2.2.1. Bacteria

2.2.1.1. *Salmonella*

All serotypes of this genus are pathogenic to humans and cause symptoms ranging from mild gastroenteritis to severe disease and death. In the United States, salmonellosis is mainly due to foodborne transmission because the bacteria found in beef and poultry are able to grow in foods (Pepper et al., 2006). *Salmonella* can apparently survive during sewage treatment and grow in biosolids under some conditions (Sahlstrom et al., 2006). Class A biosolids allows for growth of Salmonella under anaerobic concentrations (Zaleski et al., 2005a). Because of this potential for growth, Pepper et al. (2006) argue that *Salmonella* are the bacteria of greatest concern in Class B biosolids, although Skanavis and Yanko (1994) concluded a low probability of infection in most scenarios. In 40 Code of Federal Regulations (CFR) 503, *Salmonella* are the bacterial pathogen indicators for biosolids quality.

2.2.1.2. *Escherichia coli O157:H7*

Escherichia coli is found in the intestinal tract of humans and most warm-blooded animals, and most strains are not pathogenic. However, several strains can cause gastroenteritis. The greatest concern in the United States is enterohemorrhagic *E. coli* of the serotype O157:H7 (Pepper et al., 2006). The organism has been spread in contaminated drinking water, through recreational water exposure, and contaminated food (Yanko, 2005; Pepper et al., 2006; Barker et al., 1999). Cattle manure is the most significant source of exposure, but the organism has been detected in biosolids too (Lytle et al., 1999; Pepper et al., 2006).

2.2.2. Viruses

Over 140 types of enteric viruses are excreted by humans and are likely to be present in municipal wastewater. Viruses are almost always detected in Class B biosolids and by definition are not detected in Class A biosolids (Pepper et al., 2008a; Gerba et al., 2002). Examples covered here include enteroviruses, rotaviruses, caliciviruses, adenoviruses, astroviruses, and picornaviruses that may cause Hepatitis A and E.

2.2.4. Helminths

Several helminth species potentially occur in biosolids. Eggs of many helminth species probably settle in wastewater, are resistant to sewage treatment methods, and end up in biosolids (Bowman and Fayer, 2005).

2.2.4.1. *Trichuris trichiura*

Trichuris (whipworm) is a genus of nematode that is parasitic in the cecum and large intestine of mammals. It causes diarrhea. Human infections result from ingestion of infected eggs. Eggs in wastewater would be expected to settle rapidly and be found in sewage sludge wherever infected people are present in the community (Bowman and Fayer, 2005). Eggs are not likely to be damaged by the quantities of ultraviolet, ozone, or chlorine used for disinfection in wastewater treatment processes.

2.2.4.2. *Ascaris lumbricoides*

Ascaris is a genus of nematode that is parasitic in the small intestine. Adult worms may develop within the small intestine and cause digestive disturbances. Transitory liver and lung disease is caused by larval migration (Bowman and Fayer, 2005). Human infections with *Ascaris lumbricoides* result from ingestion of infectious *Ascaris* eggs usually from soil or produce grown in soil containing *Ascaris* eggs (APHA, 2004). Although *Ascaris* eggs appear to be present at very low densities in biosolids and perhaps even in raw sewage sludge (NRC, 2002), the eggs of *Ascaris* are an indicator in biosolids because of their resistance to most treatment processes and representativeness of helminth egg viability.

is humans or pigs. For *Taenia saginata*, eggs passed in the stool of humans are only infectious to cattle. Human infection is from the ingestion of raw or undercooked beef containing the larval stage (APHA, 2004). The adult worms cause few or no symptoms in humans, but eggs can develop to a larval stage (cysticercus) that can cause central nervous system and enteric symptoms. Although *Taenia* species are usually acquired from ingestion of infected beef or pork, the eggs of this pathogen have been detected in some biosolids (Barbier et al., 1990).

2.2.6. Emerging Pathogens

The lists of pathogens covered in this document should not be considered exhaustive. New pathogens are continually being identified or found in new areas for several reasons such as: changes in the way foods are produced, the global transportation of food and people, advances in molecular biology that permit the identification of new pathogens and their sources, the evolution of pathogens, aging demographics, and the use of microbial risk assessment to quantify risks from environmentally transmitted pathogens (Gerba and Smith, 2005). Emerging pathogens are novel pathogens that have not previously been characterized or established and have only recently been considered hazards of concern in particular media. Gerba et al. (2002) designated *E. coli* O157:H7, *H. pylori* and *L. monocytogenes* as newly emerging bacterial pathogens of potential concern in biosolids. Yanko (2005) points out that many of these emerging bacterial pathogens do not fit the classic fecal-oral transmission pattern. The NRC listed *Mycobacterium*, *E. coli* O157:H7, *Legionella*, *Listeria* and Microsporidia as emerging pathogens likely to be present in biosolids and Adenovirus, Norovirus, Astrovirus, Hepatitis A, Rotavirus and Hepatitis E as emerging viral pathogens likely to be present as well (NRC, 2002). Gerba (2005) listed several emerging viruses without speculating which are likely to be in biosolids, including: picobirnaviruses, picotrinaviruses, coronaviruses, and toroviruses. Yates and Yates (2007) added selected bacteria, viruses and parasites to water and/or microcosms to simulate Class A and Class B treatment. They observed that organisms surviving in the highest numbers or numbers representing the highest risk included *E. coli, Clostridium perfringens* spores, *Listeria innocua* and bacteriophage phi X174.

NRC (2002) identified criteria for selecting emerging pathogens for which additional information on occurrence, persistence, and risk is justified, and for which additional regulations may be needed. These criteria are useful for selecting pathogens on which to focus the hazard characterization in a risk assessment:

3.3.2. Pathogen Transport

Pathogens may be transported from biosolids through various environmental media such as air, soil, and water. In addition to the application process, storage, site-to-site transportation, and loading and unloading are human processes that could mobilize pathogens for transport (see Figure 2). Several mechanisms of transport are possible: aerosolization followed by aerial transport and deposition, erosion, surface runoff and leaching to surface and ground water resources (see Figure 2).

3.3.2.1. *Aerial Transport*

Yates and Yates (2007) observed no microorganisms in air samples collected in a field setting where biosolids were spiked with pathogens (*E. coli, Clostridium perfringens* spores, *Listeria innocua* and bacteriophage phi X174) and applied to monitored soil columns. However, the land application of biosolids may generate bioaerosols either through agitation of the soil during application or following a series of weathering events of deposited biosolids in association with specific climatic conditions (see hazard characterization). Biosolids left on the soil surface or lightly incorporated may be subjected to conditions that lead to drying of the material, rendering it friable. Particulates generated from the friable material are capable of becoming airborne along with the associated pathogens. Bioaerosol droplets or particles may also be generated at the site of biosolids application, storage, site-to-site transport, or loading and

2.2.7. Multiple Hazards

Microbial risk assessors typically assume that microbial pathogens act independently of each other and that the probability of an adverse effect from one type of pathogen is independent of the probability of an adverse effect from another. However, microbial risk assessors may want to consider exposures to pathogens in biosolids at offsite locations or other sources that are not the direct subject of a biosolids risk assessment. This may allow for estimation of the risks of infectious disease from biosolids combined with other sources of the same infectious disease.

There is no evidence to suggest that pathogens and chemicals such as metals in biosolids have interactive effects in humans. However, Lewis et al. (2002) suggested that chemical contaminants in biosolids might irritate the skin and mucous membranes, thereby weakening the first line of defense in the human host, leading to an increase in pathogen host susceptibility. In addition, other constituents in biosolids (e.g., chemicals, metals) may have effects on human immune status (Germolec et al., 1991). Modeling tools have not been developed that include nuances of human immune status due to factors either associated with biosolids or not associated with biosolids. However, the potential for such effects could be discussed when characterization of host susceptibility is presented.