Human and Animal Pathogens in Manure

Merle E. Olson, Microbiology and Infectious Diseases, University of Calgary

Introduction

Fecal wastes from domestic animals, wildlife and humans are applied to the soil surface and to varying extents are incorporated into the soil. These fecal wastes can also enter water systems by direct contamination of the water or through seepage or surface runoff. Humans contaminate water sources through poorly processed sewage effluents, malfunctioning septic tanks and seepage from sanitary landfills. Domestic and wild animals contaminate water by defecation in unprotected surface water, through runoff and as a result of seepage of water through soil that contains an excessive amount of animal feces. A wide variety of pathogenic viruses, bacteria and parasites may be found in the feces of wild and domestic animals and humans. Also, non-pathogenic bacteria and parasites are found in large numbers in the feces of animals as well as soil and water. Only a small number of animal pathogens in feces, water and soil have the potential to infect humans and domestic animals (Table 1). These are the pathogens that are of great concern to the public, who are usually exposed to these animal pathogens through consumption of fecal contaminated food or water.

Concentration of wildlife is also a potential source of water and soil contamination. Some types of wildlife congregate in herds and flocks and can contribute to extensive pathogen contamination to the water and soil in certain location and times of the year.

Bacterial, parasitic and viral pathogens in human fecal waste have the greatest potential to cause infection in other humans. Raw sewage is processed to varying degrees before it is distributed on soil or discharged into water systems. Failure to appropriately process human sewage probably poses the greatest threat to human health however it is often impossible to identify sources of food and water contamination. Animal feces may contain pathogens infectious to both humans and animals. As a result food animals are incriminated in many waterborne and foodborne outbreaks. It is critical for human health, animal health and agriculture sustainability reasons that water and food supplies be protected from contamination by animal feces.

Table 1. Prevalence of Enteric Pathogens in Humans, Cattle, Pigs and Poultry.

	Human	**Cattle**	**Pigs**	**Poultry**
Salmonella spp	1%	0-13%	0-38%	10-100%
E. coli 0157:H7	1%	16%	0.4%	1.3%
Campylobacter jejuni	1%	1%	2%	100%
Yersinia enterocolitica	0.002%	<1%	18%	0%
Giardia lamblia	1-5%	10-100%	1-20%	0%
Cryptosporidium spp	1%	1-100%	0-10%	0%

Parasitic pathogens

There are a large number of animal parasites that can cause infections in humans however most of these are present in developing countries and in tropical and subtropical areas. There are just four parasites of hogs that need to be considered, *Ascaris suum, Toxoplasma gondii, Giardia* and *Cryptosporidium*.

Ascaris suum* and *Ascaris lumbricodes. *Ascaris lumbricodes* is the largest intestinal roundworm of man and is especially common in the tropic and subtropics. *Ascaris suum* is the common roundworm of pigs. Pigs and humans become infected by ingestion of eggs that have developed to an infective stage in the environment. *Ascaris* eggs are environmentally resistant. After hatching, the larvae penetrate the gut wall and migrate to the lung passing through the liver. The larvae are coughed up and swallowed to develop to mature worms in the small intestine. Ascarisiasis in both species produces ill thrift, stunting, potbelly and diarrhea.

In Saskatchewan, examination of up to 50% abattoir pig livers demonstrated scarring associated with migration of ascarid larvae.[1] *A. suum* eggs under dry conditions survive for two-to-four weeks while under a moist and cool environment they can survive for over eight weeks.[2] The routine use of anthelminths (eg. Ivermectin) and containment, which breaks the parasite life cycle, have dramatically reduced the prevalence of *Ascaris* infection in pigs. *Ascaris* was identified in 60% of 50 Alberta farms but only 8.5% of animal were infected.[3] *Ascaris* was only identified on farms that kept dry sows outdoors on soil where they became infected.

The larvae of *Ascaris suum* can migrate into the tissues of many animals including man. Under certain circumstances *Ascaris suum* can produce patent infections in man, and develop readily even maturing. As *Ascaris suum* cannot be differentiated from *Ascaris lumbrocoides* it is often difficult to determine the source of human infections. It is generally accepted that humans are infected by exposure to infective eggs from human feces. Human infection from pigs is rare.[4] As *Ascaris* eggs were identified in only 1% of lagoon samples, there is a minimal risk of human infection from environmental contamination of water or soil by hog waste.[3]

Toxoplasma gondii. Toxoplasmosis is a protozoan disease caused by the microscopic parasite *Toxoplasma gondii*. It is prevalent in humans and animals throughout the world. There are three infective stages of T. gondii including tachyzoites (multiplies within the host), bradyzoites (in tissue cysts) and sporozoites (in oocysts). Cats are the definitive hosts but oocysts excreted by cats can infect a wide variety of mammalian hosts (cattle, goats, sheep, pigs, chickens) where cysts containing bradyzoites develop within their tissue. Ingestion of these bradyzoites can lead to infections in humans. Infection with *T. gondii* is widespread in human and animals. In North America it is estimated that 16-40% of people are infected. Most infections in humans and animals are asymptomatichowever the parasite can occasionally cause devastating congenital infections leading to abortions and birth defects. Post-natally acquired infection may be localized or generalized. Fever, myalgia, enlarged lymph nodes, headache and stiff neck are the most common symptoms in humans. Toxoplasmosis is frequently the cause of death in severely immunosuppressed individuals (eg. AIDS).

Toxoplasma has been demonstrated in pigs world wide. Serological testing of pigs in the United States and Canada have shown seroprevalences between 3.5 to 48%[5,6]. *Toxoplasma* was not demonstrated in farms where pigs were raised under total confinement. Infection in pigs is associated with exposure to cats and contaminated soil[5,7].

The frequency of infection through the consumption of contaminated raw meat and that due to ingestion of food contaminated by fecal oocysts from cats is not known. Recently a waterborne outbreak of toxoplasmosis was reported in British Columbia and was attributed to water contamination by cougars. Cooking meat to over 67^{o} C or cooling to less than -13^{o} C kills tissue cysts. Tissue cysts in pork can be eliminated by raising pigs in the absence of cats and ensuring that cat feces does not contaminate pig food. For pork produced under modern, contained production systems there is considered to be an extremely low risk of containing *Toxoplasma*. The majority of human infections are probably associated with their contact with fecal oocysts shed by cats.[8] Hog manure poses no risk of transmission to humans.

Giardia. Giardiasis is caused by a microscopic flagellated protozoan parasite called *Giardia duodenalis* (syn. *Giardia lamblia*). It is the most common pathogenic intestinal parasite of humans with worldwide distribution.[9] This parasite has a motile form that divides within the lumen of the small intestine. It produces highly resistant cysts that are shed into the environment. The cysts are highly infectious and as few as 10 cysts can cause infection and disease. In the past, humans, dogs, cats, and certain species of wildlife were described as the principal hosts of this parasite.[9] However, recent studies have identified domestic livestock (e.g., cattle, sheep, pigs, horses) as major hosts for this parasite[11,12,13]. The parasite colonizes the small intestine of humans and animals leading to moderate-to-severe diarrhea. Children and the immunosuppressed are the most vulnerable. The prevalence of giardiasis in humans is 2-7% in Europe and North America, whereas it can be as high as 40% in developing countries. *Giardia* is predominantly transmitted through oral-fecal routes (usually between humans) however waterborne and foodborne zoonotic transmission have been reported. Giardiasis is the most frequently diagnosed water-borne disease. Water contamination is associated with human sewage effluent and agriculture runoff. *Giardia* cysts can survive for months in water and are resistant to chlorination, which is used to remove pathogens in water. *Giardia* cysts can be removed from water through filtration or inactivated by boiling water or by powerful chemical agents (eg. ozone). The World Health Organization has recommended that *Giardia* infection be considered as a zoonoses.

Giardia duodenalis is a common parasite of wild and domesticated vertebrates. Giardia has been demonstrated in pigs in Canada, the United States and in Europe. Giardia was reported in four of six hog operations with an overall prevalence of 9%.[12] In a large Alberta study involving 1602 animals and 50 farms, Giardia was documented in 70% of farms and in 8.5% of fecal samples collected.[3] *Giardia* cysts were identified in 3.8% of piglets, 9.8% of weaners, 10.8% of growers, 15% of finishers, 5,7% of boars and 4.1% of sows.[3] A significant proportion of feral pigs (7.6%) in California have been shown to be infected with Giardia. This may pose a serious health risk to humans and be a source of infection for domestic pigs.[14] *Giardia* cysts have been shown to be degraded in hog liquid holding tanks and therefore it is unlikely that distribution of liquid manure poses a serious threat for contamination of surface water.[3]

There is strong evidence to show that at least some *Giardia* isolates are not host-specific while others are host-adapted. Thus some strains have a higher potential for human infection than other strains. Although few porcine *Giardia* stains have been biotyped, most isolates that have been characterized are unlikely to cause human infections.[3] Clearly more work is required to compare human and pig *Giardia* isolates.

Infections in domestic ruminants are of special concern because of the potential contamination of surface and groundwaters through pasture runoff and use of manure as a spray on fields. Outbreaks from water-borne giardiasis in humans have been attributed to pasture runoff leading to drinking water contamination.[9] Disease outbreaks have most often been attributed to the waterborne method of transmission.[15] It is believed that human effluent is the major source of water contamination, but certainly contamination of water with infected animal feces can lead to widespread infections in human and animals.[9,10] Water mammals, like beavers, have been implicated with many waterborne infections of *Giardia*; however, certainly other animals may be more likely candidates to contaminate water supplies. Foodborne infections have been associated with poor hygiene in food handlers and washing food with contaminated water.[9] This is a particular concern as water is important in the processing of many foods. The cysts have a protective carbohydrate wall that makes them resistant to environmental destruction.[9] and are only destroyed by desiccation, heat, UV radiation and high concentrations of biocides (bleach).[9,16]

Cryptosporidium. *Cryptosporidium parvum* is a small protozoan coccidian parasite that colonizes the small intestine of a wide variety of vertebrate animals and man. This parasite has intestinal forms that multiply within the intestinal epithelium and environmentally resistant oocysts that can be shed in the feces. Until the 1970's *Cryptosporidium* was considered as unimportant, however over the past 30 years this parasite has been identified in severe intestinal disease in both humans and animals. *Cryptosporidium parvum* infects humans a wide variety of domestic (e.g. cattle, pigs, horses, sheep, dogs, cats) and wild mammals. Other species of *Cryptosporidium* infect birds (*C. baileyi* and *C. meleagridis*), fish (*C. nasorum*), reptiles (*C. serpentis*) and small rodents (*C. muris*). Infections in animals and humans can be asymptomatic. In the young and immunosuppressed, severe watery diarrhea may develop. The clinical signs usually coincide with oocysts excretion and usually persist for one to two weeks. In immunocompromised humans, the infection is usually more severe and protracted and is frequently life threatening in humans undergoing immunosuppresive chemotherapy (e.g. transplantation, cancer) and certain infections that damage the immune system (eg. Human Immunodeficiency Virus).

As with *Giardia*, this parasite is transmitted by the oral-fecal and through the waterborne route. Poor hygiene leads to transmission between humans and from animals to humans. Fecal contamination of water by animals and humans may lead to waterborne outbreaks of cryptosporidiosis. Such an outbreak occurred in Milwaukee, Wisconsin and led to the infection of 5,000 humans.

Although there are limited studies, *Cryptosporidium* has been demonstrated in pigs throughout the world. Cryptosporidiosis may be responsible for diarrhea in piglets. In a Canadian study, *Cryptosporidium* was identified in three of four sampling sites with an overall prevalence of 11%.[3] In a larger Alberta study, *Cryptosporidium* was demonstrated in 32% of 50 farms sampled with a 2.8% overall prevalence[3]. Infection was predominately in weaners (10.4%). Oocysts were demonstrated in only 1% of hog liquid manure samples and not in soil samples, indicating that this parasite in hogs is not an environmental concern provided that manure is handled responsibly.[3]

Most human infections are acquired by person to person transmission (day care centres, hospital-acquired infections) and through consumption of drinking water contaminated by human effluent. Zoonotic infections have been attributed to contact with infected calves. There are several reports of veterinary students, farm workers and researchers developing infections after exposure to animals shedding large numbers of cysts[17].There are no reports of humans being infected with *Cryptosporidium* from pigs. Most likely the *Cryptosporidium parvum* being carried by pigs is not infective to humans.

Bacterial pathogens

Some bacteria in animals, such as *Salmonella spp*, have been known for many years to cause serious infection in humans. More recently, other pathogens such as *E. coli* O157:H7 and *Campylobacter* are emerging as important.

Salmonella. *Salmonella* is a bacterium that is widespread in the intestines of mammals, birds and reptiles. Salmonellosis is caused by many species of *Salmonella* and is characterized by three major symptoms - septicaemia, acute enteritis and chronic enteritis. The disease is observed in all animals and occurs worldwide. The incidence of salmonellosis in man has increased in recent years and animals have been incriminated[18].Feces of infected animals can contaminate animal feed, water, milk, fresh and processed meats and plant and animal products.[19] In swine, the prevalence of *Salmonella* spp in the feces has been reported in Quebec to be between 8 and 25%. [20] The disease is endemic on certain farms with sporadic outbreaks. Subclinical infections are observed in older animals. Stress such as transportation, crowding and mixing can precipitate clinical signs and shedding of the bacterium. People infected with Salmonella develop diarrhea, fever and abdominal cramps 12 to 72 hours after infection.[18] The illness lasts for less than a week and most individuals recover without treatment. The diarrhea in some people is so severe that it may require hospitalization and the infection can occasionally spread to the blood stream and other body sites. These patients may die of the infection. The elderly, infants and people with an impaired immune system are most susceptible to a severe illness. About 40,000 cases of salmonellosis are reported in Canada and the United States each year with about 1,000 people dying of acute salmonellosis each year[18].Salmonellae have become increasingly resistant to a variety of antimicrobial agents and there are concerns that some of this resistance is associated with antimicrobial use in agriculture and human medicine.[18]

A new strain of *Salmonella typhimurium* (called type DT104) has recently been recognized as a significant cause of diarrhea in animals and humans in Canada, the US and Europe[21]. This strain is of particular concern as it is resistant to several antibiotics that have traditionally been used to treat salmonellosis. The prevalence of *Salmonella typhimurium* DT 104 has been increasing in the past few years [19,21].

Salmonella is usually transmitted to humans by eating foods contaminated with animal feces.[18-21] Meat is usually contaminated at the slaughter house. Food may also be contaminated by food handlers who do not thoroughly wash their hands before touching food. The *Salmonella* bacterium is destroyed by cooking. Contaminated manure used to fertilize unprocessed foods (lettuce, sprouts, mushrooms) may be a source of human infection. Water may be contaminated by animals defecating in water or through runoff following heavy rainfall. Human infections may occur when unprocessed water is consumed or when the water is used to wash uncooked foods.[10-12]

Campylobacter. Campylobacteriosis is caused by a spiral-shaped bacterium, *Campylobacter* that is common in humans and animals. *Campylobacter jejuni* is the predominant species. *Campylobacter jejuni* colonizes the intestine of chickens, turkeys and waterfowl, however it is generally not pathogenic. It is estimated that over half of commercial poultry and free-living birds are natural reservoirs of *Campylobacter jejuni*.[18] *Campylobacter* has been isolated from the feces of pigs and calves with diarrhea however it is generally believed not to be a pathogenic cattle and hogs. *Campylobacter* is the most common bacterial cause of diarrheal illness in North America, infecting over 2 million people each year.[10] The clinical signs of people with campylobacteriosis are diarrhea, cramping, abdominal pain and fever lasting for 2 to 5 days. Nausea and vomiting are also common, although many infected people do not have symptoms. *Campylobacter* rarely causes death.

Most cases of campylobacteriosis are associated with handling of raw poultry or eating undercooked poultry products.[18] As few as 100 organisms can lead to infection in humans. Beef and pork products are less frequently involved in foodborne infections.[18] Consumption of unpasteurized cow's milk has led to outbreaks in humans.[18] Cattle and hog manure are a potnetial source of waterborne infections as direct contamination and agriculture runoff can lead to large numbers of organisms in water.[18,22.23]

Enteropathogenic *Escherichia coli*. Enteropathogenic *Escherichia coli* are present in the feces of humans and animals. Both animals and humans are responsible for pollution of lakes and streams. Although *Escherishia coli* may be found in feces, water and soil, only a small proportion (<1%) are potentially harmful strains. Most strains of *Escherichai coli* inhabit the intestines of healthy animals and humans and are harmless and in many cases beneficial. The harmful strains are called enterotoxogenic *Escherichia i coli* (ETEC) and the most common of these is *Escherichia coli* O157:H7. *Escherichia coli* O157:H7 and some other strains, produce potent toxins that can cause severe illness in humans. The combination of letters and numbers in the bacterium name refers to specific surface proteins that distinguish it from the harmless types of *Escherichia coli*. The organism can be found in the feces of some healthy cattle[24-27]. Other domestic animals (sheep, pigs,) and wildlife (e.g. deer) can also harbour *Escherichia coli* O157:H7.[18] The prevalence of *E.coli* O157:H7 has been reported to be between 0.4% and 7.5% of healthy pigs and up to 1.5% of pork meat samples. Verotoxin producing *E.coli* O157:H7 are only rarely isolated. [27] This is contrast to cattle where 15% of cattle shed *E.coli* O157:H7 and up to 99% produce toxin. The risk to humans occurs when it contaminates food (meat, milk) or drinking water supplies[23,28]. Other sources of contamination include juice and uncooked greens (lettuce, sprouts)that have been contaminated with animal feces containing *Escherichia coli* O157:H7.[27] The bacteria can be transmitted from one infected human to another through poor hygiene.[18] Humans rarely carry the bacterium however young children can shed the bacterium for one to two weeks after an infection. Ingestion of just a few organisms can lead to disease.

Escherichia coli O157:H7 infection may cause severe bloody diarrhea and abdominal cramps. Symptoms can also be mild to none at all. Usually the illness resolves in 5 to 10 days. In young children and the elderly, the infection can cause a serious complication called hemolytic uremic syndrome where the red blood cells are destroyed and the kidneys fail to function. This occurs in about 2% to 7% of the cases. These patients may die from this complication or have life-long kidney failure, seizures, blindness or high blood pressure.

As pigs rarely excrete verotoxin producing *Escherichia coli* O157:H7, pig manure is considered a very low risk for human infections.

Yersinia Enterocolitica. *Yersinia Enterocolitica* is a bacterium that has been demonstrated in the feces of pigs and cattle.[23] It is an enteric pathogen and causes fever, abdominal pain, and diarrhea throughout the world. Most animal strains are probably not a serious health risk to humans but *Yersinia enterocolitica* O:3 is a strain which causes illness in humans and can be isolated from the tonsils, oral cavity, intestines and feces of up to 83% of pigs.[27] Although there are no documented transmission studies, pigs have been implicated in human infections. Exposure to pig feces is considered an occupational risk for yersiniosis. Swine slaughterhouse workers and farmers are considered to be at high risk of developing diarrhea associated with *Yersinia Enterocolitica.*

Survival of pathogens in manure and the environment

The survival of various organisms under different condition is summarized in Table 2. It is clear that holding manure as a slurry, as a solid or as compost before it is distributed, results in a significant reduction in pathogen concentration. As most pathogens survive freezing or low temperatures for extended periods of time, the manure should not be distributed on fields where there is a potential for runoff during the spring melt.

Giardia and Cryptosporidium. The cysts and oocysts can survive for months in cold water (Table 2). *Giardia* cysts in soil and manure are inactivated by freezing, desiccation and by the bacterial degradation. Warmer temperatures accelerate the degradation process. A similar pattern exists for *Cryptosporidium* oocysts but they are inactivated more slowly than *Giardia* cysts and are resistant to freezing. Composting results in the inactivation of *Giardia* and *Cryptosporidium* oocysts, however it takes several weeks.[31]

Ascaris suum. *Ascaris suum* eggs are highly resistant to inactivation in the environment and within feces.[34] They can remain viable in soil and feces for years. Composting of manure reduces the number of eggs, although this does not totally eliminate them. To break the life cycle, pigs should not be exposed to soil or feces where infected animals were previously housed or where contaminated manure was spread on fields. Humans should avoid contact with contaminated soil and manure.

Salmonella. Table 2 summarizes the duration of time that *Salmonella* microorganisms can survive in manure, soil and water[134-36]. *Salmonella* can survive in manure for up to three weeks and in manure slurry for up to five weeks. Aeration of slurries reduced the time for the *salmonella* destruction. Destruction of the bacterium is also accelerated by increasing temperatures. Composing the manure dramatically accelerates the inactivation of *Salmonellawhich* are eliminated from composted cattle and pig manure within days once the temperatures reach 35 ^{o}C. *Salmonella* are also readily inactivated in food waste compost where they are eliminated within nine days. *Salmonella* can be detected in manure seepage water for 42 days, indicating that care must be taken to control runoff from manure and compost piles. It can survive in water for months and cold water acts to prolong the viability. *Salmonella* is not inactivated by freezing and is relatively resistant to killing by drying and freezing.

Campylobacter jejuni. Survival data *Campylobacter* is summarized in Table 2.[37-40] *Campylobacter* can be frequently identified in raw surface water. Conventional chlorination of the water destroys the bacteria. The mean survival times are extended in cold water. Formation of bacterial aggregates with other *Campylobacter* or normal water bacteria also extends the survival time in water. *Campylobacter* can survive for weeks in the frozen state however they are rapidly inactivated by desiccation. Composting manure leads to the elimination of *Campylobacter* within a week although the organism can survive for several weeks in manure. There is a substantial risk of contacting and developing campylobacteriosis from drinking unprocessed surface water.

Escherichia coli O157:H7. Although the major cause of *Escherichia coli* O157:H7 infection is fecal-contaminated meat, manure may contaminate water and soil leading to waterborne outbreaks of *Escherichia coli* O157:H7 infection. *Escherichia coli* O157:H7 is fairly environmentally resistant and has extended survival in water, feces and soil (Table 2) [38, 41-44]. Indeed, under certain conditions the organisms' numbers can increase thereby enhancing its health risk. With the low infective dose and the ability of the organism to survive under a variety of environmental conditions, *E coli* can readily contaminate surface waters and even can percolate through soil that has had excessive manure applications. Chlorination of drinking water will inactivate the *Escherichia coli* O157:H7 bacterium. Contaminated soil and manure used as fertilizer can also contaminate fruits and vegetables. Infection can result if these foods are consumed without cooking or thorough washing. Composting provides an excellent method for elimination of this pathogen from manure (table 2).

Yersinia enterocolitica. Yersinia is highly resistant to environmental degradation.[38,45] It can survive for over a year in cold water and soil although it is degraded within a month in feces and slurry.

Antibiotic resistance and exposure to manure

It has been suggested that human exposure to manure from animals given sub-therapeutic and therapeutic dosages of antimicrobial agents, is responsible for some cases of antimicrobial resistance[46-49]. This has not been scientifically documented but resistance to numerous antibiotics used to treat infections (*Salmonella, E. coli, Campylobacter*) in animals and man has been established.[46-49] Also transmission of antibiotic resistant genes from manure bacteria to pathogen bacteria has been conducted in the laboratory.[49] Indeed, there is a potential risk of antibiotic resistance transfer but the extent of the risk is unknown. Most antibiotic resistance in humans is from inappropriate use by physicians and patients.

Table 2. Survival of Animal Fecal Pathogens in the Environment

Material	Temp	Duration of Survival					
		Giardia	Crypto-sporidium	Salmonella	Campylo-bacter	Yersinia entercoliticia	E. coli O157:H7
Reference		21-23	24-25	26-28	29-31	30,37	32-36
Water	frozen	< 1 day	> 1 year	>6 mos	2-8 weeks	> 1yr	>300 days
	cold (5C)	11 wks	> 1 year	>6 mos	12 days	>1 yr	>300 days
	warm (30C)	2 wks	10 wks	>6 mos	4 days	10 days	84 days
Soil	frozen	< 1 day	> 1 yr	>12 wks	2-8 weeks	>1yr	>300 days
	cold (5C)	7 wks	8 wks	12 - 28 wks	2 weeks	> 1yr	100 days
	warm (30C)	2 wks	4 wks	4 wks	1 week	10 days	2 days
Cattle Feces	Frozen	< 1 day	> 1 yr	>6 mos	2-8 weeks	>1yr	>100 days
	Cold (5C)	1 wk	8 wks	12-28wks	1-3 week	30-100 days	>100 days
	Warm (30C)	1 wk	4 wks	4 weeks	1 week	10-30 days	10 days
Slurry		1 yr	>1 yr	13-75 days	>112 days	12-28 days	10-100 days
Compost		2 wks	4 wks	7- 14 days	7 days	7 days	7 days
Dry Surfaces		1 day	1 day	1- 7 days	1 day	1 day	1 day

Groundwater. Groundwater has superior quality with respect to microbial content because of an effective barrier of soil on top of impervious rock strata. The water is not significantly influenced by climate, agricultural runoff and stormwater migrations. Unfortunately, sink holes and caverns can form, through which surface water can pass. Excessive land application of minimally treated wastewater can inundate natural soil barriers[50,51,52]. Excessive distribution of animal wastes from feedlots or hog operations, as well as poorly located and contained water plant sludges and garbage waste can contribute to significant pathogen releases in leachates. Once the aquifer becomes contaminated, restoration of water purity is very slow. Much of groundwater contamination is associated with shallow wells (less than 100 ft deep). These wells are susceptible to surface water runoff that percolates through the soil. In these cases, water quality is erratic and is influenced by storm events and excessive spreading of manure on the land.

Airborne hazards. Animal manure releases several gases (ammonia, hydrogen sulfide, carbon monoxide, methane) that pose hazards to humans and animals.[23] Sustained exposure to high concentrations in a confined space can lead to irritation of mucous membranes (ammonia, hydrogen sulfide gas). Higher concentrations of hydrogen sulfide may cause vomiting, nausea, diarrhea and acute asphyxiation. Airborne hazards tend to occur in confinement buildings in the winter where ammonia and hydrogen sulfide concentrations can reach toxic levels due to inadequate ventilation. Toxic gases are not consided to be a health concern to outside workers.[23]

Airborne dust associated with manure is a concern for animals and humans. Animal feces, urine, dander, bacteria, bacterial toxins, fungi, feed and bedding dust, pollen and insect all compromise the dust that is associated with confined and intensive outdoor livestock operations. It has been suggested that bacteria associated with manure have been responsible for both respiratory and intestinal diseases.[23] These bacteria can reach concentrations of over 1 million organisms per cubic meter. Toxins are also produced by bacteria (e.g. endotoxins). These toxins have been shown to produce fever and respiratory illness.[23] Moulds can lead to serious infections such as

Aspergillus in immunocompromized patients. For this reason individuals with an immunosuppressive disease, or who are receiving immunomodulating drugs should avoid exposure to manure dust. Some individuals may develop serious hypersensitivities to components within the manure dust (moulds, animal saliva, pollen) that may result in pulmonary damage, skin rashes, and asthma. It is recommended that anyone working in an area where there is significant manure dust particles should wear a protective mask to prevent both hypersensitivities and infections. It has also been suggested that odours from animal production areas may have psychological effects such as depression and anger.[53]

References

1.Wagner B. et al (1997) Ascaris suum prevalence and intensity: an abattoir survey of market hogs in Saskatchewan. Veterinary Parasitology 73:309-313.

2. Gassenbeek C.P. et al (1998) Studies on the survival of Ascaris suum eggs under laboratory and simulated field conditions. Veterinary Parasitology 75:227-234.

3. Guselle M. et al. (1999) Human pathogens in Alberta Hog Operations. Report to Alberta Pork Producers.

4. Anderson T.J. et al (1997) Host specificity, evolutionary relationships and macrogeographic differentiation among Ascaris populations from humans and pigs. Parasitology 115:325-342.

5. Gajadhar A.A. et al (1998) Prevalence of *Toxoplasma gondii* in Canadian market age pigs. Journal of Parasitology 84:759-763.

6. Gamble H.R. et al (1999) Prevalence of *Toxoplasma gondii* infection in domestic pigs in the New England states. Veterinary Parasitology 82:129-136.

7. Davies P.R. et al (1998) Seroprevalence of *Toxoplasma gondii* and *Trichinella spiralis* in finishing swine raised in different production systems in North Carolina, USA. Preventative Veterinary Medicine 36:67-76.

8. Dubey J.P. (1998) Toxoplasma, sarcocystosis, isosporosis and cyclosporosis. *In* Zoonoses, Eds. S.R. Palmer, Lord Soulsby and D.I. H. Simpson D.I.H., Oxford University Press, Oxford, pp 579-597.

9. Wolfe MS. Giardiasis. Clinical Microbiology Reviews 1992; 5: 93-100.

10. Xiao L. Giardia infection in farm animals. Parasitology Today 1994; 10: 436-438.

11. Olson M.E., Thorlakson C.L., Deselliers L., Morck D.W., McAllister T.A. *Giardia* and *Cryptosporidium* in Canadian Farm Animals. Veterinary Parasitology. 1997; 68: 375-381.

12. Olson M.E., Guselle N.J., O'Handley R.M., Swift M.L., McAllister T.A., Jelinski M.D., Morck D.W. *Giardia and Cryptosporidium* in dairy calves in British Columbia. Can Vet J 1997; 38: 703-706.

13. O'Handley RM, Cockwill C, McAllister T.A., Jelinski M., Morck D.W., Olson M.E. Duration of naturally acquired giardiosis and cryptosporidiosis in dairy cattle and their association with diarrhea. Journal of the American Veterinary Medical Association 1999; 214: 391-396.

14. Atwill E.R. et al (1997) Prevalence and risk factors for shedding *Cryptosporidium parvum* oocysts and *Giardia* cysts within feral pigs. Applied and Environmental Microbiology 63:3946-3949.

15. Wallis P.M., Erlandsen S.L., Issac-Renton J.L., Olson M.E., Robertson W.J., H. Van Keulen. Prevalence of *Giardia* cysts and *Cryptosporidium* oocysts and characterization of Giardia spp isolated from the drinking water in Canada. Applied and Environmental Microbiology 1996; 62: 2789-2797.

16. Marshall M.M., Naumovitz D., Ortega Y., Sterling C.R. Waterborne protozoan pathogens. Clinical Microbiology Reviews 10: 67-85, 1997.
17. Coop R.I. (1998) Cryptosporidiosis. *In* Zoonoses, Eds. S.R. Palmer, Lord Soulsby and D.I. H. Simpson D.I.H., Oxford University Press, Oxford, pp 563-578.
Rose J.B., T.R. Slifko. Giardia, Cryptosproidium and Cyclospora and their impact on foods: a review. Journal of Food Production 62: 1059-1070, 1999.
18. Tauxe R.V. Evolving foodborne diseases: an evolving public health challenge. Emerging Infectious Diseases. 3: 425-434, 1997.
19. Ekperigin H.E., K.V. Najaraja. Veterinary Clinics of North America 17-29, 1998.
20. Letellier A. Distribution of Salmonella in swine herds in Quebec. Veterinary Microbiology 67: 229-306, 1999.
21. Gynn M.K., Bopp C., Dewitt W., Dapney P, Mokhtar M, Angulo FJ. Emergence of multidrug resistant *Salmonella typhimurium* DT104 infections in the United States. New England Journal of Medicine 338: 1333-1338, 1998.
22. Bushwell CM, Herlihy YM, Lawrence L.M., McGuiggan J.T., Marsh P.D., Keevil C.W., Leach S.A. Extended survival and persistence of Campylobacter in water and aquatic biofilms and their detection by immunofluorescent-antibody and rRNA staining. Applied and Environmental Microbiology 64: 733-741, 1998.
23. Cole D.J., V.R. Hill, F.J Humenik, Sobsey M.D. Health, safety and environmental concerns of farm animal waste. Occupational Medicine, 14: 423-448, 1999.
24. Laegreid W.W., R.O. Elder, J.E. Keen. Prevalence of Escherichia coli O157:H7 in range beef calves at weaning. Epidemiology and Infection 123: 291-298, 1999.
25. Hancock D.D., D.H. Rice, L.A. Thomas, D.A. Dargatz, T.E. Besser. Epidemiology of Escherichia coli O157:H7 in feedlot cattle. Journal of food Production 60: 462-465, 1997.
26. Zhao Z., M.P. Doyle, J. Shere, L. Garber. Prevalence of enterohemorrhagic Escherichia coli O157:H7 in a survey of diary herds. Applied and Environmental Microbiology 61: 1290-1293, 1995.
27. Tauxe R.V. Emerging foodborne diseases: an evolving public health challenge. Emerging Infectious Diseases 3:425-434, 1997.
28. Cieslak P.R., T.J. Barrett, P.M. Griffin, K.E. Gensheimer, G. Beckett, J. Buffington , M.G. Smith. Escherichia coli O157:H7 infection from a manured garden. Lancet 342: 367, 1993.
29. Schiemann D.A., C.A. Flemming. Yersinia enterocolitica isolated from the throats of swine in eastern and western Canada. Canadian Journal of Microbiology 27: 1326-1333, 1981.
30. Olson M.E., Goh J., Phillips M., Guselle N., McAllister T.A. Giardia cyst and Cryptosporidium oocyst survival in water soil and cattle feces. J. Environ Quality 1999; 28: 1991-1996.
31. McAllister T. A., Olson M.E. (Unpublished results)
32. Robertson L.J., A.T. Campbell, H.V. Smith. Survival of Cryptosporidium parvum oocysts under various environmental pressures. Applied and Environmental Microbiology 58: 3494-3500, 1992.
33. Fayer R., J,M. Trout, M.C. Jenkens Infectivity of Cryptosporidium parvum oocysts in water at environmental temperatures. Journal of Parasitology 84: 1165-1169, 1998.
34.HimathongkhamS., S. Bahari, H. Riemann, D. Cliver. Survival of E. coli O157:H7 and Salmonella typhimurium in cow manure and cow slurry. FEMS Microbiology letters 178: 251-257, 1999.
35. Plym-Forshell L. Survival of Salmonella and Ascaris suum eggs in a thermophilic biogas plant. Acta Veterinaria Scandinavica 36: 79-85, 1995.

36. Plym-Forshell L., I. Ekesbo. Survival of Salmonella in composed and not composted solid animal manure. Journal of Veterinary Medicine B 40: 654-658, 1993.
37. Kenneth R.W., Hudson J.A., Thom K. Aerobic growth and survival of Campylobacter jejuni in food and stream water. Letters in Applied Microbiology 27: 341-144, 1998.
38. S.I. Terzieva, G.A. McFeters. Survival and injury of Escherichia coli, campylobacter jejuni and Yersinia enterocoliticia in a stream. Canadian Journal of Microbiology 37: 785-790, 1991.
39. U.K. Wolverhampton Evaluation of the effect of temperature and nutrients on the survival of Campylobacter spp in water. Journal of Applied Microbiology 86: 1024-1032, 1999.
40. Wang G., Doyle M.P. Survival of enterohemorrhagic Escherichia coli O157 in water. Journal of Food protection 61: 662-667, 1998.
41. S.G. Jackson et al Escherichia coli O157:H7 diarrhea associated with well water and infected cattle on an Ontario farm. Epidemiology and Infection 120: 17-20, 1998.
42. Kudva I.T., Blanch K., Hovde C.J. Analysis of Escherichia coli O157:H7 survival in ovine or bovine manure and manure slurry. Applied and Environmental Microbiology. 64: 3166-3174, 1998.
43. Bolton D.J., Byrne C.M., Sheridan J.J., McDowell D.A., Blair I S. The survival characteristics of a non-toxogenic strain of Escherichia coli O157:H7. Journal of Applied Microbiology 86: 407-411, 1999.
44. Kudva I.T., K. Blanch., Hovde C.J. Analysis of Escherichia coli O157:H7 survival in ovine or bovine manure and manure slurry. Applied and Environmental Microbiology 64: 3166-3174, 1998.
45. Chao W-L, Ding R-J, Chen R-S. Survival of Yersinia entercolitica in the environment. Canadian Journal of Microbiology 34: 753-757, 1988.
46. Huovinen P. Bacterial resistence; an emerging health problem. Acta Vet Scandinavia 92: 7-13, 1999.
47. Wegner H.C., F. M. Aarestrup, P. Gerner-Smidt, F. Bager. Transfer of antibiotic resistant bacteria from animals to man. Acta Vet Scandinavia 92: 51-57, 1999.
48. Franklin A. Current status of Antibiotic Resistance in Animal Production. Acta Vet Scandinavia 92: 23-28, 1999.
49. Kruse H. Indirect transfer of antibiotic resistance genes to man. Acta Vet Scandinavia 92: 59-65, 1999.
50. Jones P.W. Health Hazards associated with the handling of animal wastes. Veterinary Record 106: 4-7, 1980.
51. Jogbloed A.W., N.P. Lenis Environmental concerns about animal manure. Journal of Animal Science. 76: 2641-2648, 1998.
52. Kowel N.E. 1982 Health effects of land treatment: microbiological U.S. Environmental Protection Agency, EPA-600/1-82-007. Health Effects Research Laboratory, Cincinnati. OH.
53. Schiffman S.S. Livestock odours: Implications for human health and well being. Journal of Animal Science 76: 369-375, 1995.