

***HUMAN HEALTH RISK EVALUATION OF LAND
APPLICATION OF SEWAGE SLUDGE/BIOSOLIDS***

Occupational and Environmental Epidemiology Branch
NC Health Department
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I. Introduction

The Occupational and Environmental Epidemiology Branch (OEEB) has received a number of complaints from residents living adjacent to sites where treated sewage sludge (biosolids) has been applied to land. These complaints are about odors as well as adverse health effects in persons living in close proximity to a land application site. A recent source of complaints in North Carolina is from persons living near a land application site along the Orange/Alamance County line. Residents living in this area have reported past health effects from land applications of biosolids within 400 feet of their homes as well as nitrate contamination of private wells at a site in Raleigh (1). In addition, the OEEB is aware of nitrate contaminated groundwater at sites where there has been land application of biosolids as close as 400 feet from adjacent residences. As a result of these reports and health complaints about land application of biosolids in general, OEEB has reviewed the scientific literature on land application of biosolids, contacted experts involved in studying the potential health effects of land applied biosolids, and has met with staff in the Division of Water Quality, in the North Carolina Department of Environment and Natural Resources (DENR), about permit requirements for biosolids land application. This paper is a review of the production and chemical and microbial composition of biosolids, rules governing land application of biosolids, and some health effects that might result from land application of biosolids. This report will make some recommendations about land application of biosolids based on the information in this report.

II. Background

A. Definition of terms

Biosolids and sewage sludge: Sewage sludge is defined in Chapter 40 Part 503 of the Code of Federal Regulations (40 CFR Part 503) as “the solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Biosolids are defined as sewage sludge that has been treated to meet standards for land application under the Environmental Protection Agency’s Clean Water Act Part 503 or any other equivalent land application standards (2). Residuals is the general term used in North Carolina for the waste material that is obtained from the wastewater. The primary treatment of residual sludge is through the use of aerobic and anaerobic processes. Biosolids are divided into two groups based on pathogen content and degree of treatment:

Class A biosolids: more vigorously treated; fewer living pathogens. There are no land use restrictions for applying Class A biosolids.

Class B biosolids: less vigorously treated, but still with reduced level of pathogens compared to untreated sewage sludge.. Many restrictions govern application of Class B biosolids (2). These will be detailed below.

Land application is a general term for spraying or spreading of residuals onto the surface of the land or injection or incorporation below the top surface of the soil. The types of sub-surface land application include:

Incorporation- mixing of residuals with topsoil to a minimum depth of four inches by methods such as disking, plowing, or rototilling

Injection- subsurface application of liquid residuals to a depth of four to twelve inches

Agronomic rates are the rates at which waste can be applied to growing plants that will meet the nutrient needs of the plants but does not overload the soil with nutrients or other constituents that will adversely impact plant growth, soil quality or water quality.

B. Description of production and composition of biosolids

The primary end products of the wastewater treatment process are liquid effluent and sewage sludge. The effluent can be disposed of by using one of several methods.

These include discharge into surface waters. Injection of untreated liquid effluent into groundwater is not allowed under North Carolina rules. Sewage sludge, or biosolids, can be disposed of by incineration or placement in solid waste landfills, but the expense of these methods limits their utility. Treated sewage sludge can also be applied to land. Land application has been desirable to some landowners because the nutrient content of the sludge is seen as a substitute for the use of commercial fertilizers and the organic matter in the sludge is good for the soil. As a result, land application of biosolids is the preferred method of waste disposal for many North Carolina municipalities. However, biosolids contain many waste products such as living pathogens (including bacteria and viruses), and organic and inorganic chemicals. These waste products may be potential hazards when they are land applied. Further, depending on the method of treatment of the residuals, there can be an objectionable odor of these land-applied biosolids. Therefore, the land application of biosolids, while often the preferred method of disposal, has often been a controversial method due to the potential for contamination of soil, crops, and water sources (2) and for the potential for objectionable odors.

The EPA sewage sludge rules, described below, were developed based on risk assessments done in the late 1980's and early 1990's. These risk assessments evaluated the risk from chemicals and pathogens found in sewage sludge. It was felt that the guidelines based on these risk assessments would be protective of public health. Based on these risk assessments, EPA set guidelines for pathogen treatment procedures and methods to reduce the amount of vector attraction. For land application, the EPA rules regulated nine inorganic metals (chemicals). Levels of these regulated metals in biosolids were required to be below established, specific maximal concentrations and for some uses, under monthly average concentrations. The regulated metals include arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Initially the EPA recommended that dioxins be added to the list of regulated chemicals (3) but the EPA more recently determined that dioxins did not need to be on the regulated list.

EPA determined that the following pathogen reduction processes could be used to generate Class A biosolids: composting, heat drying, heat treatment, beta or gamma ray irradiation pasteurization, in addition to other procedures. In comparison, while EPA

rules for Class B biosolids require that levels of pathogens be reduced after biosolids production and before land application, these reductions are not to the degree of reduction required for Class A biosolids (2).

In North Carolina, the majority of biosolids that are land applied are Class B biosolids because the expense for the treatment requirements for Class B is lower than that for Class A.

C. Description of pertinent rules and regulations governing biosolids disposal

1. Federal rules: Part 503 in Chapter 40 of the Code of Federal Regulations (CFR) by the Environmental Protection Agency (EPA): This rule (termed “Part 503” in this paper) was published on March 22, 1993. It established land application and other practices for sewage sludge in order to facilitate removal of waste products from wastewater treatment facilities. Biosolids produced from sewage sludge must meet the standards of Part 503. The Part 503 rules require this treatment be at a level that ensures protection of public health upon release of the biosolids to the environment 2.

2. Current and proposed North Carolina Rules for Land Application of Sludge (4):

The Division of Water Quality in the North Carolina Department of Environment and Natural Resources (DENR) is the state agency responsible for evaluating and permitting the land application of biosolids and other wastewater residuals. This includes the establishment of relevant rules which govern the evaluation and permitting of land application of biosolids. DENR is also responsible for investigating citizen complaints involving land application of biosolids. DENR utilizes the Part 503 rules as the basis for establishing North Carolina rules. The North Carolina rules include required “setbacks” for land application sites. These setbacks regulate the minimum distance land application is allowed from various natural and man-made features such as residences and water sources. North Carolina rules that have been established by DENR are stricter than the Part 503 rules (4). For example, the North Carolina rules require larger setbacks than required by the federal rules. The federal rules (503.14 c)

require a 10 meter (32.8 feet) setback from surface waters while the state rules (15A NCAC 02T.1109) require a 100 foot setback from surface waters.

DENR has established a permitting process to approve the land application of sewage sludge. The rules require a “site assessment” which includes the following:

- a. Soil scientist evaluation including an evaluation of water table depth
- b. Topography map
- c. Watershed determination
- d. Buffer map which is often “field verified” by DENR

The permit includes allowed “setbacks,” control of pathogens/vector attraction and the nine inorganic chemicals regulated by federal rules. In addition, the permit requires an additional level of control of hazardous materials. This is accomplished by the use of processes such as chemical leaching tests, reactivity tests, corrosivity tests, and ignitability tests.

In general, DENR rules will not allow surface land application of bulk liquid residuals if the proposed site has a slope greater than 10%, and will not allow injection or incorporation of bulk liquid residuals if the slope of the land is greater than 18%. Variance requests can be made and approved in some cases. Under North Carolina rules, site-specific agronomic rate calculations by DENR are not required for a site to be permitted. Instead, agronomic rates are calculated based on geographic specific rates that are specific for a region or type of soil in an area, but are not based on the specific site on which residuals are proposed to be applied. The proposed rules provide more specific calculations for a particular site than do the existing rules but still will not require site specific agronomic rate calculations at all proposed sites.

As noted in the Background Section, there are no restrictions in Part 503 for the land application of Class A biosolids. In contrast, the following proposed North Carolina rules govern the land application of Class B biosolids:

- a. Public access to land-applied sites “with a high potential for public exposure” is prohibited for one year following application. This does not apply to farm workers. Although agricultural land is private property and is not considered to have a high likelihood of public access, these restrictions still apply.

- b. Restrictions on growing and harvesting of crops vary by the type of crop.
- c. Grazing by animals on crops in fields where land application has occurred is prohibited for 30 days following application.
- d. Application is allowed on agricultural and forest land, but is prohibited on public lawns or gardens.

The following setback rules have been established or are being proposed by DENR:

- a. Residences, churches and schools: Land application of biosolids must be at a minimum of 400 feet if biosolids are “surface applied.” If biosolids are applied by injection/incorporation then it must be at a minimum of 200 feet from the structure.
- b. Property lines: Minimum distance from a property line is 50 feet for surface application by vehicle, 150 feet for surface application by irrigation, and 50 feet by injection/incorporation methods of application.
- c. Drinking water sources: Minimum distance from wells used for drinking water is 100 feet for both surface and subsurface land application.

It is not known how these setback distances were determined. Discussions with DENR staff indicate that the basis for these setback distances is not generally known as they were established some time in the past. It is important that these distances be determined using appropriate research design and data in order to ensure that contaminants will not leach into water supplies or adversely impact the health of surrounding residents. OEEB feels that this data should be developed to determine if the allowed setback distances are appropriate.

The permitting process may require monitoring wells at dedicated sites but not at nondedicated sites. The use of monitoring wells would indicate whether contaminants are leaching into groundwater and are a quality control method to ensure that contaminants are not threatening the public health.

There are no specific restrictions in the state permit rules on frequency of land application at a site. In some rare cases, there may be seasonal restrictions on

frequency of application. However, in most instances, the frequency of application will be based on the needs of the biosolids producer to remove sewage sludge from their facility and the needs of the landowner to use the sewage sludge as fertilizer for their crops. The use of agronomic rates and frequency of application limits which allow agronomic rate calculations for sites to be achieved may not parallel the needs to land apply discussed above for the sewage sludge producer and land applicator. As a result, protection of public health may not be achieved under the current EPA and state rules.

3. Permitting procedures: A water treatment facility desiring to apply biosolids first sends an application to the central DENR office with a copy to the regional DENR office. DENR reviews the application, and may send comments back to the applicant. DENR may choose to issue or deny a permit as a whole, or may permit or deny portions of the permit.

III. Issues needing review and OEEB recommendations

Staff in OEEB feel the following issues should be addressed in the permitting of land application of biosolids due to its concerns that the current EPA and state rules regarding land application of biosolids may be posing increased health risks to residents adjacent to these sites in North Carolina.

- a. Siting of biosolids application sites, including setbacks and proximity issues
- b. Amounts of biosolids that can be applied. This includes the issue of “agronomic rates.”
- c. Concerns of odor from biosolids
- d. Concerns of exposure and adverse health effects from biosolids contaminants in humans and animals

A. Siting of biosolids application sites

As noted above, DENR evaluates proposed land application sites from a number of standpoints. DENR does a site evaluation of each proposed application site and considers many features of the site in it’s assessment, but there are few specified

topographical features that will lead to a disqualification of a site. For example, while slope is considered in the evaluation of a site for application of liquid residuals (see above) there are no restrictions on slope for the application of more solid materials. The proposed rules do not specify what topographical features, such as surface water distance from the proposed site that would lead to disqualification of a site because of the potential for contamination of these topographical features. OEEB feels that it is important to specify how topographical features would be considered in the site assessment and develop criteria for acceptable and unacceptable topographical features.

The proposed state rules include siting criteria that include many allowable “setbacks” from various topographical features such as property lines and drinking water wells. As mentioned earlier, the setbacks required by state rules are greater than those required by federal rules. It is not known how these distances were determined, and discussions with DENR staff indicate that this is not well known. These distances seem to be minimal, and it is not known whether there are any data to support these setback distances. However, there is some published epidemiologic evidence that suggests that these setback distances may not be adequate to eliminate the risk to public health (1,5-8) OEEB feels that there should be research to determine if these setback distances are adequate to protect both water supplies and public health. This research should include monitoring well data for land application sites.

There is evidence that nitrate contamination at levels that might pose an increased health risk has occurred in drinking water wells near land application sites. In one instance nitrate contamination of 18 wells located as far as 800 feet from the City of Raleigh Water Treatment Plant application site has been documented by DENR (1) at levels that exceed the EPA nitrate standard of ten parts per million (ppm). Hydrogeological investigations by DENR (1) have determined that the frequency of land application of biosolids that caused an exceedance of the agronomic rates for this site occurred causing residential private well and groundwater contamination. Nearby private well contamination may have been associated with this application. In another case, groundwater near a biosolids application site in Rutherford County was contaminated with nitrates at levels greater than the EPA standard of ten ppm. The

existence of this contamination suggests that land application of biosolids may have been responsible for contaminating groundwater and residential private wells. DENR has documented nitrate groundwater contamination from a spray field in Robeson County that caused nitrate contamination of residential wells in exceedance of the 10 ppm EPA limit as far as 1400 feet from the edge of the land application site (8). This data indicates that land application of biosolids under the current EPA and state rules can result in groundwater and private well contamination of nitrates that has the potential to travel as far as 1400 feet from the edge of a land application site. The extent of groundwater contamination at biosolids land application sites may never be known because there are no current requirements for monitoring wells in the state rules and no frequency requirements that would assure the achievement of agronomic rates for all specific biosolids land application sites.

Because of these instances of groundwater contamination and the public health risks that might occur from contamination of drinking water wells, OEEB feels that a monitoring program should be in place to determine if land application sites are causing nitrate contamination of water sources. This program should include monitoring wells around the perimeter of dedicated and selected non-dedicated land application sites in order to detect possible groundwater contamination. The monitoring wells should be located at one-half of the required setback distance away from the boundary of the dedicated land application site and between the land application site and the location of drinking water wells. Until more data are available to scientifically determine appropriate setbacks, the currently proposed allowable setbacks should be doubled. This will take into consideration the OEEB's concern that nitrate groundwater contamination may extend beyond the current setbacks and will decrease the likelihood of groundwater contamination and adverse effects on public health.

B. Amounts of biosolids that can be applied, including the issue of “agronomic rates”

The proposed DENR rules specify criteria to limit the concentration of the nine “regulated” inorganic chemicals, and set forth criteria to require “pathogen reduction.” However, there are no specific limitations on amount of biosolids that can be applied to

a particular site. There is some evidence in the literature (9) that suggests that applied contaminants may accumulate and increase in concentration over time. This is not universally accepted, as the Division of Solid and Hazardous Materials within the New York State Department of Environmental Conservation has argued against the findings of Harrison (10). Gibbs et al (1997) showed that pathogens are able to grow and accumulate under favorable conditions in soil and that soils could become pathogen-rich over time. They also showed that this was true for chemicals that can bind to soil and then slowly leach into groundwater (11).

Agronomic rates are an important consideration in determining the allowable amount and frequency of biosolids application (1,2, 4-8). During the 1990's agronomic rates were used by the hog industry to justify safe levels of waste disposal, but the discovery of nitrate contamination of groundwater near several hog waste spray fields raised questions about the usefulness of agronomic rates to protect groundwater quality in these circumstances, especially as they related to the lack of control over the frequency of land application (5-8). However, it is logical that plants would have a maximal rate for uptake of nutrients and agronomic rates are a means to account for this. OEEB feels that it is important to carefully determine standardized site specific agronomic rate calculations for all biosolids application sites that have a frequency requirement as an added safeguard to protect against water contamination. A requirement for monitoring wells at all land application sites would be a means of assuring that groundwater is protected from contamination.

As discussed above, an additional consideration in whether land application at a particular site is not in excess of its capacity to absorb the waste materials is the frequency of biosolids application. OEEB feels that this should be evaluated for each site as an added safeguard to protect against water contamination. An allowable application frequency should be based on measurements of contaminants in the soil and by the system of monitoring wells discussed above.

C. Concerns of odor

Objectionable odors can be associated with application of biosolids (2). In fact, OEEB has received complaints about odors from residents near land application sites. Odors are logically a part of these residuals. The nature and severity of the odors can

be the result of the type of treatment of residuals. Aerobic treatment is usually associated with the least objectionable odors, while anaerobic treatment of residuals that are allowed to be treated for an extended length of time, can be associated with a more disagreeable odor (2).

Since application of biosolids can occur in relatively close proximity to residents, OEEB feels that it is important to take whatever steps are necessary to minimize or eliminate odors from land applied biosolids. These should follow established “best practices.” These could include measures such as requiring aerobic treatment of residuals if these are to be applied within a pre-determined distance from a residence. These measures could also include establishing greater setbacks than currently exist to provide an additional buffer against the odors. OEEB encourages more research into the odor issue so that appropriate measures can be taken to minimize or eliminate odor from land applied biosolids. OEEB encourages the use of any developed guidelines be included in any established rules so that odors experienced by residents near these application sites are minimized or eliminated.

D. Concerns of adverse health effects in humans and animals from exposure to contaminants in land applied biosolids

Tables 1-4 list the various contaminants that may be found in biosolids. These contaminants can impact humans and animals through several routes of exposure (Table 5) and can have both acute and chronic effects based on the type of exposure. Further, there are different interactions among these contaminants that may increase their pathogenicity. While the DENR rules limit exposure of humans and animals to application sites it may still be possible that humans and animals may be exposed to these various toxicants and pathogens. For example, Gibbs et al (1997) have shown that conditions may exist for pathogen growth after application of Class B Biosolids. As a result grazing animals may ingest and become infected by viable pathogens (11). There are anecdotal reports and some published data that suggest that persons residing near application sites and workers exposed to biosolids may experience adverse health effects such as respiratory and gastrointestinal symptoms as well as studies that did not report adverse health effects. Symptoms reported in some of the

residential studies include burning eyes, cough, headaches, difficulty breathing, chest tightness, neurotoxicity, gastrointestinal effects, nausea and fatigue (12-17). Studies of workers exposed to biosolids and sewage sludge have reported nasal irritation, gastrointestinal complaints, diarrhea, headaches, sore throats, dizziness, respiratory problems, skin irritation and eye irritation (2, 18-31).

Based on these studies, OEEB feels that a surveillance program of humans living near application sites should be developed to determine if there are adverse health effects in humans and animals as a result of biosolids application. This surveillance program should be combined with a well-monitoring program that will determine if contaminants are leaching into groundwater as well as amended setback distances that account for the distances of concern for nitrate groundwater contamination. OEEB will work with DENR in developing a health surveillance plan and looking for funds for supporting the surveillance program.

Table 1 – Compounds Detected in Biosolids 2, 32,33)

SUBSTANCE

Halogenated volatiles

1,4-Dichlorobenzene
cis-1,2-Dichloroethylene
Dichloromethane
Tetrachloroethylene

Non-halogenated volatiles

Toluene
Meta- and para-xylene
Ortho-xylene
Total xylenes (calculated)
Volatile petroleum hydrocarbons

Base-neutral extractables

Benzyl butyl phthalate
Bis(2-ethylhexyl) phthalate
Di-n-butyl phthalate
Diethyl phthalate
Dimethyl phthalate

Polycyclic aromatic hydrocarbons

Acenaphthene
Acenaphthylene
Anthracene
Benz(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Fluoranthene
Fluorene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Phenanthrene
Pyrene

Chlorinated and nonchlorinated phenolics

4-Chloro-3-methylphenol
2,4 and 2,5 Dichlorophenol
3,4,5-Trichlorophenol
2,3,4,5-Tetrachlorophenol
2,3,4,6-Tetrachlorophenol
Pentachlorophenol
m-Cresol
o-Cresol
p-Cresol
2,4-Dimethylphenol
2-Nitrophenol
4-Nitrophenol
Phenol

Extractables

Light extractable petroleum
Hydrocarbons (LEPHs)
Heavy extractable petroleum

Hydrocarbons (HEPHs)

Dioxins

2,3,7,8-TCDD
TCDD – Total
1,2,3,7,8-PCDD
PCDD – Total
1,2,3,4,7,8-HexCDD
1,2,3,6,7,8-HexCDD
1,2,3,7,8,9-HexCDD
HexCDD – Total
1,2,3,4,6,7,8-HCDD
HCDD – Total
OCDD – Total

Furans

2,3,7,8-TCDF
TCDF – Total
1,2,3,7,8-PCDF
2,3,4,7,8-PCDF
PCDF – Total
1,2,3,4,7,8-HexCDF
1,2,3,6,7,8-HexCDF
2,3,4,6,7,8-HexCDF
1,2,3,4,7,8,9-HexCDF
HexCDF – Total
1,2,3,4,6,7,8-HCDF
1,2,3,4,7,8,9-HCDF
HCDF – Total
OCDF – Total

PCDDF's TEQs

2,3,7,8-TCDD TEQs
2,3,7,8-TCDD TEQs

Metals/Inorganic Chemicals

Arsenic
Barium
Cadmium
Chromium
Cobalt
Copper
Lead
Molybdenum
Nickel
Selenium
Silver
Tin
Zinc

Table 2 – Carcinogens (suspected and confirmed animal and human) that have been found in Land Applied Sludges (2,32,34,35)

Aldrin
Arsenic
Benzene
Benzo(a)pyrene
Beryllium
Asbestos
Bis(2-ethylhexyl)phthalate
Benzo(a)anthracene
Benzidine
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Cadmium
Chlordane
Chloroform
Chrysene
Chromium VI
Creosote
Chrysene
Dimethyl nitrosamine
Dioxin
DDD
DDE
DDT
Dibenzo(a,h)anthracene
Dieldrin
Dimethyl nitrosamine
1,2 Dichloroethane
1,2,Dibromoethane
Heptachlor
Indeno(1,2,3-c,d)pyrene
Lead
Lindane
Methylene chloride
Nickel
PCBs
Toxaphene
Trichloroethylene
Tetrachloroethene
1,1,2,2,Tetrachloroethane

Table 3 – Odorants Found in Biosolids (2,34,36,37)

Class	Compound^a	Formula^a	Character^a
Sulfurous	Hydrogen sulfide	H ₂ S	Rotten eggs
	Dimethyl sulfide	(CH ₃) ₂ S	Decayed vegetables, garlic
	Diphenyl sulfide	(C ₆ H ₅) ₂ S	Unpleasant, burnt rubber
	Carbon disulfide	CS ₂	Decayed vegetables
	Dimethyl disulfide	(CH ₃) ₂ S ₂	Putrification
	Methyl mercaptan	CH ₃ SH	Decayed cabbage, garlic
	Ethyl mercaptan	C ₂ H ₅ SH	Decayed cabbage
	Propyl mercaptan	C ₃ H ₇ SH	Unpleasant
	Allyl mercaptan	CH ₂ CHCH ₂ SH	Garlic
	Benzyl mercaptan	C ₆ H ₅ CH ₂ SH	Garlic
Thiocresol	CH ₃ C ₆ H ₄ SH	Skunk, rancid	
Nitrogenous	Ammonia	NH ₃	Sharp, pungent
	Methylamine	CH ₃ NH ₂	Fishy
	Dimethylamine	(CH ₃) ₂ NH	Fishy
	Trimethylamine	(CH ₃) ₃ N	Fishy, ammoniacal
	Ethylamine	C ₂ H ₅ NH ₂	Ammoniacal
	Triethylamine	(C ₂ H ₅) ₃ N	
	Pyridine	C ₆ H ₅ N	Disagreeable, irritating
	Indole	C ₈ H ₆ NH	Fecal, nauseating
Scatole or Skatole	C ₉ H ₈ NH	Fecal, nauseating	
Acids	Acetic (ethanoic)	CH ₃ COOH	Disagreeable, irritating
	Butyric (butanoic)	C ₃ H ₇ COOH	Rancid, sweaty
Aldehydes & ketones	Acetaldehyde	CH ₃ CHO	Fruit, apple

Table 4 – Principle Pathogens of Concern in Biosolids (2,38-48)

Organism	Disease/Symptoms
Bacteria	
Salmonella sp.	Salmonellosis (food poisoning), typhoid fever
Shigella sp.	Bacillary dysentery
Yersinia sp.	Acute gastroenteritis (including diarrhea, abdominal pain)
Vibrio cholerae	Cholera
Campylobacter jejuni	Gastroenteritis
Escherichia coli	Gastroenteritis (pathogenic strains)
Enteric Viruses	
Hepatitis A virus & E Norwalk & Norwalk-like Viruses	Infectious hepatitis
Rotaviruses	Epidemic gastroenteritis with severe diarrhea
Enteroviruses	Acute gastroenteritis with severe diarrhea
Polioviruses	Poliomyelitis
Coxsackieviruses	Meningitis, pneumonia, hepatitis, fever, cold-like symptoms, etc.
Echoviruses	Meningitis, encephalitis, fever, cold-like symptoms, diarrhea, etc.
Reovirus	Respiratory infections, gastroenteritis
Astroviruses	Epidemic gastroenteritis
Caliciviruses	Epidemic gastroenteritis
Protozoa	
Cryptosporidium	Gastroenteritis
Entamoeba histolytica	Acute enteritis
Giardia lamblia	Giardiasis (including diarrhea, abdominal cramps, weight loss)
Balantidium coli	Diarrhea and dysentery
Toxoplasma gondii	Toxoplasmosis
Helminth Worms	
Ascaris lumbricoides	Digestive and nutritional disturbances, abdominal pain, vomiting, restlessness
Ascaris suum	May produce symptoms such as coughing, chest pain, and fever
Trichuris trichiura	Abdominal pain, diarrhea, anemia, weight loss
Toxocara canis	Fever, abdominal discomfort, muscle aches, neurological symptoms
Taenia saginata	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Taenia solium	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Necator americanus	Hookworm disease
Hymenolepis nana	Taeniasis

Table 5 – Pathways of Exposure for Class B Biosolids and associated regulatory controls(2)

Pathways	Part 503 Required Site Restriction
Skin exposure from handling soil from fields where sewage sludge has been applied	No public access* to application sites until at least 1 year after Class B biosolids application.
Skin exposure from handling soil or food from home gardens where sewage sludge has been applied Inhaling dust**	Class B biosolids may not be applied on home gardens. No public access to application sites until at least 1 year after Class B biosolids application.
Skin or respiratory exposure from walking through fields where sewage sludge has been applied**	No public access to fields until at least 1 year after Class B biosolids application.
Consumption of crops from fields on which sewage sludge has been applied	Site restrictions which prevent the harvesting of crops until environmental attenuation has taken place.
Consumption of milk or animal products from animals grazed on fields where sewage sludge has been applied.	No animal grazing for 30 days after Class B biosolids have been applied.
Ingestion of water contaminated by runoff from fields where sewage sludge has been applied	Class B biosolids may not be applied within 10 meters of any waters in order to prevent runoff from biosolids amended land from affecting surface water.
Ingestion of inadequately cooked fish from water contaminated by runoff from fields where sewage sludge has been applied	Class B biosolids may not be applied with 10 meters of any waters in order to prevent runoff from biosolids amended land from affecting surface water.
Contact with vectors which have been in contact with sewage sludge	All land applied biosolids must meet one of the Vector Attraction Reduction options (see Chapter 8).

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