us/water/cafo/*

Indiana

- **Extent of Manure Irrigation Use:** No response on number of farms using manure irrigation or equipment types.
- **Complaints**: As of the review, the staff responding reported that no complaints had been received by the agency related to manure irrigation (e.g., odors, drift, health impacts).
- **Setbacks/Other Requirements:** No specific manure irrigation setbacks. 100 ft setbacks for surface waters, conduits to surface waters, tile inlets, wells, sinkholes (same as Federal CAFO requirements or department approved alternative). 10 foot setbacks when vegetative buffer established. No application allowed within grassed waterways or swales that are conduits to surface waters
- **For more information:** Indiana CAFO permit: *http://www.in.gov/legislative/iac/T03270/A00160.PDF* - page 27 setbacks

Michigan

- **Extent of Manure Irrigation Use:** Only a few CAFO's use manure irrigation (permanent center pivots).
- **Complaints:** Complaints received by the agency for manure irrigation as well as other methods of manure application include: odors, flies, hydrogen sulfide poisoning, drift. No confirmation of chronic or acute public health impacts from complaint investigations.
- **Setbacks/Other Requirements:** No specific manure irrigation setbacks. 100 ft Setbacks for surface waters, conduits to surface waters, tile inlets, wells, and sinkholes -(same as Federal CAFO requirements or department approved alternative). 35 foot setbacks when vegetative buffer established. No application within grassed waterways or swales that are conduits to surface waters
- **For more information:** *http://www.michigan.gov/documents/deq/wb-npdes-cafo-generalpermit-MIG019000-2010_316373_7.pdf*

Minnesota

- **Extent of Manure Irrigation Use:** Only a few CAFO's use manure irrigation method; permanent pivots and mobile guns are used.
- **Complaints:** No complaints received by the agency related to manure irrigation (e.g., odors, drift, health impacts).
- **Setbacks/Other Requirements:**
  - 10 counties in MN have passed ordinances prohibiting spray irrigation (permanent or mobile) and at least 9 other counties have ordinances that do not directly ban spray irrigation, but instead require mechanical incorporation of manure within 24 hrs.
  - CAFO's have specific spray irrigation manure setbacks: For CAFOs, no surface application within 300ft of lakes, streams, intermittent streams, wetlands, waterways w/o berms, wells.

    - Smaller farms also have spray irrigation setbacks (cant spray wider than 50ft within special protection areas (e.g. Lakes streams, intermittent streams, wetlands, waterways w/o berms, wells). If spray is less than 50ft spray irrigation allowed in special protection areas.
- **For more information:** *http://www.pca.state.mn.us/index.php/view-document.html?gid=3530*

Ohio

- **Extent of Manure Irrigation Use:** Manure irrigation is limited to a few farms. Permanent pivots and mobile guns are used.
- **Complaints:** Limited number of manure irrigation complaints received by the agency. Fecal drift does not appear to be a large issue (odor is the issue).
- **Setbacks/Other Requirements:**
    - Required setbacks specify distances from various water and land features (e.g. wells) to be followed when land-applying manure application methods. The setbacks range from 100 feet to 300 feet.
    - Land application restrictions also specify considerations for determining the appropriate timing, location, and methods for land application of manure, including considerations for soil types and field conditions, weather conditions and seasonal considerations, location of subsurface tile drains, and the like. Part VII of individual permits [PDF 113K] contain the standard language CAFOs must comply with.
- **For more information:**
    - *http://epa.ohio.gov/dsw/cafo/land_app.aspx*
    - *http://epa.ohio.gov/Portals/35/cafo/CAFO_NPDES_PARTVII.pdf*
    - *http://www.lakeimprovement.com/sites/default/files/manure-management-guide.pdf.* See pages 54-57, 82-84, 96-97, and 110 for manure irrigation and pathogen information

Other States

Idaho

- **Extent of Manure Irrigation Use:** No information provided.
- **Complaints:** No information provided.
- **Setbacks/Other Requirements:** No information provided.
- **For more information:**
    - Wastewater Irrigation Guidelines: *https://www.deq.idaho.gov/media/529643-microbial_risk_assessment.pdf*

Iowa

- **Extent of Manure Irrigation Use:** Some confinement feeding operations use manure irrigation method; permanent pivots and mobile guns are used.
- **Complaints:** Complaints related to odors, drift, concerns about health have been received. Public health impacts have not been confirmed.
- **Setbacks/Other Requirements:** Manure irrigation requirements include:
    - General
        - Equipment shall be operated in a manner and with an application rate and timing that does not cause runoff of the manure onto the property adjoining the property where the spray irrigation equipment is being

operated.

    - For manure from an earthen waste slurry storage basin, earthen manure storage basin, or formed manure storage structure, restricted spray irrigation equipment shall not be used unless the manure has been diluted with surface water or groundwater to a ratio of at least 15 parts water to 1 part manure. Emergency use of spray irrigation equipment without dilution shall be allowed to minimize the impact of a release as approved by the department.
  - Setbacks
    - *Required separation distance from a residence* not owned by the titleholder of the land, a business, a church, a school, or a public use area is 750 feet, as specified in Iowa Code section 459.204. The separation distance for application of manure by spray irrigation equipment shall be measured from the actual wetted perimeter and the closest point of the residence, business, church, school, or public use area.
    - *Separation distance for spray irrigation from property boundary line.* Spray irrigation equipment shall be set up to provide for a minimum distance of 100 feet between the wetted perimeter as specified in the spray irrigation equipment manufacturer's specifications and the boundary line of the property where the equipment is being operated. The actual wetted perimeter, as determined by wind speed and direction and other operating conditions, shall not exceed the boundary line of the property where the equipment is being operated. For property which includes a road right-of-way, railroad right-of-way or an access easement, the property boundary line shall be the boundary line of the right-of-way or easement.
    - The separation distance specified above shall not apply if any of the following apply:
      - The liquid manure is injected into the soil or incorporated within the soil not later than 24 hours after the original application.
      - The titleholder of the land benefitting from the separation distance requirement executes a written waiver with the titleholder of the land where the manure is applied.
      - The liquid manure originates from a small animal feeding operation.
      - The liquid manure is applied by low-pressure spray irrigation equipment
    - *Distance from structures for low-pressure irrigation systems.* Low-pressure irrigation systems shall have a minimum separation distance of 250 feet between the actual wetted perimeter and the closest point of a residence, a business, church, school or public use area
    - *Manure application on land adjacent to water bodies* - Unless adequate erosion controls exist on the land and manure is injected or incorporated into the soil, manure application should not be done on land areas located within 200 feet of and draining into a stream or surface intake for a tile line or other buried conduit. No manure should be spread on waterways except for the purpose of establishing seeding.
- **For more information:**
  - *http://www.iowadnr.gov/afo/files/sepdstb4.pdf*

  - *http://search.legis.state.ia.us/NXT/gateway.dll/ar/iac/5670___environmental%20protection%20commission%20__5b567__5d/0650___chapter%2065%20animal%20feeding%20operations/_c_5670_0650.xml?f=templates$fn=default.htm*

Nebraska

- **Extent of Manure Irrigation Use:** No information provided.
- **Complaints:** No information provided.
- **Setbacks/Other Requirements:** Manure irrigation requirements include:
  - Summary: 100 ft standard setbacks; no drift or pathogen reduction requirements; backflow prevention requirements for irrigation equipment
  - University of Nebraska Extension document on Manure Irrigation equipment, management practices and regulatory requirements: *http://ianrpubs.unl.edu/live/ec778/build/ec778.pdf*
- **For more information:**
  - Nebraska CAFO Manure or Process waste water Regulations:
    - Title 119 - Rules and Regulations Pertaining to the Issuance of Permits under the National Pollutant Discharge Elimination System
    - Title 130 - Livestock Waste Control Regulations
    - Nebraska Land Application of Wastewaters Regulations: Title 119 Chapter 12 provides Authorization by Rule for domestic wastewater treatment plant effluent land application. For these facilities that meet the requirements of the chapter and maintain records in accordance with this chapter, no NPDES permit is necessary.

North Carolina

- **Extent of Manure Irrigation Use:** Big gun hose reel irrigation is used by estimated > 95% of swine facilities in the state.
- **Complaints:** No information provided about type or extent of complaints. Staff commented that NC has not had any documented public health impacts from manure irrigation applications.
- **Setbacks/Other Requirements:**
  - See: *http://www.ncagr.gov/SWC/tech/documents/AppenxWasteAppSetbacks.pdf*
  - Prohibition on new facilities or existing facilities that expand above current live weight *http://www.ncleg.net/EnactedLegislation/Statutes/pdf/BySection/Chapter_143/GS_143-215.10I.pdf*
- **For more information:**
  - *http://portal.ncdenr.org/web/wq/aps/afo/rules* - See SB 1217 info
  - *http://portal.ncdenr.org/web/wq/aps/afo/news* -see performance standards for New or Expanding Swine Farms
  - General Permits for Swine Dairy and Poultry - some irrigation requirements noted in I-1 and II-19 *http://portal.ncdenr.org/web/wq/aps/afo/perm*

Other General Information about Manure spreading setbacks and other restrictions within multiple states

- *http://www.extension.org/pages/14881/state-specific-manure-nutrient-management-information*
- *http://nmplanner.missouri.edu/software/setbacks.asp*

Appendix C: Airborne Pathogens from Dairy Manure Aerial Irrigation and the Human Health Risk

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Pathogens in Dairy Manure

Dairy manure, like the fecal excrement from any domesticated or wild animal, can contain pathogens capable of infecting humans and causing illness or even death. Pathogens in dairy manure can be broadly divided into categories of taxonomy or infectiousness. Dividing by taxonomy there are three pathogen groups in dairy manure: viruses (e.g., bovine rotavirus), bacteria (e.g., *Salmonella* species), and protozoa (e.g., *Cryptosporidium parvum*). There are two categories of infectiousness for pathogens found in animals: those that are zoonotic and those that are not. A zoonotic pathogen is one that can infect both human and animal hosts. Some zoonotic pathogens found in dairy manure cause illness in both hosts (e.g., *Salmonella*) while other zoonotic pathogens, like *Escherichia coli* O157:H7, (enterohemorrhagic E. coli (EHEC)) cause illness only in humans. As a general rule, the gastrointestinal viruses found in dairy manure are not zoonotic. While there are exceptions (e.g., rare reports of bovine rotavirus infecting children), for the most part the viruses in dairy manure are not a human health concern. The primary concerns are the zoonotic bacteria and protozoa in dairy manure.

Six zoonotic pathogens found in dairy manure are frequently associated with human health effects: *Salmonella* spp., enterotoxigenic *E. coli*, *Campylobacter jejuni, Listeria monocytogenes, Cryptosporidium parvum,* and *Giardia lamblia* (US EPA 2013). These all cause acute gastrointestinal illness with diarrhea, abdominal pain, fever, nausea, and vomiting. In some cases illness can progress to a systemic infection involving other organ systems, for example, kidney failure caused by toxigenic *E. coli* or acute paralysis (i.e., Guillain-Barré syndrome) caused by *Campylobacter jejuni*. There are another eight zoonotic pathogens that are sometimes present in dairy manure but are rarely associated with illnesses in humans. These are microsporidia, *Brucella* spp., *Bacillus anthracis, Clostridium perfringens, Coxiella burneti, Leptospira* spp., *Mycobacterium bovis,* and Apthovirus (foot and mouth disease) (Atwill et al. 2012; Dungan 2010).

A recent study conducted by the Centers for Disease Control and Prevention estimated the annual burden of gastrointestinal illness in the United States caused by direct or indirect contact with animals to be more than 440,000 gastrointestinal illnesses per year (Hale et al. 2012). Animals in the study by CDC included livestock and pets such as dogs, cats, reptiles and amphibians. Four pathogens were respon-

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sible for the majority of these illnesses: *Campylobacter* spp. (17%), *Cryptosporidium* spp. (16%), toxigenic *E. coli* (14%), and *Salmonella* spp. (11%). These four pathogens are some of the most common found in dairy manure and thus were the focus of the Wisconsin study investigating the human health risk from airborne pathogens from dairy manure irrigation.

Conceptual Model of Pathogen Transport in Air

When considering how pathogens in irrigated dairy manure could travel through the air, come into contact with a person, and cause illness, it is helpful to break down the process into a sequence of steps (Figure C-1). First, manure is released from the irrigation nozzle in the form of droplets. This release results in a rapid pressure change to the pathogen where the effect, called the impact factor, sometimes has been found to decrease pathogen numbers by death (US EPA 1982), increase pathogen numbers by disaggregating particle clumps (US EPA 1982), or have no effect at all (Dungan et al. 2011).

Following release, the larger droplets fall by gravity to the ground whereas smaller droplets can become aerosolized, suspended in the air, and transported by wind. During airborne transport, aerosolized pathogens are subjected to environmental factors that can kill them. This process is called inactivation, and the three main factors relevant to airborne pathogens are warm temperatures, low humidity, and ultraviolet light as part of sunshine. Inactivation can be fast. A representative inactivation rate during daytime conditions is $-0.07\ s^{-1}$ (Teltsch et al. 1980). This means, for example, that 1% of the original number of pathogens traveling at a wind speed of 5 miles per hour would still be alive when they reach 500 feet from the irrigation nozzle. Of course, the absolute quantity of pathogens – the number most important for determining infection risk – could still be high if the original number of pathogens is high. One percent of a large number is still a large number. Inactivation is much slower during nighttime darkness, cool temperatures, and high humidity (Teltsch et al. 1980; Paez-Rubio and Peccia 2005)

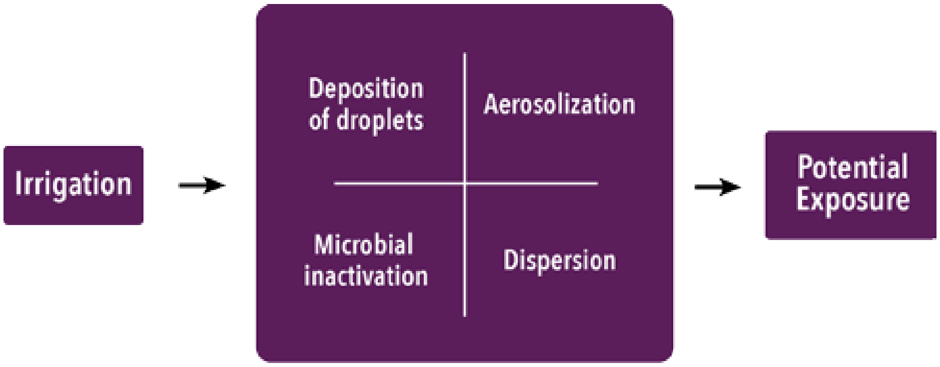

Figure C-1. Conceptual model of pathogen airborne transport and human exposure during manure irrigation.

Human Exposures to Airborne Pathogens

Human exposure to those pathogens that survive transport through the air can result from four general routes: 1) inhalation, with some fraction of the inhaled aerosols being swallowed and reaching the gastrointestinal system; 2) deposition of the pathogens onto a food product or crop that is then ingested; 3) deposition of pathogens onto an inanimate surface (i.e., a fomite), such as a toy, that through hand to mouth behavior results in ingestion; and 4) contact with a vector, such as a pet or insects, that through multiple possible indirect routes could result in human exposure. After ingestion, it is possible that the previously airborne pathogen could initiate infection and, consequently, illness.

Two additional concepts are necessary for understanding the potential health risks from airborne pathogens in irrigated dairy manure. First, people exposed to pathogens, regardless of the source, vary in their susceptibility to infection. Most susceptible are young children, the elderly, and people with compromised immune systems resulting from chemotherapy, organ transplants, HIV infection, or certain medications. Second, it is important to recognize that the number and types of pathogens in dairy manure can be highly variable from herd to herd and even in the same herd through time. Thus, exposure to dairy manure does not always equate to exposure to human pathogens. On the other hand, the absence of pathogens in a specific dairy herd at a specific point in time does not equate to the universal absence of health risk from exposure to dairy manure. The risk assessment described in this report accounted as best as possible for varying infection susceptibilities in the population and varying pathogen presence in dairy manure.

Previous Studies on Fecal-Borne Pathogens in Air and Health Risk

There are seven previous studies that have investigated the human health risk from airborne pathogen transport from aerosolized manure, human wastewater, or municipal biosolids. Five of these studies (Brooks et al. 2005a; Brooks et al. 2005b; Brooks et al. 2012; Dowd et al. 2000; Dungan 2014) have been published in the peer-reviewed, scientific literature. A sixth study (Hardy et al. 2006) is outlined in a report assembled by the Idaho Department of Environmental Quality (IDEQ) while the seventh study (Michael Cook, personal communication) is unpublished data produced by IDEQ. Only three of the seven studies deal with bovine manure (Brooks et al. 2012; Dungan 2014; Michael Cook, personal communication), and only two of those three consider irrigation (center pivot) of livestock manure (Dungan 2014; Michael Cook, personal communication). None of these studies considered traveling gun application of livestock manure. Only two studies consider more than one wind speed (Dowd et al. 2000; Michael Cook, personal communication). This is a significant shortcoming of the existing body of knowledge, because wind speeds can vary significantly over both short and long time-scales. Airborne pathogen transport in four studies was predicted by some formulation of the traditional air dispersion model (Dowd et al. 2000; Hardy et al. 2006; Michael Cook, personal communication; Dungan 2014). Versions of this model (varying in their levels of sophistication) are used widely by atmospheric scientists and contain input parameters that make them adaptable to a wide variety of meteorological conditions, source geometries, and landscape features. The three studies by Brooks et al. relied on the same empirical fate and transport model reported in Brooks et al. 2005a. Empirical models can be extremely practical and effective, but many times are constructed in a fashion that limits their application to conditions similar to those under which the models were developed.

Thus, existing studies on airborne pathogen transport and health risk vary significantly in their methods, assumptions, fecal source types, pathogens, exposure times, and application methods. This variation in approach produces significant variation in the risk estimates. Nonetheless, such variation in study design yields insights on those factors which require further investigation and, *in toto,* allows the weight of evidence for airborne disease transmission from manure irrigation to be evaluated.

Figure C-2 summarizes the risk estimates from the seven studies relative to distance from the fecal source. The horizontal dashed line at 10^{-4} indicates the acceptable level of risk for drinking water in the United States, one infection per 10,000 people per year. The vertical dashed line indicates the 500 foot distance, Wisconsin's current regulatory setback from a manure irrigation source to an inhabited dwelling. Five of the seven studies predict that by the time pathogens are transported 200 feet downwind from the fecal source the risk of infection is less than 1 in 10,000. The other two studies predict much higher risk levels. Dungan 2014 is not shown in Figure C-2 because the downwind distances in his study are from 3,300 to more than 30,000 feet, making it difficult to scale the figure to include all studies. At the 3,300 foot distance, Dungan reports risk estimates that range from 1×10^{-15} infections per person per exposure event to almost 1 infection per person per exposure event. This variation in risk estimates is a function of the variation in input parameters Dungan considered in his risk assessment model. Dowd et al. (2000) also predict much higher risk levels than the majority of studies. Dowd et al. worked with two different air dispersion models: a point-source model and an area-source model. The output from the latter is reported in the figure. However, they made unconventional modifications to the point-source model that appear to produce invalid air concentrations, and it is not clear if they made the same modifications to their area-source model.

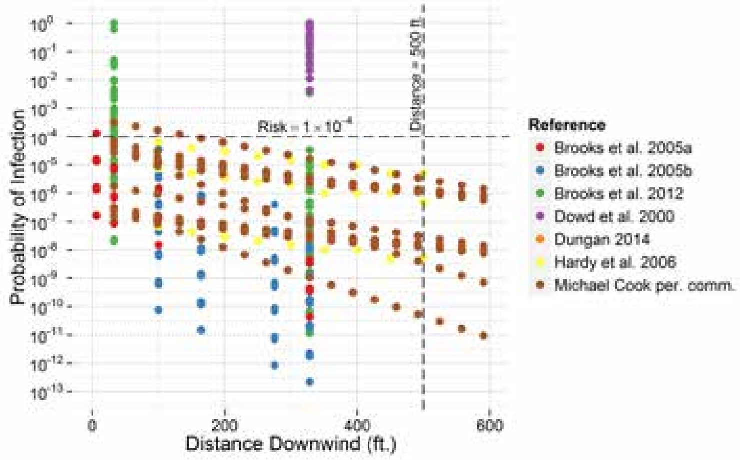

Figure C-2. Risk estimates of airborne pathogen transmission from previous studies.

One recent study investigated the risk of illness from eating leafy green vegetables grown downwind from a dairy manure application site (Jahne et al. 2016). The study focused on three pathogens (Salmonella spp., Campylobacter spp., and E. coli O157:H7) and movement of bioaerosols from the soil surface to leafy vegetable surfaces, after manure had been applied. The median level of risk was less than 1 infection per 10,000 people per year at 525 feet downwind, although at that distance the parameter termed peak risk by the researchers (the 95th percentile) was 1 in 100.

A key difference between the Wisconsin manure irrigation and human health risk study and the previous studies is the number of air samples collected to estimate downwind transport of pathogens and other microorganisms. Only three previous studies collected air samples (of indicator microorganisms), and the number of samples were limited. Brooks et al. 2005a used a series of indicator concentrations at multiple distances from a tanker truck spraying groundwater seeded with an indicator virus to develop their empirical model. Brooks et al. 2005b used coliphage and total coliform concentrations at only one distance very close to the source to establish initial concentrations for the application of the empirical model from Brooks et al. 2005a. Dowd et al. 2000 also used indicator concentrations close to the source to determine a source term for their air dispersion model. None of the three studies that considered livestock manure as a source collected actual air samples; pathogen concentrations in air were estimated from their concentrations in the source manure. The Wisconsin study is the first to collect air samples downwind from dairy manure irrigation.

Wisconsin Study on Dairy Manure Irrigation and Human Health Risks

The growing use of aerial irrigation equipment to apply dairy manure in Wisconsin and concerns about airborne pathogens generated from this practice prompted the Department of Natural Resources to fund field research on this topic. The interdisciplinary research team included microbiologists, engineers, and risk modelers from USDA-Agricultural Research Service, USGS Wisconsin Water Science Center and University of Wisconsin – Madison Department of Biological Engineering. Funding for the study was also provided by USDA-ARS.

Study Objectives and Approach

The Wisconsin study had two primary objectives.

1. Identify weather variables (e.g., wind speed, solar radiation, and relative humidity) most important for airborne pathogen transport during manure irrigation.
2. Use microbial risk assessment to estimate the risk of illness for people exposed to airborne pathogens downwind from manure irrigation sites.

At the foundation of this effort was extensive field sampling for airborne pathogens during multiple irrigation events from 2012 through 2014. The researchers' goal was to obtain the most comprehensive data set to date on airborne pathogens downwind from a fecal source. Two approaches were taken to model and predict downwind pathogen transport based on these air measurements: 1) empirical statistical modeling and 2) Gaussian air dispersion modeling. The output from each approach is air concentration of pathogens as a function of downwind distance from the irrigation source. These concentrations provided the input values for risk assessment modeling. At the present time, the research team is relying on the statistical model output for the risk assessment.

Sampling for airborne microbes

Air samples were collected by two methods: 1) button samplers for collecting microorganism genetic material quantified by real-time quantitative polymerase chain reaction (qPCR) and 2) impactor samplers for quantifying culturable bacteria on solid growth media. The latter included media for gram negative bacteria, *E. coli,* enterococci, and *Campylobacter* spp. Bacterial colonies observed growing on the media were tested by qPCR to confirm their taxonomic identity. Liquid manure sampled at the time of irrigation from a center pivot nozzle or a traveling gun pump valve was always analyzed first in the laboratory before the air samples. If a particular microorganism, for example, *E. coli* O157:H7 was not present in the irrigation source manure, the air samples were not tested for this microorganism. We took this approach to save time and reduce costs.

The configuration of air samplers in irrigated fields was nearly the same for every irrigation trial. Sometimes conditions at the site or problems with equipment meant there were small changes in the ideal sampling configuration. Samplers were placed downwind of the irrigation equipment in a line parallel to the predominant wind direction at approximately 100, 200, 350, 500, and 700 feet from the edge of the irrigated wetted perimeter. At each distance two identical sets of samplers (a set is defined as one button and two impactor samplers) were placed 50 feet apart, perpendicular to the wind direction. Two sets of air samplers were placed far upwind of the irrigation equipment to serve as controls, one for background air concentrations of manure-related microorganisms before irrigation commenced and the other for upwind concentrations during irrigation. Meteorological conditions during irrigation were measured using a portable weather station set up at the same location as the upwind controls.

The start time for air sampling was coordinated to maximize the likelihood of detecting airborne microorganisms. For center pivot systems, air sampling began as soon as the system was fully pressurized and the nozzle boom started pivoting away from the samplers. For the traveling gun, the travel rate was measured, and the air samplers, placed approximately 2/3s of the pull distance from the reel, were turned on for the one hour period when the gun was located most directly upwind of the samplers. The time length of air sampling was either 60 minutes (traveling guns) or 90 minutes (center pivots) for the button samplers and 20 minutes for the impactors. After 20 minutes, the growth media was exchanged for a duplicate plate and another 20 minute sample was collected.

We conducted air sampling during 23 irrigation trials on three dairy farms in Wisconsin. Irrigation was by center pivot for 8 trials and by traveling gun for 15. Two trials are omitted from this analysis because the wind direction shifted 85° or more during irrigation and the samplers were no longer downwind (i.e., 21 trials were analyzed). Three trials were conducted under low light conditions at sunset or nighttime. Air samples were analyzed for culturable bacteria in 13 trials and for microorganism genetic markers in 23 trials. In two additional trials we measured airborne transport of microorganisms during conventional manure application by a tanker with a high splash-plate.

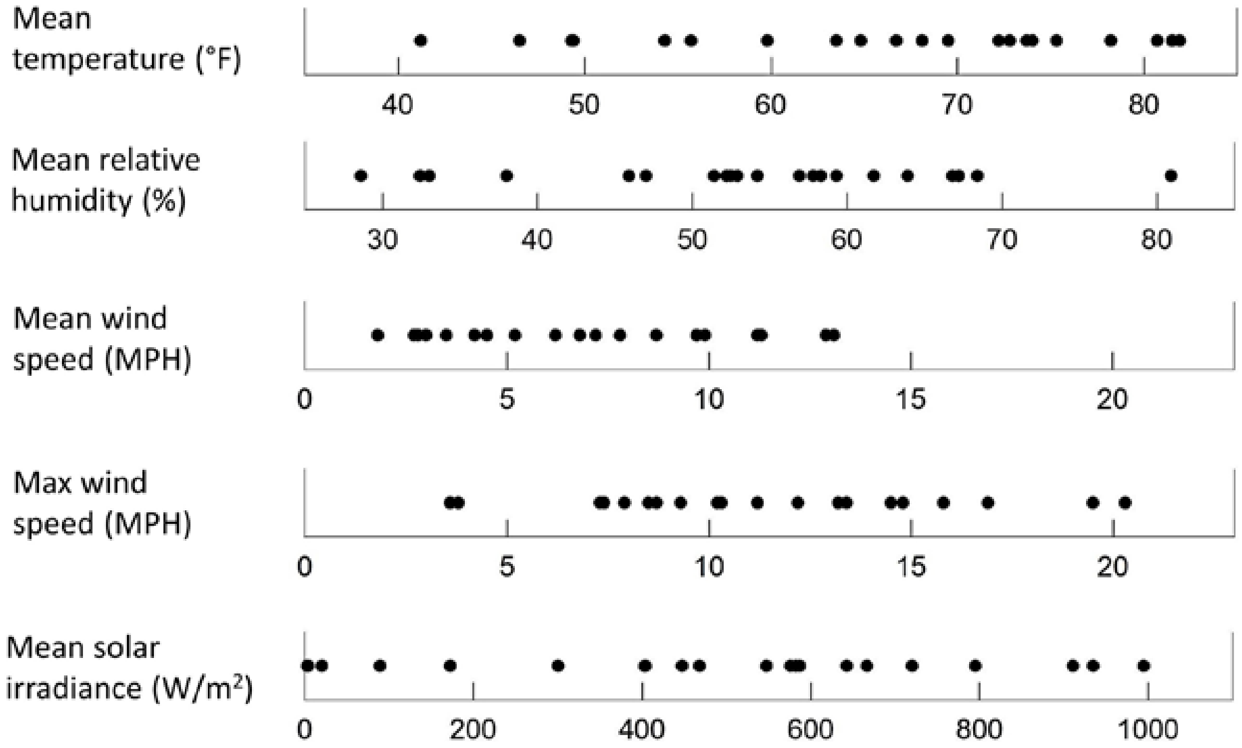

Figure C-3. Weather conditions during the irrigation trials. Each point represents a trial.

Weather conditions

Sampling for airborne pathogens during manure irrigation was conducted under a wide range of meteorological conditions (Figure C-3). No samples were collected during snowfall or rainfall conditions.

Risk assessment

Figure C-4 depicts the first steps of the quantitative microbial risk assessment (QMRA) – calculating the dose of pathogens ingested from the air. As depicted by the blue boxes in the figure, we used the air sample data of non-pathogenic bacteria that were always present in cattle manure, for example, bovine *Bacteroides* to construct a statistical model to predict downwind concentrations. These surrogate bacteria were necessary because pathogenic bacteria were rarely detected in the manure from the three participating farms.

Statistical modeling. The statistical modeling approach we used to relate bacterial air concentrations to distance from the irrigation equipment is called hierarchical or multilevel modeling. This approach accounts for the many levels of variability that can affect a measurement. In this study there were two levels: 1) the level of irrigation trials (which includes variability due to weather conditions, irrigation equipment, and the farm where measurements were taken); and 2) the level of individual samples (which includes the effect of distance). Taking into account these multiple sources of variability makes model interpretation practical and useful. There is no need to preface the predictions of downwind microbe concentrations with a series of "it depends" statements. For instance, when obtaining a prediction it is not necessary to specify that it depends on a particular farm, or type of irrigation equipment, or set of weather conditions. Instead we can make general predictions of microbe concentrations in air based solely on distance. All the variability in predicted air concentrations that result from differences in farms, irrigation equipment, weather, has already been accounted for.

Pathogen-to-surrogate ratios. Surrogate bacteria concentrations we measured in dairy manure samples collected just before the manure was irrigated were used to calculate pathogen-to-surrogate ratios. As *Salmonella* and *E. coli* O157:H7 were never detected in our study, we relied on the scientific literature for concentrations of these two pathogens in stored dairy manure. *Campylobacter jejuni* was present in the manure samples we tested, making it possible to derive a *C. jejuni*-to-surrogate ratio specific to our study. These ratios were used to translate surrogate air concentrations to pathogen air concentrations as related to distance from the irrigation equipment.

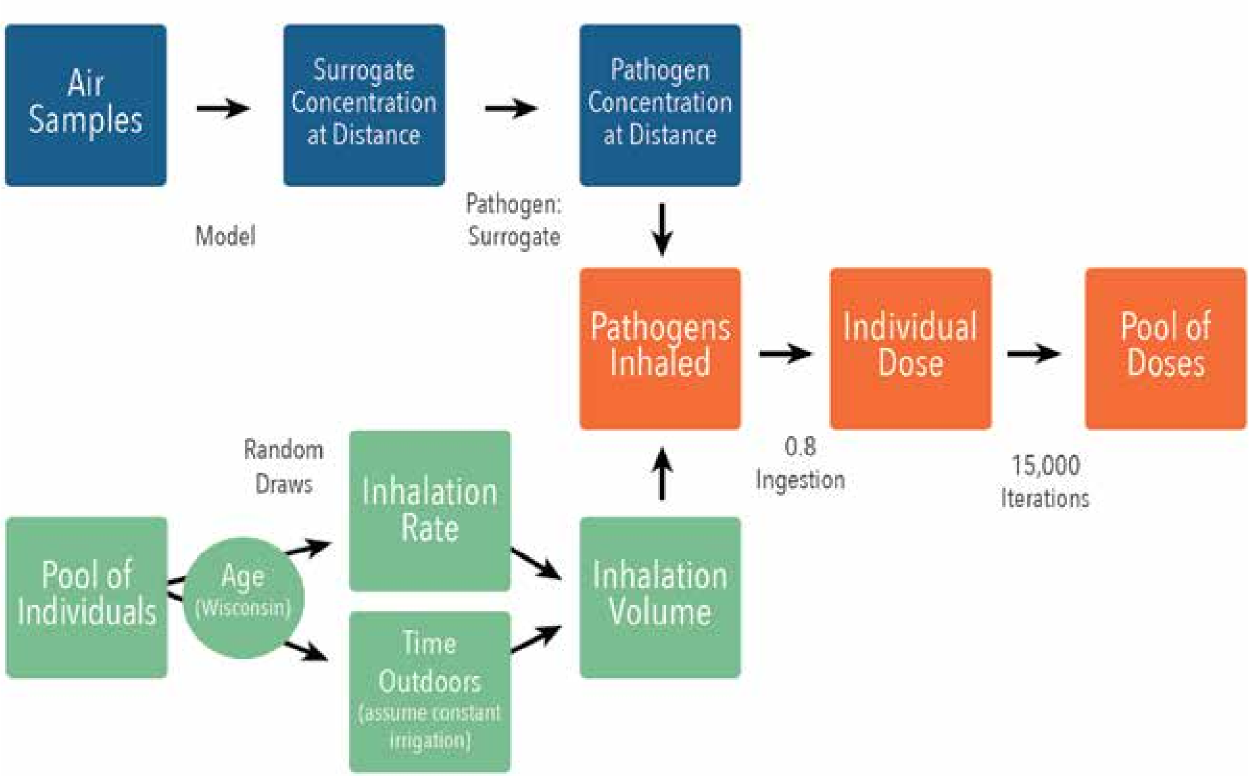

Figure C-4. Schema for calculating pathogen dose and accounting for variability in exposure.

Inhalation volumes. The green boxes in Figure C-4 show the steps for developing the statistical distribution of inhalation volumes. From a hypothetical pool of 15,000 individuals a "person" is randomly drawn from the age distribution for Wisconsin residents as reported in the 2010 USA census. Age determines the distributions for inhalation rate and time spent outdoors from which values are randomly drawn for the "person". These distributions are from the US EPA Exposure Factors Handbook (2011). Inhalation rates relate to light intensity activities, like walking or watering plants, and time spent outdoors refers to activities outside one's home. We used distributions, instead of point estimates, for age, inhalation rate, and time outdoors to account for the variability in these parameters. Multiplying inhalation rate and time for 15,000 individuals results in the statistical distribution of inhalation volumes.

We assume manure irrigation is underway the entire time period our "person" is spending outdoors. In other words, if the random draw yields a five minute outdoor time we assume the pathogens from manure irrigation are in the air at the concentration predicted by the statistical model at a specified distance for the five minute period. If a one hour time was randomly selected, the pathogens are assumed to be in the air for one hour, etc. Our risk assessment does not address pathogens in the indoor air environment that have entered from open windows, doors, or other openings to the air outside. We do not have information on the fraction of outdoor airborne pathogens that can enter indoors and selecting such a value would just be a guess. In our opinion, the assumption that manure irrigation occurs for at least as long a time period as the individual is outdoors is already conservative towards protecting public health.

Pathogens ingested. The last set of steps (orange boxes in Figure C-4) combines the inhalation volumes and pathogen air concentrations to yield the number of pathogens inhaled and ultimately ingested (i.e., the dose). Pathogens in manure are transmitted by the fecal-oral route. In other words, the pathogens must be ingested to initiate infection. As we are dealing with gastrointestinal pathogens in air, we must estimate the number of ingested pathogens from the number that are inhaled. In our opinion, the manure irrigation risk assessment conducted by the Idaho Department of Environmental Quality provides the soundest estimate of the ingested fraction of inhaled pathogens, 80%. This number is derived from estimates of the aerosol particle size distribution of irrigated human wastewater (assumed to be similar to irrigated manure) and an understanding of human physiology and the size of aerosol particles that are swallowed following inhalation. Multiplying the number of pathogens inhaled by 0.8 for the 15,000 individuals yields a distribution of pathogen doses.

Dose-response curves. The last step of the risk assessment is to calculate the probability of illness based on dose-response curves selected from the literature. We used dose-response curves for three pathogens: *Salmonella* spp., *C. jejuni,* and EHEC (enterohemorrhagic E. coli) (Figure C-5). Each pathogen has its own dose-response curve because pathogens differ in how many must be ingested to cause illness. Our major criteria for selecting among alternative dose-response curves for each pathogen was to use disease outbreak-based curves whenever they were available. Outbreak-based curves reflect real-world strains of pathogens circulating in the population rather than strains that have lived in a laboratory for years losing their potential for infection. They are also usually representative of the population in terms of age and immune status. In contrast, dose-response curves derived from controlled feeding studies rely on healthy young adults, which likely results in curves that underestimate risk. Outbreak-based curves were available for *Salmonella* and EHEC. Thus, insofar as these dose-response curves reflect the general population, the risk estimates for *Salmonella* and EHEC in this report account for people living near manure irrigation that vary in age, health, and immune status. We used a feeding study-based curve for *C. jejuni* because reliable outbreak-based curves for this pathogen are currently not available. The *C. jejuni* dose-response curve that we selected is based on a biologically plausible range of dose-response parameters, as opposed to other *C. jejuni* dose-response models that allow for extremely wide variation in the host-pathogen interaction.

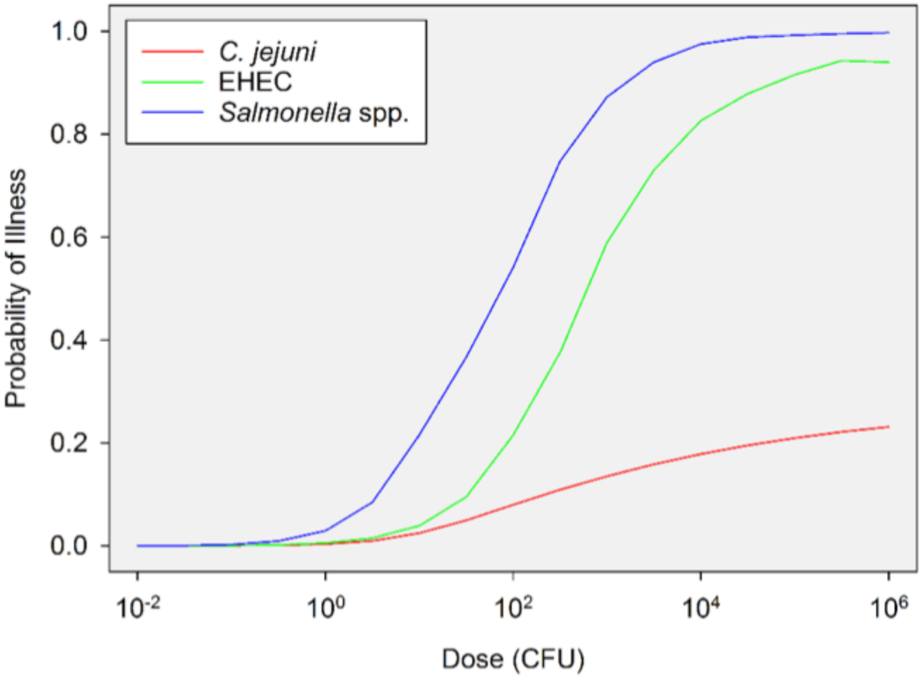

Figure C-5. Example of pathogen dose-response curves.

Because the doses input into a dose-response curve are a statistical distribution, it is important to keep in mind that the output of illness risk probabilities is also a statistical distribution. The benefit of using a risk distribution instead of a single number is that a distribution conveys the variability and uncertainty of the risk estimates. Still, for ease of presentation, for this study we will often report the risk estimates as a single number, the median of the risk distribution.

Study Findings

Airborne bacteria detection frequencies and concentrations. Table 1 reports how often various types of bacteria were detected in irrigated manure and in air samples collected downwind during manure irrigation. Not surprisingly, bacteria that normally live in the gut tract of cattle (*Bacteroides,* gram negative bacteria, *E. coli,* and *Enterococci*) were present in manure 100% of the time. Among the three bacterial pathogens analyzed, only one *(C. jejuni)* was present in the study manure. While *Bacteroides,* gram negative bacteria, commensal *E. coli, Enterococcus* spp., and *C.*

jejuni were detected frequently in manure samples, they were detected less frequently in downwind air samples. The greatest difference was for non-pathogenic *E. coli;* it was detected in 100% of manure samples but only 11% of air samples.

Table 1. Detection frequencies of bacteria in manure and in air downwind of manure irrigation.

Microbe (method)	Manure Detection % (n of total trials)	Downwind Air Detection % (n of total air samples)
Bovine Bacteroides (qPCR)	100% (18 of 18)	86% (159 of 185)
Gram negative bacteria (culture)	100% (10 of 10)	54% (68 of 127)
Commensal E. coli (culture)	100% (8 of 8)	11% (10 of 92)
Enterococcus spp. (culture)	100% (10 of 10)	56% (55 of 98)
C. jejuni (qPCR)	89% (16 of 18)	17% (30 of 176)
C. jejuni (culture)	70% (7 of 10)	6% (7 of 112)
E. coli O157:H7 (qPCR)	0% (0 of 17)	Not measured
Salmonella spp. (qPCR)	0% (0 of 17)	Not measured
Salmonella spp. (culture)	0% (0 of 10)	0.8% (1 of 126)

Like detection frequencies, concentrations of the bacteria in air decreased with increasing distance downwind from manure irrigation. Figure C-6 illustrates this relationship for one bacteria group that had the highest overall detection frequency in air, bovine *Bacteroides.* The blue lines represent the change in concentrations for each irrigation trial. The red line is the overall trend determined by the statistical analysis, and it represents a typical irrigation event encompassing all the variability introduced by weather conditions, irrigation equipment, farm, etc. In general, the *Bacteroides* concentration decreased approximately 30% for every 100-foot increase in downwind distance. At a distance of 500 feet the expected *Bacteroides* concentration is one genetic copy (equivalent to one bacterium) per liter of air (1,000 genetic copies per cubic meter). When *C. jejuni* and non-pathogenic *E. coli* are detected in air the expected concentrations are much lower, on the order of 0.001 colonies per liter of air.

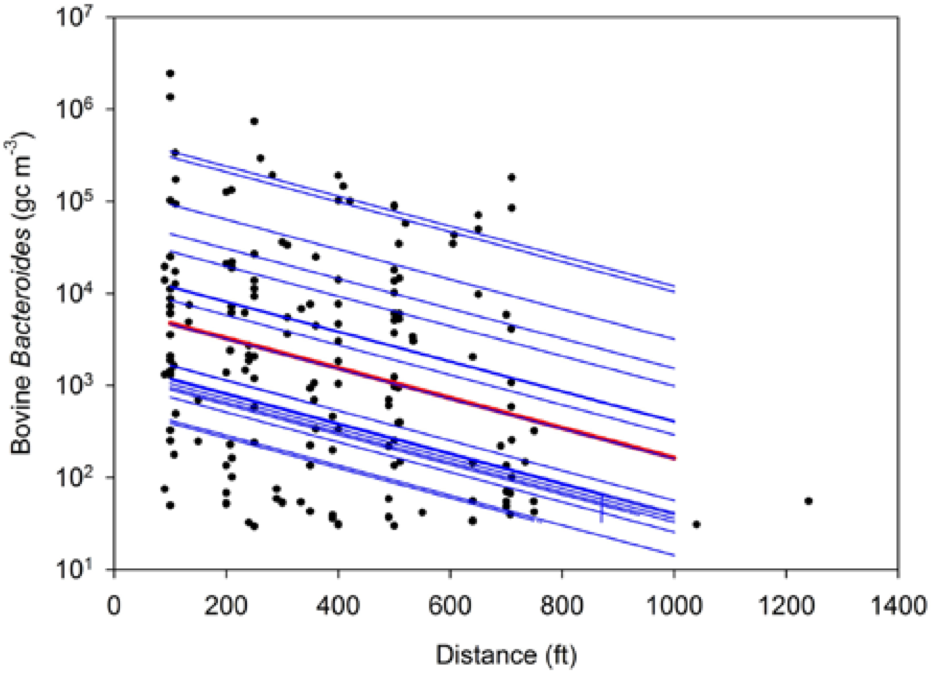

Figure C-6. Air concentrations of bovine Bacteroides as related to distance from the wetted perimeter of irrigated manure. Each blue line represents an irrigation trial (n = 20). The red line shows the overall trend determined from the statistical model.

Losses in airborne bacteria. The decrease in detection frequency and concentration when bacteria move from liquid manure to air during irrigation is demonstrated visually in Figure C-7. The figure shows colonies of gram negative bacteria from samples collected during one manure irrigation trial. The colonies are the pink dots on the growth media plates. There are many colonies in the manure sample, but at 100 feet downwind from the edge of the area wetted by irrigated manure, there were only two colonies in 540 liters of air. There were also two colonies at 350 feet, but at 500 and 670 feet no colonies were detected.

Why are bacteria detections and concentrations in air so much less than in manure? Four well-known processes are responsible, although from our study design it is difficult to ascertain which process is the most important during manure irrigation. 1) When liquid manure is released through an irrigation nozzle, very few bacteria become aerosolized and suspended in the air. In a study conducted by the US EPA of irrigated municipal wastewater, the aerosolization efficiency was only about 1% (US EPA 1980). 2) Gravitational settling of manure aerosols onto surfaces, like plants and soil, as they move through the air removes aerosol-associated bacteria from the air stream, reducing their concentration further downwind. 3) Dilution by the wind scattering and dispersing manure aerosols and bacteria into the larger atmosphere also reduces bacteria concentrations. 4) Lastly, inactivation by warm temperatures, low humidity, and sunshine kills the bacteria, reducing their numbers in air. Despite

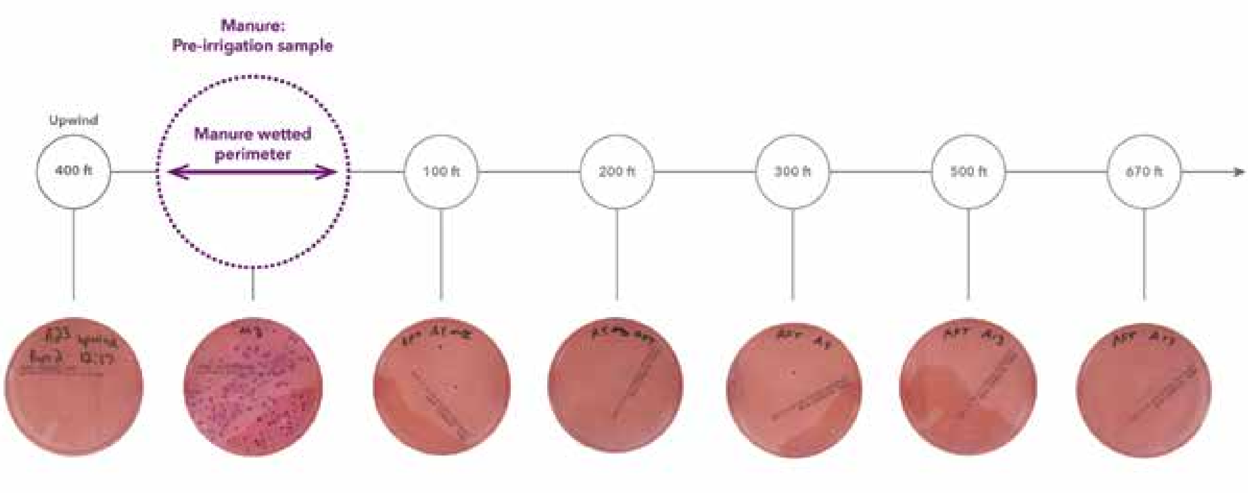

Figure C-7. Gram negative bacteria (pink dots) in air upwind and at five distances downwind from dairy manure irrigated by traveling gun, May 22, 2014. Air sampling was by Andersen impactors containing the MacConkey agar plates shown here. Air volume sampled = 540 liters; wind speed = 11 mph; solar irradiance = 530 Watts/m^2; relative humidity = 50%, temperature = 68°F. Manure collected before it exited the traveling gun was diluted 1:100 with sterile water before plating 100 microliters on MacConkey agar (upper, second from left, plate).

these environmental processes, manure-borne bacteria can still be measured downwind from manure irrigation and the question then becomes: "Do these concentrations pose a risk to public health?"

Illness risk as related to distance. Figure C-8 reports illness risk levels as related to the distance downwind from the edge of the area being wetted during manure irrigation. The relationship was obtained by repeating the QMRA process illustrated in Figure C-4 at 50-foot distance increments. Bacteria concentration at each distance input into the QMRA was determined from the statistical models (e.g., the red line in Figure C-6). It is important to recognize that the red line is illustrating only the general trend, and the actual bacteria air concentrations input at each distance were from a distribution encompassing the variability introduced by weather conditions, irrigation method, farm, and initial manure concentration. This generates a distribution of risk estimates at each distance and is the reason the median risk is reported in Figure C-8.

Figure C-8 is organized as a 2x2 table where the columns and rows are pathogen prevalence in manure and surrogate type, respectively. These are two of the main determinants of risk in this study. The surrogates bovine *Bacteroides* and gram negative bacteria are presented because they span differences in air measurement methods (gram negatives were measured by culture and *Bacteroides* by qPCR), differences in inactivation (*Bacteroides* are the most environmentally resistant surrogate group) and differences in air concentrations. The risk assessment was conducted at two levels of prevalence in dairy manure for each pathogen: 1) 100% prevalence, which assumes the pathogen is present during every exposure to aerosolized dairy manure, and 2) a pathogen-specific "typical" prevalence value. These pathogen-specific values were 39%, 40%, and 90% for EHEC, *Salmonella* spp., and *C. jejuni,* respectively (USDA 2003, USDA 2011). The typical prevalence values for EHEC and *Salmonella* spp. represent national averages. The *C. jejuni* value was derived from our own field data and is close to its corresponding national average (93%) (USDA 2011). The four panels in Figure C-8 circumscribe the range of risk estimates obtained in this study.

Setting pathogen prevalence levels in dairy manure to typical values and using gram negative bacteria as the surrogate yields the least conservative risk estimates (Panel A). Under this scenario, the median risk levels for one-time exposures to spray irrigated dairy manure are near zero for EHEC and *Salmonella,* and the corresponding risk level for *C. jejuni* is approximately 1 in 100,000. They are all well below 1 infection/10,000 people/year, which is the acceptable level of illness risk for drinking water in the United States (US EPA 1989). At the same prevalence levels but using *Bacteroides* as the surrogate (Panel B), the risk for illness from *C. jejuni* exceeds the drinking water threshold at distances less than about 500 feet. When pathogen prevalence is changed to 100% and using the gram negative bacteria surrogate (Panel C), the illness risk from *Salmonella* exceeds the drinking water threshold at all distances up to 1,000 feet. Panel D represents the most conservative scenario, with pathogen prevalence equal to 100% and bovine *Bacteroides* as the pathogen surrogate. This scenario results in illness risk levels that exceed the drinking water risk threshold for all three pathogens. Furthermore, *Salmonella* risk levels are near the acceptable level of risk for recreational water in the United States (32 illnesses per 1,000 swimmers per exposure event) at distances less than approximately 500 feet (US EPA 2012). Using the other two surrogate groups, *Enterococci* and an alternative measure of bovine *Bacteroides* (M3 *Bacteroides*), or using a direct risk assessment of the air concentration data for the pathogen *C. jejuni,* all result in risk estimates consistent with or lower than those reported in Figure C-8.

Cumulative risk estimates. The risk estimates reported in Figure C-8 are for a one-time exposure event to manure irrigation. According to DNR staff some dairy farms irrigate with manure up to 12 times on a field. The cumulative risk from exposures at a 500 foot distance to multiple irrigation events is reported in Figure C-9. The figure is organized as previously, with four scenarios varying pathogen prevalence and surrogate. When the number of irrigation events is greater than one, three of the four scenarios result in risk estimates that exceed the drinking water threshold. Under the scenario most conservative towards public health (100% prevalence, *Bacteroides* as the surrogate), irrigating more than seven times results in *Salmonella* illness risk levels greater than the acceptable level of risk for recreational water. Cumulative risk, as calculated here, refers to multiple exposures from discrete irrigation events over time (e.g., three events in a month); this risk assessment does not explicitly address exposure from multiple irrigation events happening simultaneously on different agricultural fields.

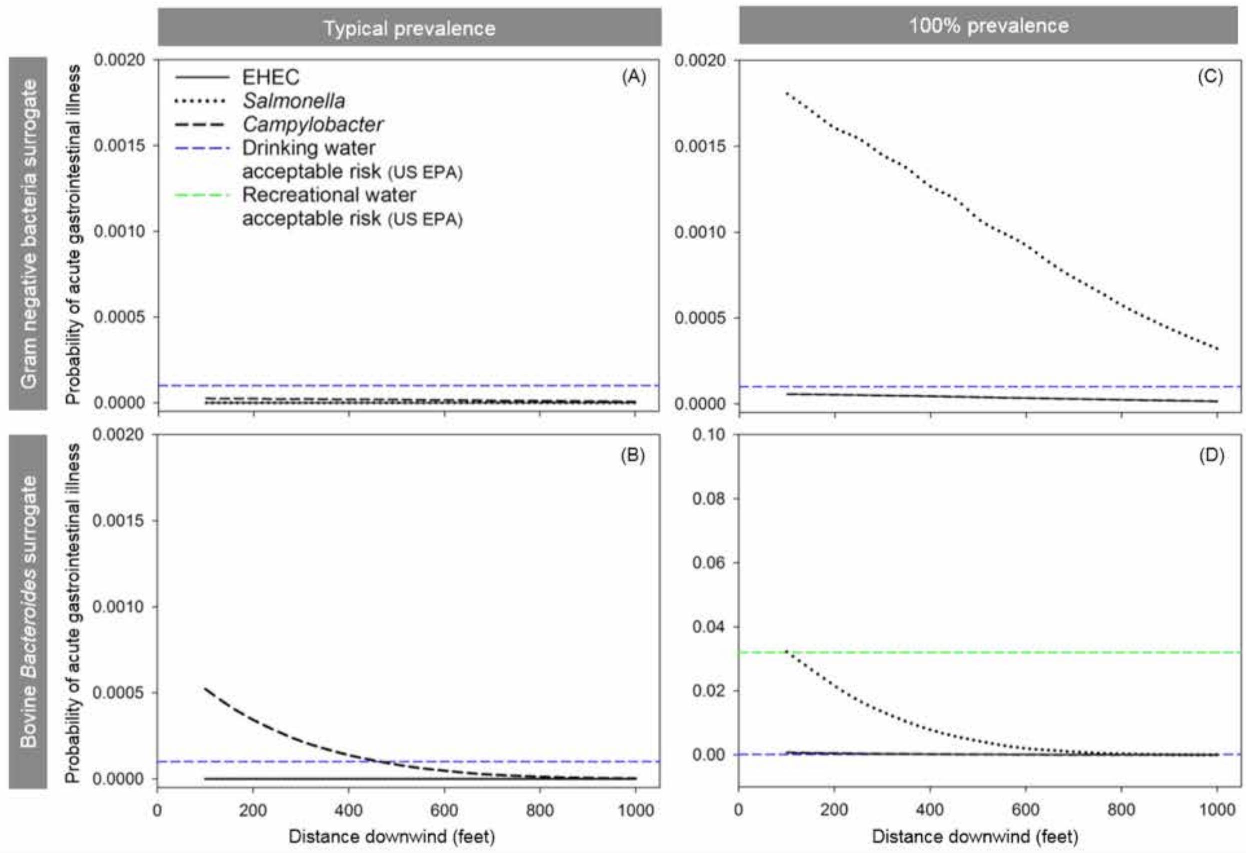

Figure C-8. Risk estimates for acute gastrointestinal illness caused by three pathogens as related to distance from the wetted perimeter of dairy manure irrigated by traveling gun or center pivot. Panels represent pathogens modeled using typical prevalence values and gram negative bacteria as a surrogate (A), typical prevalence values and bovine Bacteroides as a surrogate (B), 100% prevalence and gram negative bacteria as a surrogate (C), and 100% prevalence and bovine Bacteroides as a surrogate (D). The lines report the median of the risk distribution (i.e., half the risk estimates are higher and half are lower than the line). Horizontal blue and green dashed lines indicate benchmarks in the United States for acceptable levels of risk from exposures to drinking water and recreational water, respectively. Plots are organized by surrogate type and pathogen prevalence in dairy manure as a means of circumscribing the range of risk estimates obtained in this study (see text for details). Note the change in the y-axis scale for Panel D.

Sensitivity analysis. We performed a sensitivity analysis to determine the factors most important to the outcomes of the risk analysis. Pathogen prevalence in dairy manure has the greatest influence, and this intuitively makes sense. When manure does not contain a particular pathogen, it is not possible for that pathogen to appear *de novo* in the air during irrigation and cause illness. The length of time a person is exposed to manure irrigation and the effect of distance on decreasing pathogen concentration were two factors with an intermediate level of influence on the risk outcomes. A person's breathing rate and age had only negligible influence on the risk outcomes.

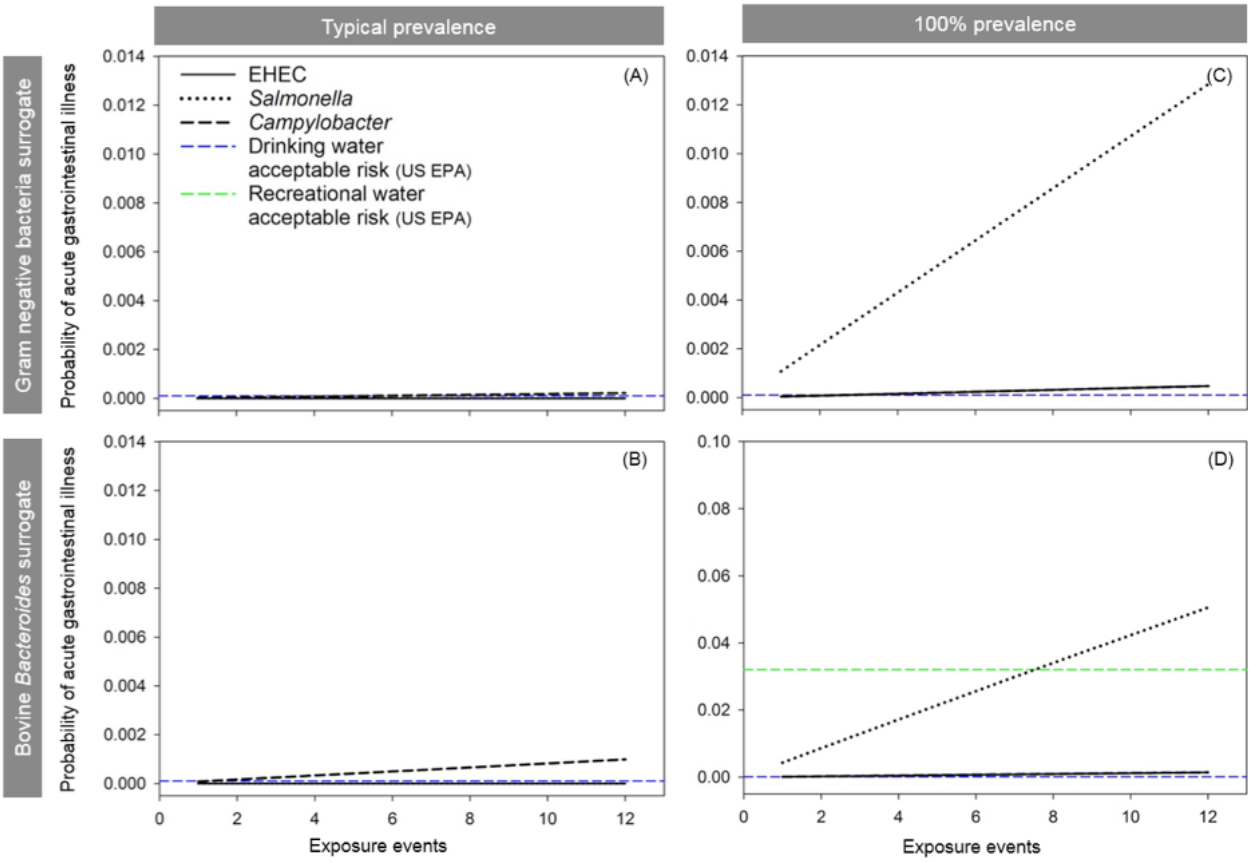

Figure C-9. Cumulative risk (median) for acute gastrointestinal illness at 500 feet from irrigated manure wetted perimeter as related to the number of exposure events (i.e., number of irrigation events). Line and panel designations are the same as the previous figure. Note the change in the y-axis scale for Panel D.

Factors that affect downwind microbe concentrations. As described earlier, for predicting downwind microbe concentrations that were input into the QMRA, we used a hierarchical statistical model that mathematically accounted for the variability in air concentrations introduced by the combined effects of weather conditions and microorganism concentrations in manure. Lumping the effects of these variables together was advantageous for interpreting the risk outcomes because it avoided having to make a number of conditional statements, for example, "the risk was W when wind speed was X and temperature was Y but not when temperature was Z." However, to understand the individual effects of weather conditions and microorganism concentrations in manure on microbe concentrations in air downwind from manure irrigation, we constructed a second set of statistical models using these variables as explicit predictors.

The most important weather variable in determining downwind microbe concentrations is wind speed. Other studies have shown that high solar irradiance and low relative humidity favor rapid inactivation of airborne pathogens, but with our data we did not see clear-cut effects of these two weather variables. Solar irradiance and relative humidity were only rarely significant predictors of microbe air concentrations, and the observed relationship between relative humidity and microbe air concentrations was opposite that of what we would expect based on biological mechanisms. This does not mean necessarily that solar irradiance and relative humidity do not affect microbe air concentrations during manure irrigation, only that of the weather variables measured, wind speed is the best at predicting downwind concentrations.

Two non-weather variables that were as important as wind speed in predicting microbe concentrations downwind from manure irrigation were distance downwind and the microbe concentration in the manure source. One way to compare these variables is to examine their equivalent effects, that is, how much one variable must change to equal the effect of another variable. For wind speed, a decrease of 2 miles per hour would have the same reducing effect on *Bacteroides* air concentration as increasing the distance approximately 190 feet. Such comparisons, while illustrative, are cumbersome for setting specific quantitative weather conditions for manure irrigation because there are so many permutations. In general, what this analysis shows is that four actions provide the biggest payoff in reducing the risk of airborne disease transmission from dairy manure irrigation: 1) Improve herd health and prevent pathogens from being present in manure in the first place; 2) If pathogens are present, use practices and treatments to reduce their concentrations; 3) Irrigate under low wind speed conditions; 4) Maximize the distance between irrigated manure and people living downwind.

Comparison of manure irrigation with conventional spreading by tanker
On two dates we measured airborne transport of pathogens and microbial surrogates during dairy manure application by conventional tanker. Two tankers applied manure to the field site, alternately traveling between the field and manure lagoon. Manure exited the tankers approximately 8 feet from the ground, hitting a splash plate to create a fan pattern. Air sampling equipment was located downwind from the manure application site, and the weather conditions were similar to the manure irrigation trials, (daylight hours, wind speeds of 5 and 7 mph, and relative humidity of 69% and 73%). There was no clear pattern in the differences in downwind microbe concentrations during manure application by tanker or irrigation (Tables 2 and 3). Depending on the microbe type measured and the method of measurement (qPCR or culture) for some comparisons there was no statistical difference between application methods, and for other comparisons sometimes the tanker produced significantly lower air concentrations and sometimes irrigation produced significantly lower air concentrations. With only two tanker trials, it is not possible to determine definitively which application method creates the fewest airborne microbes.

Table 2. Comparison of tanker and irrigation manure application methods on the probability of detecting microbes downwind.

Microbe (Measurement)	P-Value of Statistical Significance	Method with Lower Probability of Detection	Number of Measurements	Number of Trials
Bovine Bacteroides (qPCR)	0.05	tanker	205	22
M3 Bacteroides (qPCR)	0.004	tanker	215	23
Enterococcus spp. (culture)	0.2	Indeterminate[1]	114	25

[1] Two trials were by tanker manure application.
[1] P-value is greater than the statistical threshold of 0.05.

Table 3. Comparison of tanker and irrigation manure application methods on the concentration of microbes downwind.

Microbe (Measurement)	P-Value of Statistical Significance	Method with Lower Concentration	Number of Measurements	Number of Trials
Bovine Bacteroides (qPCR)	0.07	Indeterminate[1]	170	22
M3 Bacteroides (qPCR)	0.8	Indeterminate	132	22
Enterococcus spp. (culture)	0.9	Indeterminate	61	19
Gram Negative Bacteria (culture)	0.001	irrigation	88	24

[1] Two trials were by tanker manure application.
[1] P-value is greater than the statistical threshold of 0.05.

Traveling gun versus center pivot manure irrigation

Comparing traveling gun versus center pivot manure irrigation methods, there are no statistical differences in the probabilities of detection or levels of concentration of airborne bovine *Bacteroides* or gram negative bacteria (Tables 4 and 5). The traveling gun method did result in a significantly lower probability of detection and concentration of enterococci bacteria in air. Overall, however, there was no clear pattern of differences between traveling gun and center pivot manure irrigation methods in the downwind transport of microbes.

Table 4. Comparison of traveling gun and center pivot manure irrigation on the probability of detecting microbes downwind.

Microbe (Measurement)	P-Value of Statistical Significance	Method with Lower Probability of Detection	Number of Measurements	Number of Trials
Bovine Bacteroides (qPCR)	0.06	Indeterminate[1]	185	20
M3 Bacteroides (qPCR)	0.4	Indeterminate	195	21
Enterococcus spp. (culture)	0.002	Traveling gun	98	21
Gram Negative Bacteria (culture)	0.3	Indeterminate	127	21

[1] P-value is greater than the statistical threshold of 0.05.

Table 5. Comparison of traveling gun and center pivot manure irrigation on the concentration of microbes downwind.

Microbe (Measurement)	P-Value of Statistical Significance	Method with Lower Concentration	Number of Measurements	Number of Trials
Bovine Bacteroides (qPCR)	0.5	Indeterminate[1]	159	20
M3 Bacteroides (qPCR)	0.1	Indeterminate	130	21
Enterococcus spp. (culture)	0.007	Traveling gun	55	17
Gram Negative Bacteria (culture)	0.6	Indeterminate	68	20

[1] P-value is greater than the statistical threshold of 0.05.

Study Limitations and Data Interpretation

Several limitations of the study design need to be kept in mind when interpreting the data. Likely the most important was using non-pathogenic microbes in manure as surrogates for pathogens. This was necessitated because during the study period pathogen prevalence on the three study farms was low; only *C. jejuni* was detected. While the surrogate-to-pathogen ratios we used were based on a combination of published data and our own study data, it was not possible to explore the variability of the ratios and what effects these would have on the risk outcomes. To mitigate this limitation our analysis relied on multiple surrogates and variable levels of pathogen prevalence as a means of circumscribing the range of predicted risks.

This study focused on the primary zoonotic pathogens in dairy manure; we did not conduct analyses for less common but still important pathogens, for example, *Listeria monocytogenes* or *Leptospira*. For many of these less common pathogens, the requisite data for conducting the QMRA are limited or unavailable. We chose to focus on common pathogens for which the abundant information available would yield the most robust QMRA with the least number of assumptions. The importance of pathogen prevalence and concentration in dairy manure in determining risk for *C. jejuni,* EHEC, and *Salmonella* suggests that risk levels are probably the same or lower for less common pathogens like *Listeria.*

It is tempting to think the risk levels determined in this QMRA are the risk levels for every dairy farm that practices manure irrigation. However, this type of thinking, where an attribute of the group is applied to a specific individual, is a common error called the “ecological fallacy”. For example, suppose a school has the highest average reading score in the state. This does not necessarily mean that every student in the school is an excellent reader. Each student is just one member of the distribution of reading scores that is summarized by the school’s average. Similarly, the manure irrigation risk values reported here are medians that summarize the risk distribution; a specific dairy farm or specific manure irrigation event could have risk levels that are higher or lower than the median.

In using scientific data in setting public policy it only makes sense to use a group-level measure because the policy will apply to the group. Intuitively, we know airborne pathogen measurements on one farm do not represent all farms, just like all students of a school do not have the same reading scores. It is the summary measure of the group that is informative. For this QMRA, we have chosen to report the median risks where half of the irrigation events have higher risks and the other half are lower. For a more conservative approach, policymakers could use the 75th percentile risk level, meaning 25% of irrigation events exceed the summary measure (Figure C-10), or the 95th percentile where only 5% of the risk estimates are higher (Figure C-11). The difficult decision is which summary measure to use.

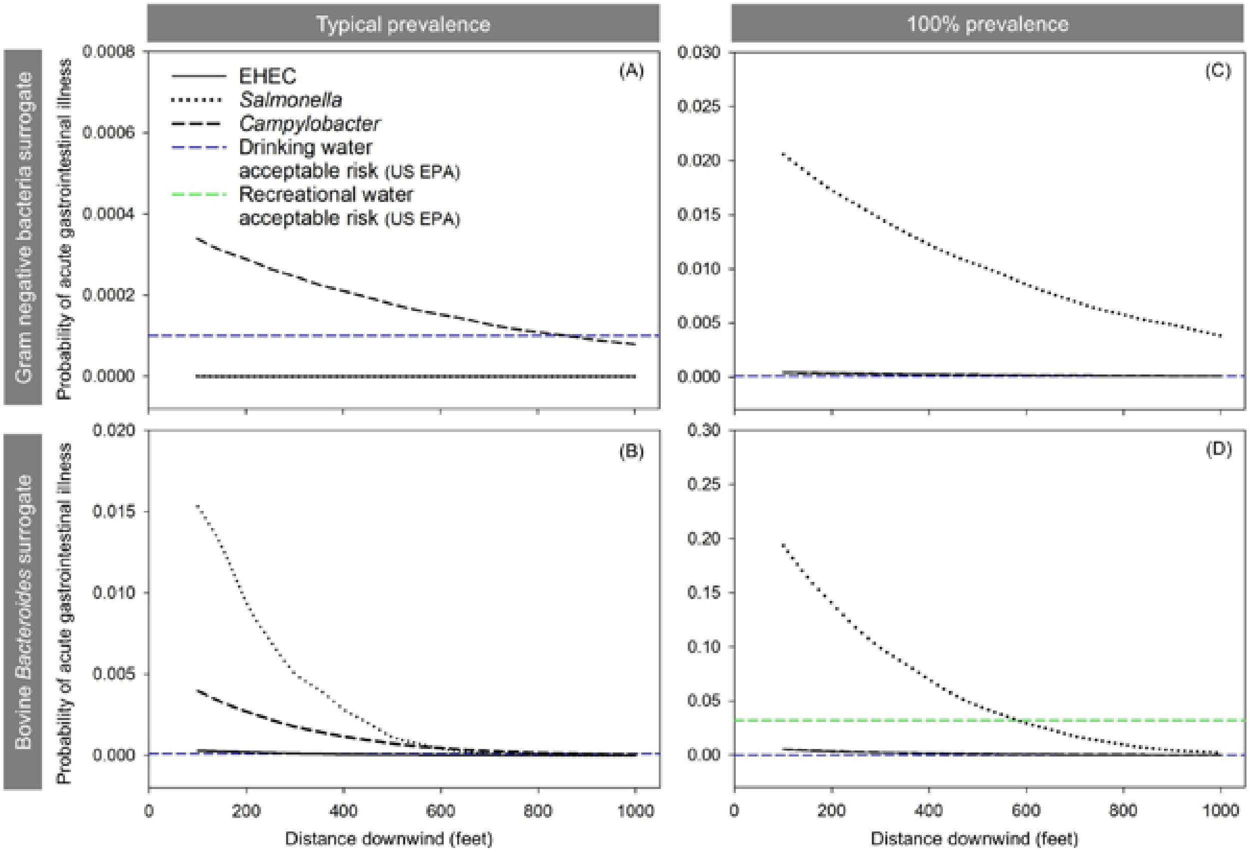

Figure C-10

Figure C-10. Risk estimates using the 75th percentiles of the risk distributions for acute gastrointestinal illness caused by three pathogens as related to distance from the wetted perimeter of irrigated dairy manure. Irrigation was by traveling gun or center pivot. The lines for each pathogen indicate the risk estimate at which 25% of the risk estimates are higher and 75% are lower. Notation and organization of the plots are identical to Figure C-8.

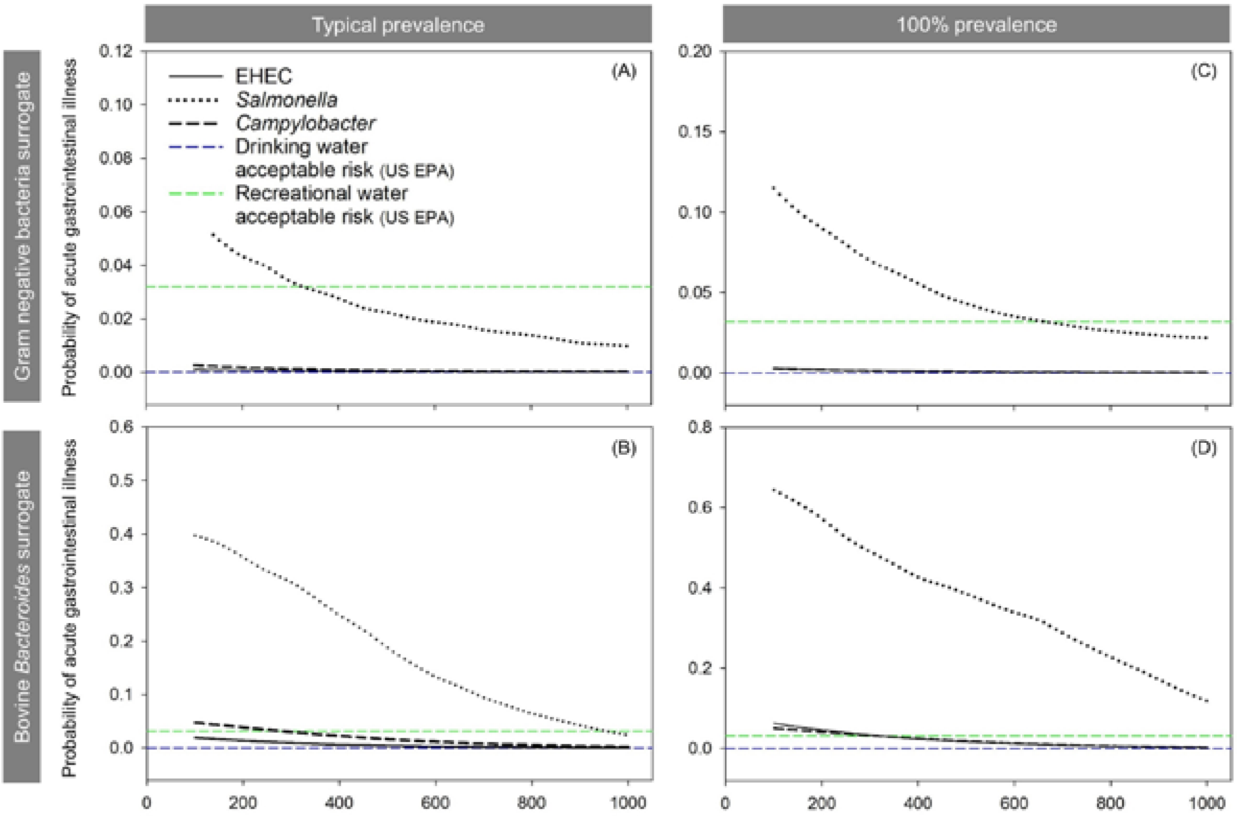

Figure C-11

Figure C-11. Risk estimates using the 95th percentiles of the risk distributions for acute gastrointestinal illness caused by three pathogens as related to distance from the wetted perimeter of irrigated dairy manure. Irrigation was by traveling gun or center pivot. The lines for each pathogen indicate the risk estimate at which 5% of the risk estimates are higher and 95% are lower. Notation and organization of the plots are identical to Figure C-8.

Study Summary

This is a non-technical summary of a study that has extensive supporting data and technical analysis. Data, statistical models, and results are available from the authors upon request. Another publication, with additional details of the study, is anticipated.

Application of liquid dairy manure by traveling gun or center pivot irrigation systems is becoming more common in Wisconsin because it offers several potential benefits: reduced road impacts from hauling, optimal timing for crop nutrient uptake, and reduced risks of manure runoff and groundwater contamination. However, irrigation could also increase the risk of airborne pathogen transmission from manure to humans and livestock compared to other application methods. We measured air concentrations of manure-related microbes during 23 manure irrigation events on three Wisconsin dairy farms at multiple distances, typically up to 700 feet, downwind from the irrigated wetted perimeter. We also measured background air concentrations before irrigation and upwind concentrations during irrigation. Air was sampled by two methods at each distance: button samplers for qPCR analysis of microbial targets and Andersen impactors for culturable bacteria. Meteorological conditions during irrigation were measured with a portable weather station.

Results show that microbial concentrations decline with distance, but can still be measurable at 700 feet downwind from irrigation depending on wind velocity and the microbe initial concentration in manure. Using quantitative microbial risk assessment, we estimate the risk for acute gastrointestinal illness for exposure to airborne pathogens 500 feet downwind from dairy manure irrigation is on the order of 0.00001 to 0.01 (1 in 100,000 to 1 in 100) per irrigation event. The risk estimate depends primarily on pathogen type, pathogen prevalence on dairy farms, downwind distance from the irrigation equipment, and the number of irrigation events during a growing season. Also, it is important to recognize the risk values reported herein are medians of the risk distribution; users of this report might decide to use lower or higher percentiles of the risk distributions.

This comprehensive risk assessment is the first to use measured concentrations of airborne pathogens during manure irrigation. Overall, the decisions made in conducting this risk assessment were conservative towards protecting public health. Using bovine *Bacteroides* as a surrogate, which possesses high resistance to environmental inactivation, likely leads to higher detection frequencies and concentrations downwind than what might be expected for most pathogens. Assuming that 100% of dairy farms have a specific pathogen, like *Salmonella,* in their manure also results in conservative risk estimates. Other elements of the risk assessment were favorable for producing the most accurate risk estimates. The bacteria air concentrations during manure irrigation were from actual field measurements. The dose-response models derived from outbreak data likely represent the pathogen strains circulating in the population and likely include the health outcomes of the most vulnerable populations. The distributions for age, inhalation rate, and time spent outdoors were from widely accepted sources. And, the ingestion to inhalation ratio was derived from empirical data and first principles.

The findings from this study will be useful to policymakers and public health officials for establishing safe setback distances from irrigated dairy manure.

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