ehp

THEMATIC LESSON 1 OF 2:

Traveling Pathogens
From Farm Fields to Groundwater

Summary

Students read an article about a model developed to estimate the risk of exposure to pathogenic microbes when treated sewage waste (biosolids) is applied to fields. Next, they conduct an experiment to identify how soil/substrate material can affect water flow and design a simple model to show how different soils/substrate materials might affect bacteria survival. Students think critically to identify additional variables considered in the model.

Lesson Type

Experiment—students collect, manipulate, and/or summarize data from an experiment or activity they conduct.

Thematic—this lesson can be used alone or as part of a series of lessons to develop deeper understanding of a topic or concept. Thematic Lesson 2 for September 2008, "Will I Get Sick? Modeling Microbe Exposure with Math," can be implemented after this lesson to develop greater understanding of modeling, the use of mathematics in modeling, and assumptions made in modeling.

***EHP* Article**

Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk
Environ Health Perspect 116:A258 (2008)
http://www.ehponline.org/docs/2008/116-6/ss.html#gett

Objectives

By the end of this lesson, students should be able to

- conduct an experiment testing how water flows through three different materials;
- describe how soil/substrate material type affects water flow;
- speculate about how the risk of pathogen exposure from sewage application to soil may change based on soil/substrate type;
- calculate simple flow rates; and
- identify additional variables that may affect the risk of pathogen exposure from sewage application to land areas.

Class Time

1–1.5 hours

Grade Level

High school, college

Subjects Addressed

Biology, Chemistry, Environmental Science, General Science

Aligning with Standards

SKILLS USED OR DEVELOPED

- Classification
- Communication (note-taking, oral, written—including summarization)
- Comprehension (listening, reading)
- Critical thinking and response
- Experimentation (conducting, data analysis, design)
- Manipulation
- Modeling
- Observation
- Research

SPECIFIC CONTENT ADDRESSED

- Modeling
- Pathogens
- Water contamination
- Water flow through different soils

NATIONAL SCIENCE EDUCATION STANDARDS MET

Science Content Standards

Unifying Concepts and Processes Standard

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

Science as Inquiry Standard

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Life Science Standard

- Interdependence of organisms
- Behavior of organisms

Science in Personal and Social Perspectives Standard

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

History and Nature of Science Standard

- Nature of scientific knowledge

Prepping the Lesson (35–45 minutes)

INSTRUCTIONS

1. Download the article "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk" at http://www.ehponline.org/docs/2008/116-6/ss.html#gett.
2. Thoroughly review the entire lesson before conducting this activity. The "Assessing the Lesson" section can help you identify any additional guidance your students will need to help them succeed (e.g., your expectations for descriptive observations).
3. Obtain the materials needed to conduct the experiment. If you do not have stands and clamps to hold the pipe soil columns, you will need to purchase a rigid material (such as galvanized hardware cloth) to place over the opening of the catch container. The soil column can sit on top of the galvanized hardware cloth and be either held in place by a student or wired into place on the galvanized hardware cloth.
4. Decide which questions on the Student Instructions the students will complete independently or as a group.
5. Make copies of the Student Instructions and Group Data Sheet.
6. Make an overhead transparency of the Class Data Sheet or make enough copies that the class has access to the data.
7. Pre-cut the galvanized hardware cloth to save time and prevent students from injuring themselves. The weed barrier cloth also should be pre-cut. The galvanized hardware cloth pieces and weed barrier pieces can be reused among classes.

MATERIALS

per student

- 1 copy of "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk," preferably in color
- 1 copy of the Student Instructions

per group of 3–5 students

- 1 copy of the Group Data Sheet
- 3 aluminum fence sleeve pipe sections (PVC pipe also works); each section should be 1 3/8" in diameter × 6" long
- 3 3" × 3" pieces of weed barrier cloth (large enough to cover the bottom of the pipe and be held in place by a rubber band. Small amounts are sold prepackaged, such as 35"-diameter rings designed to fit around the base of a tree.)
- 3 rubber bands
- markers

- labels
- 50 mL rocks/gravel (preferably "pearl stone" landscaping gravel or fish tank gravel)
- 50 mL sand
- 50 mL soil (you can use soil from the schoolyard if the soil is finer than sand and does not contain a lot of rock or gravel; do NOT use potting soil because it is designed for rapid drainage)
- 3 baggies or small containers to hold 50 mL each of rocks/gravel, sand, and soil
- 1 300- to 500-mL measuring cup or beaker (ideally no more than 1 liter in size)
- 200 mL water
- 1 container that can catch at least 300 mL of water (disposable plastic food containers work well)
- 1 stand and clamp to hold the pipes *OR* 1 square of galvanized hardware cloth 1/4" mesh cut large enough to sit on top of the catch containers (students can hold the pipe soil column in place on top of the galvanized hardware cloth or use wire to hold the pipe soil column in place)
- 1 stopwatch or timer

Cost estimate (assuming 6 groups per class, 5 classes, with supplies reused where appropriate; all supplies can be purchased at a local hardware store with a garden center)

• *1 5-lb bag of pearl stone gravel*	*$4.20*
• *1 5-lb bag of sand*	*3.75*
• *soil from schoolyard*	*free*
• *6 500-mL plastic measuring cups (if you do not have beakers already)*	*18.00*
• *6 disposable plastic food containers*	*4.00*
• *15 aluminum fence sleeve pipes*	*15.00*
• *1 pkg 35"-diameter pre-cut weed barrier cloth*	*4.00*
• *1 10-ft length galvanized hardware cloth (or less if the store sells smaller amounts)*	*14.00*
• *1 all-purpose metal snips or steel sheet cutters (if using galvanized hardware cloth)*	*9.00*
• *6 stopwatches*	*48.00*
• *1 box sandwich baggies*	*4.00*
HIGH-END TOTAL (includes all supplies listed above)	*$123.95*
LOW-END TOTAL (assumes some supplies such as beakers, catch containers, and stopwatches are already available)	*$27.95*

per class

- 1 overhead transparency of the Class Data Sheet (or enough copies that the entire class has access to the data)

VOCABULARY

- aerobic digestion
- anaerobic digestion
- attenuation
- class A biosolids
- class B biosolids
- exposure model
- indicator organisms
- pathogen
- quantitative assessment
- risk estimate

BACKGROUND INFORMATION

Treated biosolids, or sewage sludge, are applied to land as a fertilizer. The advantage of reusing biosolids lies in recycling a common waste product that would otherwise be incinerated or placed in a landfill. The concern about land application of biosolids is that these wastes can contain human pathogens as well as numerous toxic chemicals and pharmaceutical products.

The research article associated with this lesson describes a risk assessment model to estimate the risk of a person being exposed to and getting sick from land-applied biosolids. Although other risk assessment models exist, this model attempts to provide, in the words of the authors, "more robust estimates."

Models can be simple or complex; often, the better we understand a system, the more complex a model becomes to provide more accurate estimates of what is being modeled. For example, the better we understand the weather system, the more accurate the forecast. In the case of applying biosolids to land, numerous factors (or variables) should be considered. The model referred to in this lesson considers the following elements (Eisenberg et al. 2008):

Virus concentration in raw sludge: Rotavirus, a common pathogen found in sewage sludge, was used as the "model" organism.

Four different biosolid treatment processes: The study authors looked at "one or two digesters, with or without lime treatment," which estimates the attenuation of bacteria from each process.

Size of the biosolids pile is 1,000 kg: This is the amount of biosolids after treatment and before application.

Frequency of biosolid application: Application is assumed to be 2 times per year for 3 days per application.

Exposure pathways: The authors considered two categories of exposure pathways: a) workers and children living near treated fields receive direct ingestional exposure to biosolids during application to fields, and b) people living near treated fields are exposed by drinking contaminated groundwater. Other residential estimates include inhalation exposure if the wind blows and carries the waste. Direct ingestion carries one of the highest risks; risk from groundwater exposure varies depending on the type of soil/substrate and the depth of the well, but can also have a very high risk because of the potential for microbes to accumulate. (This lesson focuses on the groundwater exposure pathway part of the model, and additional information is provided below about potential groundwater exposure.)

Risk characterization: With risk characterization, we can calculate the risk of getting sick depending on the type of pathogen (in this case, rotavirus) and the dose of the pathogen. Lesson 2 for September 2008, "Will I Get Sick? Modeling Microbe Exposure with Math," focuses on the risk characterization part of the model and the mathematics used to calculate risk.

This lesson focuses specifically on the contaminated groundwater exposure pathway via ingestion. Whenever it rains or water is applied to land, the water either runs off rapidly ("runoff") to the lowest point in the area, often a river, or is absorbed into the ground. In the case of fields where biosolids have been applied, whatever is present in those biosolids—for instance, pathogens, nitrates, or other chemicals—can be carried with the water. The ground can act as a filtering system as the water travels through it, depending on the type of soil or substrate, the depth of the water table, and the behavior or characteristics of the chemicals or pathogens in the water. Shallow wells and substrate conditions that allow rapid transport of contaminated water to groundwater pose the highest risk of exposure to contaminants from runoff. Bedrock (which can have large cracks in it) and sand both allow water to pass through quickly and often have minimal physical or chemical filtering effects; thus, the contaminant can reach a well and, depending on the rate of water flow beneath the ground, the contaminant can accumulate. The finer the soil, the slower the water flow, and the more opportunity for physical and chemical filtering. Slowing down the migration of a contaminant to groundwater can also have the benefit of time, as more pathogens may die or biodegradable toxic chemicals may break down to less toxic forms.

Reference

Eisenberg JNS, Moore K, Soller JA, Eisenberg D, Colford JM Jr. 2008. Microbial risk assessment framework for exposure to amended sludge projects. *Environ Health Perspect* 116(6):727–733. http://www.ehponline.org/members/2008/10994/10994.html

RESOURCES

Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov/. Choose Agriculture/Farming, Drinking Water Quality, Risk Assessment

Montana State University. Soil and water management, module 1: basic soil properties AND module 4: water and solute transport in soils. http://landresources.montana.edu/SWM/

University of Florida, Institute of Food and Agricultural Sciences Extension

Soils as a porous medium: basics of soil–water relationships—Part I. http://edis.ifas.ufl.edu/SS108

Retention of water: basics of soil–water relationships—Part II. http://edis.ifas.ufl.edu/SS109

Movement of water: basics of soil–water relationships—Part III. http://edis.ifas.ufl.edu/SS110

U.S. Environmental Protection Agency

Use and disposal of biosolids (sewage sludge). http://www.epa.gov/waterscience/biosolids/

Recommended EPA biosolids resources. http://oaspub.epa.gov/webimore/aboutepa.ebt4?search=22,242,973

U.S. Department of Agriculture, Natural Resources Conservation Service. Soil taxonomy. http://soils.usda.gov/technical/classification/taxonomy/

Implementing the Lesson

INSTRUCTIONS

1. Have the students read "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk." Discuss the vocabulary and content as needed to help students understand the main idea of the research discussed in the article.
2. Tell students they will be conducting an experiment to test the flow of water through small soil columns made out of pipe and filled with three different substrate materials (rocks/gravel, sand, and soil).
3. Ask students how this experiment relates to the microbial exposure risk model described in the article. Soil type is one potential factor that may influence whether a person becomes exposed to a pathogen (a disease-causing microbe) through drinking water that is obtained from beneath the ground (groundwater).
4. Prompt students to think about other factors that may affect microbial exposure risk. Encourage them to write down any thoughts or ideas because they will be asked to share some of those ideas later.
5. Break the class into groups of 3–5 students and have them complete Steps 2–6 of the Student Instructions, recording their data on their Group Data Sheet. Tell students which steps they need to do as a group and which should be completed independently (e.g., in Steps 3 and 4 students describe the soil/substrate materials and write their hypotheses, which can be done individually or as a group). As needed, orient your students to the concept of a hypothesis and ways to calculate an average. Advanced students should also calculate a standard deviation.
6. After students enter their data on the Class Data Sheet, discuss the results to orient the students on how to analyze the data. Tell students whether they should complete Steps 7–9 individually or as a group.

   Students are asked to calculate both the group and class average of the repeated trials for each of the soil/substrates. This is an excellent opportunity for a short side lesson in comparing averages and looking at how averages (and, for more advanced or college level students, their associated standard deviations) change as sample size increases. Unless there is small variability in the trials, the average of a small number of trials may look different from the average of a large number of trials. The more trials, or samples, the more the average represents "reality."
7. Discuss Steps 7–9 as needed to clarify points or advance student understanding. The "Assessing the Lesson" section provides important talking points.

NOTES & HELPFUL HINTS

- Make sure students collect and record their data in the proper units (time in seconds, water in milliliters) so the class data can be averaged.
- This activity can be done as a demonstration if time and supplies are limited. However, the materials can be obtained easily from a local hardware store, and students will benefit the most from conducting the full experiment themselves.
- Time can be saved in class if some materials are already pre-cut or prepared ahead of time.
- The amounts of soil/substrate materials suggested in the Materials list are based upon using pipe that is 1 3/8" in diameter × 6" long. You may need to adjust the amounts of material if you use a different size pipe for the soil columns. There should be several inches of material in the pipe and equal amounts of the different materials in each pipe.
- The water should flow through the rocks/gravel quickly and through the sand almost as quickly. The students may be surprised by how quickly the water flows through and may need to do a trial run with the rocks/gravel to get the hang of simultaneously starting the timer while pouring the water and then stopping the timer quickly to correspond with the exit of all the water. Conversely, the flow of water through the soil may be quite slow. If that is the case, students should calculate a flow rate per 60 seconds. There is the potential that little to no water will flow through in 60 seconds. If that is the case, have students recheck their soil columns at given intervals.

Assessing the Lesson (steps not requiring teacher feedback are not listed below; see Student Instructions for complete step-by-step instructions)

Step 3 **Thoroughly describe each soil/substrate material (e.g., texture, grain size, what it feels like dry and/or wet, color).**

Students should accurately describe the materials they use. The goal is to help them refine their observational and descriptive skills. Students could use descriptions and measurements, such as “the rocks are gray and have a diameter of approximately # centimeters,” or, where appropriate, they can use relative descriptions, such as “the sand is tan and typical of what is found in sandboxes. The individual grains are visible, and their size falls between the rocks and the soil.” If the sand grains are large enough, students could use calipers to measure the diameter of the grain. Students can also touch the material when it is wet and dry and provide additional description. A finer grained soil, like silt, will feel soft or silky when dry and slippery or slimy when wet. A description of “we had rocks” is insufficient.

Step 4 **Write a hypothesis (or multiple hypotheses) about which soil/substrate material you think will allow water to pass through a) the fastest and b) the slowest. Write a hypothesis (or multiple hypotheses) about which soil/substrate material you think will allow c) the most and d) the least amount of water to pass through.**

The students’ hypotheses should be very simple and relate to the experiment. Check to make sure the students wrote a hypothesis for fastest and slowest flow, and for most and least water. Sometimes hypotheses offer a potential reason or explanation, such as “I think the water will pass through the rocks the fastest because there is more space between the rocks.” This is good forward thinking by the student, but a hypothesis needs to be testable. In this experiment, we will not be measuring the distance between particles/rocks (called pore size), just how the water behaves in the different materials. Students should not lose points for this, nor for having a very simple hypothesis. The hypotheses need to make sense and address all materials.

Step 5 **Assemble the soil columns, test the flow rate of the different materials, and record the data on the Group Data Sheet.**

Make sure all the data for all three trials are present, make sense relative to the rest of the class data, and are expressed in the correct units.

Step 6 Students should record their data from all three trials on the Class Data Sheet, then calculate the average of the class data.

Step 7 **a. Summarize the results of the experiment by answering the following questions:**

- **Through which material did water flow the fastest? The slowest?**

  The rocks/gravel should have the fastest water flow, sand next (although the flow rates of rocks/gravel and sand may be very similar), and soil the slowest.

- **Through which material did the most water flow? The least?**

  The largest amount of premeasured water should have flowed through the rocks/gravel, the least through the soil. The flow rate of sand may be similar to that of rocks/gravel.

b. Do the data support or not support your hypotheses? Use the combined class results to develop your response.

Students should restate their hypotheses and provide an evidence-based explanation of why the data did or did not support their hypotheses. It is alright if the data did not support their hypotheses (or supported one and not the other). The most important element of this question is that each of the hypotheses is discussed with logical explanations and sufficient data.

c. List one primary variable in your experiment that affected water flow.

The variable that affected water flow was the type of material/the grain size of the material. Soil saturation can also significantly affect water flow, particularly in large areas as in "real-life" scenarios. The extent of the effects of saturation depends on the type of soil. For example, water flow generally increases when soils with large pore sizes, such as sand, are already filled with water. Soils with a large clay fraction (with small pore size) may have decreased water flow as saturation occurs. These differences are probably not noticeable with this activity.

d. Using the class averages, calculate the flow rate for each material (amount of water in milliliters/amount of time in seconds). Show your work and write your final response below.

Students should show their work, reduce fractions to the lowest common denominator, and/or write their answer in decimals; all units must be present.

Step 8 **a. Based on your data and observations, and the information that the bacteria die within 1 minute of exposure to air or the soil/substrate, draw a diagram or model showing the following:**

- **the possible path of the bacteria for each material, and possible changes in the amounts of the bacteria;**

  This can be a less-than/more-than type of simple description; just make sure it is logical and accurate.

- **the flow rate (calculated in Step 7d) for each material in your diagram; and**

  Students should list the calculated flow rate.

- **an arrow and label indicating which soil/substrate material is most likely to have the most living bacteria come out of the other end of the pipe soil column.**

  Make sure students' selections are logical and based upon the data.

b. Imagine that biosolids containing pathogens were applied to some nearby land, and it rained soon after the application. In which situation would a person be most at risk: someone with a nearby well beneath rocky substrate; someone with a nearby well beneath sandy soil; or someone with a nearby well beneath a fine-grained soil? Explain your answer.

The riskiest scenario would be a well beneath the rocky substrate because if it rains or water is applied to the area with the biosolids, the water could pick up the bacteria and quickly flow into the water pumped up into the well. Depending on how quickly the water flowed through the sand, the students could argue the risk for sand may be similar to that for a rock substrate. The smaller the pore size, the more likely pathogens may "stick" to the substrate materials. Other important factors include the depth of the well, distance of the well from the site of biosolid application, and the direction of groundwater flow.

Step 9 **b. Soil/substrate material type is an important factor in microbial exposure risk when sewage is applied to the land. List at least three additional microbial exposure risk model variables described in the summary article.**

Different settings; pathogen exposure pathways (ingestion, drinking contaminated groundwater, and inhalation); bacterial attenuation from different digestion processes (anaerobic with and without lime and natural attenuation)

c. The article highlights only a few of many factors/variables actually considered in the model. Identify at least three additional variables that might affect the risk of a person being exposed to harmful pathogens from the application of sewage sludge to land areas.

The initial amount of pathogens in the sludge; the length of time the pathogens can live in the sludge; the amount of sludge in an application; the frequency of sludge application or repeated exposure; the wind (speed and length of time it blows), which can carry dust with pathogens; the distance of humans from the sludge; the age of those exposed; the current health of those exposed; and precipitation levels are some other factors. The students may identify additional variables, just make sure they make sense and relate to the question.

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Give us your feedback! Send comments about this lesson to ehpscienceed@niehs.nih.gov.

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STUDENT INSTRUCTIONS:

Traveling Pathogens
From Farm Fields to Groundwater

Step 1 Read the article "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk."

Step 2 Per your teacher's instructions, divide into groups of 3–5 and gather the following materials:

- 3 sections of pipe (or soil columns)
- 3 pieces of weed barrier cloth
- 1 stand and clamp, or pre-cut squares of wire mesh/galvanized hardware cloth
- 3 rubber bands
- markers
- labels
- 50 mL rocks/gravel
- 50 mL sand
- 50 mL soil
- 200 mL water
- 1 300- to 500-mL graduated cylinder, beaker, or measuring cup
- 1 stopwatch or timer
- 1 catch container that can hold at least 300 mL

Step 3 Thoroughly describe each soil/substrate material (e.g., texture, grain size, what it feels like dry and/or wet, color).

Rocks/Gravel:

Sand:

Soil:

Step 4 Write a hypothesis (or multiple hypotheses) about which soil/substrate material you think will allow water to pass through a) the fastest and b) the slowest.

a.

b.

Write a hypothesis (or multiple hypotheses) about which soil/substrate material you think will allow c) the most and d) the least amount of water to pass through.

c.

d.

Step 5 Assemble the soil columns, test the flow rate of the different materials, and record the data on the Group Data Sheet.

a. For each of the three sections of pipe, place the weed barrier cloth over one end and secure with a rubber band.

b. Label one pipe "rocks/gravel," one pipe "sand," and one pipe "soil."

c. Measure 50 mL of rocks/gravel and pour into the pipe labeled "rocks/gravel."

d. Secure the pipe to a stand using a clamp. If no stands and clamps are available, place pre-cut wire mesh/galvanized hardware cloth over one of the catch containers. You can wire the pipe to the wire mesh/galvanized hardware cloth to hold it in place or have a group member hold it in place straight up and down.

e. Choose one person in the group to work the stopwatch. Have another person in the group ready to record data on the Group Data Sheet.

f. Measure 200 mL of water. Get ready to pour the water into the pipe/column containing the rocks/gravel. The timer needs to start the stopwatch at the SAME TIME the water is poured and stop the stopwatch when the water has stopped dripping and you can no longer see water sitting above the rocks/gravel.

g. Record how long it took the water to pass through the rocks/gravel on the Group Data Sheet.

h. Pour the water from the catch container into the empty beaker/measuring cup. Measure the amount of water in milliliters and write down the amount on your Group Data Sheet.

i. Repeat Steps f–h two more times so you have a total of three trials for rocks/gravel.

j. Set the rock/gravel-filled pipe aside.

k. Measure 50 mL of sand and pour into the pipe labeled "sand." Conduct Steps d–i so you have three trials using the sand (measuring, pouring, timing, re-measuring the water, and recording the data).

l. Measure 50 mL of soil and pour into the pipe labeled "soil." Repeat Steps d–i for the soil. If the water flows through in less than 60 seconds, stop the watch when the water has completely flowed through (i.e., the water is not sitting on top of the soil). If the water is still sitting in the pipe soil column and is dripping slowly at 60 seconds, use "60 seconds" as your measure of time. After you have poured the water and allowed it to sit for 60 seconds, remove the catch container and measure the amount of water in milliliters. Record the amount on your Group Data Sheet.

m. Calculate the average water flow-through time and water volume for your trials.

Step 6 Record all three trial results on the Class Data Sheet and, using the class data, calculate the average length of time it took for the water to flow through each material and the average amount of water that came out the end of the pipe.

Step 7 Answer the following questions about your experiment:

a. Summarize the results of the experiment by answering the following questions:

- Through which material did water flow the fastest? The slowest?

- Through which material did the most water flow? The least?

b. Do the data support or not support your hypotheses? Use the combined class results to develop your response.

c. List one primary variable in your experiment that affected water flow.

d. Using the class averages, calculate the flow rate for each material (amount of water in milliliters/amount of time in seconds). Show your work and write your final response below.

Rocks/Gravel:

Sand:

Soil:

Step 8 Imagine that the water you poured through each soil/substrate material contained harmful bacteria that die within 1 minute of being exposed to air (for this activity, assume that the bacteria live only if they remain in the water that passes through the material into the catch container within 1 minute).

a. Based on your data and observations, and the information that the bacteria die within 1 minute of exposure to air or soil/substrate, draw a diagram or model showing the following:

- the possible path of the bacteria for each material, and possible changes in the amounts of the bacteria;
- the flow rate (calculated in Step 7d) for each material in your diagram; and
- an arrow and label indicating which soil/substrate material is most likely to have living bacteria come out the other end of the pipe soil column.

b. Imagine that biosolids that contained pathogens were applied to some nearby land, and it rained soon after the application. In which situation would a person be most at risk: someone with a nearby well beneath rocky substrate; someone with a nearby well beneath sandy soil; or someone with a nearby well beneath a fine-grained soil? Explain your answer.

Step 9 The goal of an environmental model is to show how something like a chemical or disease behaves in the environment, and how it may come into contact with humans. Simple models consider a few factors or variables, and complex models try to consider many different factors or variables. Complex models try to mimic "real life" because usually there are many different elements or variables influencing exposure risk in the real world.

a. Re-read the article "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk."

b. Soil/substrate material type is an important factor in microbial exposure risk when sewage is applied to the land. List at least three additional microbial exposure risk model variables described in the summary article.

c. The article highlights only a few of the many factors/variables actually considered in the model. Identify at least three additional variables that might affect the risk of a person being exposed to harmful pathogens from the application of sewage sludge to land areas.

Group Data Sheet

Traveling Pathogens: From Farm Fields to Groundwater

	Substrate	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
Amount of Water (in mL)	**Rocks/Gravel**				
	Sand				
	Soil				
Water Flow Time (in sec)	**Rocks/Gravel**				
	Sand				
	Soil (stop the trial at 60 seconds even if the water has not already completely flowed through)				

Group members:

Class Data Sheet

Traveling Pathogens: From Farm Fields to Groundwater

Group No.	Trial	Amount of Water (in mL) Rocks/Gravel	Amount of Water (in mL) Sand	Amount of Water (in mL) Soil	Water Flow Time (in sec) Rocks/Gravel	Water Flow Time (in sec) Sand	Water Flow Time (in sec) Soil
1	1						
	2						
	3						
2	1						
	2						
	3						
3	1						
	2						
	3						
4	1						
	2						
	3						
5	1						
	2						
	3						
6	1						
	2						
	3						
Average							