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THEMATIC LESSON 2 OF 2:

Will I Get Sick?

Modeling Microbial Exposure with Math

Summary Students are introduced to a microbial risk assessment model to estimate the risk of illness resulting from sewage waste being applied to land. Students learn about the concept of modeling and the use of mathematics in modeling. The lesson concludes with students using different exposure scenarios to calculate the probability of getting sick from exposure to rotavirus.

Lesson Type

Graphic Organization and Modeling—this lesson has students organize information graphically (e.g., using figures, graphs, and/or webs) or by creating a model.

Data Analysis—students read, interpret, and apply data from graphs or figures.

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 1 for September 2008, "Traveling Pathogens: From Farm Fields to Groundwater," can be implemented before this lesson to develop greater understanding of modeling in general as well as a more specific understanding of how soil or substrate type can affect contaminant transport and human exposure.

***EHP* Articles**

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

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

Objectives

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

- identify the basic mathematical components of a microbial exposure risk assessment model;
- calculate the probability of a person getting sick from exposure to biosolids;
- describe in simple, accurate terms what the calculated risk probability means; and
- identify elements of the microbial exposure risk assessment model that increase or decrease risk.

Class Time 1 hour

Grade Level Upper high school, college

Subjects Addressed Biology, Environmental Science, General Science, Math (Algebra)

Aligning with Standards

SKILLS USED OR DEVELOPED

- Classification
- Communication (note-taking, oral, written—including summarization)
- Comprehension (listening, reading)
- Computation
- Critical thinking and response
- Modeling

SPECIFIC CONTENT ADDRESSED

- Biosolids
- Microbial risk assessment
- Modeling
- Risk
- Probability
- Rotavirus

National Institute of Environmental Health Sciences

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

Science as Inquiry Standard

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

Science in Personal and Social Perspectives Standard

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards

History and Nature of Science Standard

- Science as a human endeavor
- Nature of scientific knowledge

Prepping the Lesson (10 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. If you are interested in reading the entire original research article, you can download the article at http://www.ehponline.org/docs/2008/10994/10994.html. However, the entire article is not needed to conduct the lesson; a flow chart depicting the model is found on page 2 of the Student Instructions.
3. Review the Background Information, Instructions, Assessing the Lesson, and Student Instructions sections of this lesson.
4. Make copies of the Student Instructions and "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk."

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

VOCABULARY

- anaerobic digestion
- beta-Poisson dose–response function
- exposure
- lime treatment
- model
- pathogen
- plaque-forming unit (PFU)
- probability
- qualitative
- quantitative
- risk
- risk assessment
- rotavirus

BACKGROUND INFORMATION

The Student Instructions provide a general introduction to systems and models as well as a summary of the elements of the microbial risk assessment model addressed in this lesson. Refer to Figure 1 on page 2 of the Student Instructions to orient yourself to the parts of the model. The goal of this lesson is to demonstrate how mathematics quantifies the predictions made by the model. Although students may not be familiar with some of the mathematical concepts briefly touched on in this lesson (such as lognormal distribution), students can still conceptually explore the use of math to describe behaviors and chance (probability). For your reference, a brief explanation of some of the mathematical concepts, such as lognormal distribution, is provided in the math notes in the "Implementing the Lesson" section on page 4.

The underlying mathematics in many models, especially environmental and biological models, can be complex. However, some systems can be modeled well by fairly simple equations. In this exercise, the risk of acquiring an infection from exposure to microbial contamination will be modeled with the beta-Poisson dose–response equation. This simple mathematical formula can be used to calculate the probability

that, after an exposure, a given dose of an infectious agent will actually cause an infection. We have provided values for all the variables, which students plug in to the beta-Poisson dose–response equation. Thus, the math application used in this lesson should be accessible to most students.

The Resources section of this lesson provides additional information about the development and use of the beta-Poisson dose–response equation to model different infectious diseases. The student handout provides information about the basic requirements for illness to occur from exposure to an infectious agent (i.e., personal exposure to the microbe, the ability of the microbe to get past the body's barriers, and infectiousness of the microbe), but it is important to be aware of some specific points about the beta-Poisson equation.

The beta-Poisson dose–response equation is

$P = 1 - [1 + (d/\beta)]^{-\alpha}$,

where β (beta) is a threshold number of microbes in the body that results in illness and α (alpha) is the probability that someone receives a high enough dose to cause disease. β must be much greater than α ($\beta >> \alpha$) and 1 ($\beta >> 1$). The beta-Poisson dose–response equation may not be appropriate for modeling some diseases, but the literature appears to support this equation as an appropriate model for describing the infectious risk of rotavirus.

If you have advanced students, you may want to discuss some assumptions and limitations of the microbial risk assessment model used in the analysis (Eisenberg et al. 2008). For example, the model uses one type of virus—rotavirus—to estimate risk. Compared with other pathogens potentially present in sewage sludge, rotavirus has a relatively widespread human exposure and a relatively high illness risk because of its infectivity and the large amounts of the pathogen excreted from an infected individual (Ottosson and Stenström 2003). Thus, the use of rotavirus as the model pathogen builds in a "conservative" element to the model (i.e., using a higher-risk pathogen instead of a lower-risk pathogen to make estimates). Although many other pathogens may not survive the biosolids treatment process, some will; by using one of the highest-risk pathogens, the model is assumed to most closely represent total risk without further complicating it with many other pathogens. A limitation of the model is that it does not consider the risk of illness from exposure to biosolids pathogens besides rotavirus.

NOTE: The original research article on which this lesson is based (Eisenberg et al. 2008) has a misprint in the beta-Poisson distribution equation, erroneously associating "1 +" with the numerator, as shown below:

$$P = 1 - \left(\frac{1 + d}{\beta}\right)^{-\alpha}.$$

There are two problems with the equation as written in the original article. First, you cannot add a unitless constant to a number that has units (e.g., you can't add the number 10 to $5 without knowing whether the 10 is in cents, dollars, or dogs). Second, if you add 1 directly to *d*, there is essentially no difference between the estimated probability of risk with different doses. This lesson uses the correct equation.

References

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

Ottosson, J, Stenström TA. 2003. Faecal contamination of greywater and associated microbial risks. *Water Res* 37(3):645–655.

RESOURCES

Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov/. Choose Infectious Disease, Risk Assessment

Beta-Poisson distribution

Fisheries and Aquaculture Department. A primer on risk assessment modeling: focus on seafood products. Dose–response. http://www.fao.org/docrep/009/a0238e/A0238E04.htm

U.S. Environmental Protection Agency. Appendix F: Infectivity dose response relationships: description of analyses conducted to select model forms and estimate model parameters. http://www.regulations.gov/search/redirect.jsp?objectId=090000648027ce0f&disposition=attachment&contentType=pdf

U.S. Food and Drug Administration. Quantitative risk assessment on the public health impact of pathogenic *Vibrio parahaemolyticus* in raw oysters. III. Hazard characterization/dose–response. http://www.cfsan.fda.gov/~dms/vpra-3.html

U.S. Food and Drug Administration. Quantitative risk assessment on the public health impact of pathogenic *Vibrio parahaemolyticus* in raw oysters. Appendix 4: Details of the data analysis for the hazard characterization component of the *Vibrio parahaemolyticus* risk assessment model. http://www.cfsan.fda.gov/~dms/vprax4.html

Strachan NJC, et al. Dose response modelling of *Escherichia coli* O157 incorporating data from foodborne and environmental outbreaks [provides a good mathematical derivation of the beta-Poisson dose–response function]. http://www.aseanfood.info/Articles/11015073.pdf

Petterson SA, Ashbolt NJ. WHO guidelines for the safe use of wastewater and excreta in agriculture: microbial risk assessment section. http://www.who.int/water_sanitation_health/wastewater/mrareview.pdf

Disease symptoms

Mayo Clinic. Rotavirus. http://www.mayoclinic.com/health/rotavirus/DS00783

Implementing the Lesson

INSTRUCTIONS

1. This lesson and Lesson 1 for September 2008, "Traveling Pathogens: From Farm Fields to Groundwater," can be used together to develop different skills and to develop or advance the concept of modeling at different levels. If you decide to use both lessons, "Traveling Pathogens" should be implemented first, because it provides a more basic introduction of the microbial exposure risk assessment model and develops the concept of variables in a model. This lesson goes into more depth and develops the mathematical representations within the model. If students have already completed the "Traveling Pathogens" lesson, they may be able to skip Step 1 of this lesson.

2. Have the students read "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk" and complete Step 1 of the Student Instructions. Review the listed concepts with the students (if time allows, have the students work individually or in groups to find definitions, then discuss the definitions as a class). Discuss Step 1a–d, referring to the Assessing the Lesson section for talking points.

3. Have the students complete Step 2 of the Student Instructions, then review their answers as a class. Some discussion notes are provided below. You may want to provide additional information about the mathematical references depending on whether you think it will help improve student understanding.

   Students do not necessarily need to know the specifics of logarithms or lognormal distribution (although brief descriptions are provided below if needed). This step is meant to help the students identify mathematical elements and become acquainted with the various ways things are represented mathematically. A general overview is particularly important for students who have less experience with mathematics (but can even help those who can "crunch the numbers") to develop a conceptual understanding of mathematical applications, as well as understand the difference between quantitative and qualitative. Select the level of detail to use with your students based on their experience and comfort level with math. For a more detailed explanation of the mathematical concepts used in the model, please refer to the original scientific publication (Eisenberg et al. 2008).

   Math notes

   Raw sludge data: μ,σ^2 are variables in an equation that is not provided in the flow chart. Lognormal distribution describes data whose logarithm is normally distributed (i.e., has a regularly shaped, nonskewed bell curve in log space)

   Treatment process: A first-order process is described by a simple relationship involving a single parameter, whereas a second-order process is more complex, involving either two parameters or the combination of two first-order processes. Note, the terms "first-order process" and "second-order process" are used a little bit differently in subfields. Mathematically, a log removal refers to factors of 10 removal of a virus from a system (for example, a 3 log reduction means that the amount of virus has been reduced by a factor of 1,000; a 4 log is a reduction by a factor of 10,000).

   Posttreatment data: This refers to using "actual data" to double-check the equations in the model that provide estimates (i.e., how close is the estimate to an actual exposure?)

   Biosolids formation: Describes the amount of biosolids used in the model/simulation. This number is likely based on an average-size biosolids pile.

4. Have students complete Steps 3–5. Review the algebra in Steps 4 and 5 as needed. Additional information is provided in the Assessing the Lesson section.

5. You may wish to have your students perform the following extension activity or additional calculations:

   Assume the equivalent of 100 mg of biosolids is present in every drink from a contaminated well. How many drinks would it take to potentially make someone sick once? Help students think about how to approach this question by using units to inform how to set up the calculation. If you want to end up with the units # of drinks per 1 time getting sick, the number of exposures (in this case, drinks) needs to be on top.

   Untreated Biosolids

   10 exposures (drinks) / 2.26 chances of getting sick when exposed to 100 mg of untreated biosolids = 4.4 drinks / 1 sick

   Treated Biosolids

   1,000 exposures (drinks) / 2.26 chances = 442 drinks / 1 sick

6. Lead a class discussion around the question posed in Step 6: "If you were a leader in your local, state, or national government, would you allow untreated biosolids to be applied to land? Why or why not?"

   Students will most likely respond against allowing untreated biosolids to be applied to land because of the significantly increased risk of illness from untreated biosolids (6.5 out of 100 exposed people getting ill compared with 7.7 out of 10,000 exposed people). The discussion should inspire students to apply the data logically and understand the big picture uses of scientific data. Some students may argue for application of untreated biosolids to land with certain caveats, such as it is being applied only in an unpopulated area. This is a logical idea that could produce fruitful discussion about the parameters to consider in such a decision, such as runoff into a river that provides water to downstream communities or the ability of a microbe to survive under certain conditions. Risk analysis weighs multiple factors, and students should begin asking themselves questions such as how much risk they, as individuals, are willing to take and whether that risk tolerance changes when other people make decisions (such as in the form of laws) related to their personal health.

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

Step 1

a. Define the following terms and discuss the definitions within a group or as a class:

hazard: A physical, chemical, or biological element in the environment that causes injury, harm, or disease.

exposure: Physical contact with a hazard. In the case of disease agents or chemical hazards, a person may be exposed but may or may not receive a "dose." In the case of a physical hazard (such as a ledge) a person may be exposed (in this example, by standing on or very near the ledge) but may or may not be harmed (in this example, by falling off the ledge).

dose: The amount of a chemical or biological agent that actually enters the body. This is usually measured in terms of amount of agent or chemical per kilogram of body weight of the person being exposed.

routes of exposure: There are four ways an exposure to a chemical or biological agent can occur: inhalation (breathing it in), ingestion (eating or drinking it), absorption through the skin, or injection directly into the blood stream (e.g., by receiving a shot or stepping on a nail).

risk assessment: The use of qualitative (descriptive) and quantitative (numerical) evaluation methods to estimate risk, or the chance of someone becoming harmed and/or ill from exposure to a chemical or biological agent.

b. What is the goal of developing an exposure risk assessment model for the application of sewage sludge to land areas? To be able to quantitatively (i.e., numerically) estimate the risk of people being exposed to and getting sick from pathogens (disease-causing microbes) when sewage sludge is applied to land areas.

c. Why do we care if people are exposed to pathogens? People may get sick.

d. Why is it important to be able to estimate such risks for different scenarios? To be able to make decisions about how to apply the sludge to land areas in different circumstances to minimize the chance of people becoming ill.

Step 2 **Without getting into the details of the mathematics, you can logically guess how different variables and other parts of the system contribute to the risk of getting sick. Refer to the model (Figure 1) again. Next to each item below, place an up arrow (⇑) if you think the risk of getting sick goes up from that factor or part of the system or a down arrow (⇓) if you think the risk goes down.**

- **Raw sludge data:** Students should highlight or underline "estimate μ,σ^2: assume lognormal distribution." Exposure to raw sludge increases risk (⇑).
- **Treatment process:** Students should highlight or underline "retention time is either a first- or second-order process, with a log removal [removal of viruses] that is linear in time. Lime treatment [to remove viruses] is a fixed log-removal process." Single digestion compared with the other digestion options in the model will increase risk (⇑).
- **Posttreatment data:** Students should highlight or underline "consistent with posttreatment data."
- **Biosolids formation:** Students should highlight or underline "1,000-kg biosolid pile." Larger pile size may increase risk (⇑).
- **Biosolids application:** Students should highlight or underline "twice/year" and "3 days." Biosolids applied 4 times per year instead of 2 times per year will increase risk (⇑).
- **Exposure pathways:** There are no mathematical references made in this part. The risk is higher for children than for adults (⇑). A shallow well under rocky, porous soil compared with a deep well under very fine-grained soil results in a higher risk (⇑).
- **Risk characterization:** Students should highlight or underline "assume 100-mg ingestion" and "Estimate either individual or population-level risk." Ingestion of a greater amount results in higher risk (⇑). Getting sick from a pathogen that does not occur frequently in the waste, the risk is lower (⇓).

Step 4 **Answer the following questions:**

a. Calculate *P* for rotavirus if someone ingests 100 mg of untreated biosolids at one single point in time (e.g., drinking contaminated water). Show your work, including the canceling of units. Write your answer using decimals and scientific notation.

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

$\beta = 0.42$ plaque-forming units (PFU)

$\alpha = 0.26$

***d* = 0.125 PFU (assumes 5 PFU per 4,000 mg of untreated biosolids and assumes 100 mg ingested at one single point in time)**

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

$P = 1 - [1 + (0.125 \text{ ~~PFU~~} / 0.42 \text{ ~~PFU~~})]^{-0.26}$

$P = 1 - [1 + 0.298]^{-0.26} = 1 - [1.298]^{-0.26}$

$P = 1 - 0.935$

$P = 0.065$

$P = 6.5 \times 10^{-2}$

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b. Calculate *P* for rotavirus if someone ingests 100 mg of treated biosolids at one single point in time. Show your work, including the canceling of units. Write your answer using decimals and scientific notation.

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

β = 0.42 plaque-forming units (PFU)

α = 0.26

***d* = 0.00125 PFU (assumes 0.05 PFU per 4,000 mg of treated biosolids and assumes 100 mg ingested at one single point in time)**

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

$P = 1 - [1 + (0.00125 \text{ ~~PFU~~} / 0.42 \text{ ~~PFU~~})]^{-0.26}$

$P = 1 - [1 + 0.00298]^{-0.26} = 1 - [1.00298]^{-0.26}$

$P = 1 - 0.9992$

$P = 0.00077$

$P = 7.7 \times 10^{-4}$

Step 5 **Using your results from Step 4a (untreated biosolids) and 4b (treated biosolids), describe what those numbers mean in terms of the chance or probability that someone will get sick. Discuss your results in terms of rotavirus and the specific dose used in your calculation.**

Untreated biosolids: $0.065 = 6.5 \times 10^{-2}$

For every 100 times someone is exposed to untreated biosolids that contain a dose of 0.0125 PFU rotavirus, the person has a chance of getting sick 6.5 times.

OR

For every 100 people who are exposed, approximately 6.5 will get sick.

Treated biosolids: $0.00077 = 7.7 \times 10^{-4}$

For every 10,000 times someone is exposed to untreated biosolids that contain a dose of 0.00125 PFU rotavirus, the person has a chance of getting sick 7.7 times OR for every 10,000 people exposed, approximately 7.7 people will get sick.

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

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STUDENT INSTRUCTIONS:

Will I Get Sick?

Modeling Microbial Exposure with Math

Step 1 Read "Getting a Handle on Biosolids: New Model Estimates Microbial Exposure Risk" to orient yourself to the "big picture" of a model developed to estimate microbial exposure risk.

a. Define the following terms and discuss the definitions within a group or as a class.

hazard:

exposure:

dose:

route of exposure:

risk assessment:

b. What is the goal of developing an exposure risk assessment model for the application of sewage sludge to land areas?

c. Why do we care whether people are exposed to pathogens from biosolids?

d. Why is it important to be able to estimate such risks for different scenarios?

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Flow chart from the original article

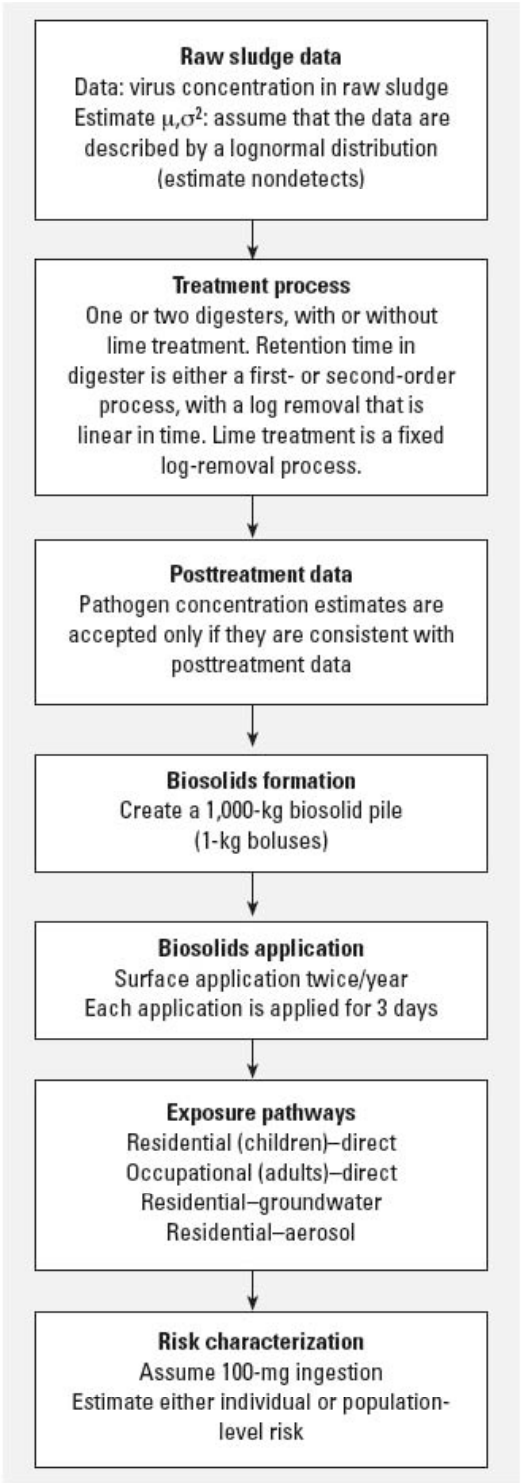

Figure 1. General model flow diagram that includes exposure assessment and risk characterization.

Source: 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.

What does it mean?

Raw sludge data: This part of the model estimates the original virus concentration in sewage sludge. As the amount of virus in the sludge increases, so increases the risk. To simplify the model, the authors use one virus (rotavirus) commonly found in sewage sludge. There are many other microbes present in sludge; the model assumes rotavirus behaves similarly to those other pathogens.

Treatment process: Sludge is treated using a digestion process to kill pathogens that may be present. This part of the model provides an estimate of how much of the "model" virus remains in sludge after different types of treatments. A single digestion alone does not remove as many pathogens as a single digestion with lime. Double digestion with lime removes the most pathogens. Retention time refers to time in the digestor.

Posttreatment data: This is an internal check used when developing the model. The authors developed the mathematical formulas to estimate the concentration of viruses that would remain after treatment. Then they experimentally tested for the concentration of the virus in treated sewage sludge.

Biosolids formation: The virus concentration in a pile of treated sludge may change depending on how much virus remained after treatment, how long the pile sits and under what conditions (e.g., temperature), and the pile's size and shape.

Biosolids application: This part of model assumes sludge is applied to agricultural land 2 times per year and that each application periods lasts 3 days.

Exposure pathways: Once the sludge is applied to land, nearby populations may be exposed to pathogens in it. This model looks at 4 different exposure scenarios (children, workers who apply sludge, residents who drink contaminated groundwater, and residents who breathe in the virus). In the third scenario, the risk of exposure goes up if the well is shallow and the water moves quickly through the soil. The risk goes down if the well is deep and the water moves slowly through the soil.

Risk characterization: The authors calculate the chance of a person getting sick after ingesting 100 mg of biosolids (ingestion being the most hazardous exposure route for rotavirus). They also calculate the risk of getting sick if 1 person were exposed repeatedly over a year, and how many people would get sick if a population (e.g., a town, were exposed over a year.

Step 2 The world is a complicated place made up of different individual parts that are interconnected to create whole systems. For example, the digestive system is composed of many different parts that work together to break down food to give the body energy and nutrients. To better understand how a system works, you must identify the individual parts and describe the role or contribution of each part to the whole.

Sometimes only a few parts of a system are identified and described; other times the system is described in great detail. For example, in a simple description of the digestive system, the food enters the mouth and is chewed, then passes through the stomach and into the intestines, where the nutrients are absorbed, and the waste finally exits the body. A detailed description of the system would include information about the specific enzymes that aid digestion and the role of the liver, gallbladder, pancreas, duodenum, small intestine, and so on.

Descriptions of a system are sometimes qualitative (describing qualities) and sometimes quantitative (describing quantities). When the parts of the system are identified and their relationships are described, you have a model. Models are often used to make predictions about a system. For example, a qualitative prediction for the digestive system would be "if you eat food, it will leave your body as waste." A quantitative prediction would be "if you eat food, it will leave your body as waste in about 6 to 8 hours" or "if you eat X grams of food you will excrete Y grams of waste."

You began this lesson by reading a short article summarizing the results of research conducted to develop a quantitative model to estimate (or predict) potential risk of exposure to pathogens after sewage sludge is applied to land areas. The article describes a few elements of the model and provides a general, simplified description of the microbial exposure risk assessment model. To better understand this model and the complexity of the system the scientists are trying to understand, you must go to the original research article, "Microbial Risk Assessment Framework for Exposure to Amended Sludge Projects."

In the original research article, the authors include a flow chart of the model that shows the factors or variables they considered in the model (Figure 1, page 2 of these Student Instructions). This risk estimate model shows many elements of a complex system, each of which contributes to the risk of getting sick from exposure to treated biosolids from land application. Each of the individual parts of the entire model has mathematical calculations to estimate its potential contribution to the entire system.

Read the information in each box of Figure 1, as well as the explanation box next to it. Underline quantitative (numerical) or mathematical references in the box. Don't worry if you don't understand everything described in Figure 1. Part of learning how to read science is to first work with the pieces you understand to develop a general idea of what is being described. Then you dig into one or two elements you do not understand and look up definitions or talk to an expert to learn new information to help you understand.

Without getting into the details of the mathematics, you can logically guess how different variables and other parts of the system contribute to the risk of getting sick. Refer to the model (Figure 1) again. Next to each item below, place an up arrow (⇑) if you think the risk of getting sick goes up from that factor or part of the system or a down arrow (⇓) if you think the risk goes down.

Raw sludge data—exposure to raw (untreated) sludge compared with treated sludge:

Treatment process—single digestion without lime compared with the other digestion options in the model (a single digestion with lime and a second digestion with and without lime):

Biosolids formation—if the pile size is larger:

Biosolids application—if biosolids are applied 4 times per year instead of 2 times per year:

Exposure pathways—risk for children compared with adults:

Exposure pathways—a shallow well under rocky, porous soil compared with a deep well under very fine-grained soil:

Risk characterization—ingestion of a higher amount of biosolids:

Risk characterization—a pathogen that does not occur very frequently in the waste:

Step 3 The quantitative references in Figure 1 are shortened references to the underlying mathematics in each part of the model. Now we are going to explore in greater depth one of the mathematical components of the model: risk characterization (the last box in Figure 1).

Risk characterization is the chance (or probability, *P*) that a person who is exposed to a specific disease-causing microbe gets sick. We are exposed to disease-causing microbes every day but do not always get sick from them. For example, imagine someone sitting next to you has a cold. If that person coughs in your face, you have a higher risk of catching the cold, but you may or may not catch the cold depending on numerous other factors, such as the strength of your immune system and the amount of virus or bacteria in the cough.

This risk of getting sick from an exposure can be described mathematically using variables such as dose, *d* (that is, the amount or concentration) of the microbe; and characteristics of specific types of microbes, such as a microbe's infectiousness, which are described by variables such as β (beta) and α (alpha). Some diseases are easier to transmit than others, and some diseases can pass through the multiple defense barriers in the body more easily than others (e.g., an ingested microbe has to get past the stomach acid and the immune system). These differences can be described mathematically.

For the microbial risk exposure assessment model described in study, the researchers used β and α specifically for rotavirus, a microbe that can cause fever, vomiting, watery diarrhea, and abdominal pain. β and α are different for various disease-causing organisms because of the differences in each disease's ability to cause infection.

Step 4 Since we know the variables that can affect a person's risk of getting sick (such as the dose and the infectiousness), let's look at the equation the scientists used to estimate the chance that someone will get sick when exposed to rotavirus. The equation is called the beta-Poisson (pronounced "pwah-sohn") dose–response equation. That equation is

$P = 1 - [1 + (d / \beta)]^{-\alpha}$,

where P is the probability (or chance) that an exposed person will become infected (sick), d is the the dose of the microbe, β (beta) is a threshold number of microbes in the body that results in illness, and α (alpha) is the probability that someone receives a high enough dose to cause disease.

Now you are going to play with some numbers and compare the estimated risk of infection for two scenarios: exposure to rotavirus in untreated and in treated sewage sludge. Answer the following questions:

a. Calculate P for rotavirus if someone ingests 100 mg of untreated biosolids at one single point in time (e.g., drinking contaminated water). Show your work, including the canceling of units. Write your answer using decimals and scientific notation.

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

$\beta = 0.42$ plaque-forming units (PFU)

$\alpha = 0.26$

$d = 0.125$ PFU (assumes 5 PFU per 4,000 mg of untreated biosolids and assumes 100 mg ingested at one single point in time)

b. Calculate P for rotavirus if someone ingests 100 mg of treated biosolids at one single point in time. Show your work, including the canceling of units. Write your answer using decimals and scientific notation.

$P = 1 - [1 + (d / \beta)]^{-\alpha}$

$\beta = 0.42$ plaque-forming units (PFU)

$\alpha = 0.26$

$d = 0.00125$ PFU (assumes 0.05 PFU per 4,000 mg of treated biosolids and assumes 100 mg ingested at one single point in time)

Step 5 What do the numbers you calculated in Step 4 actually mean? If you calculated a probability (*P*) of 0.003 (or 3×10^{-3}), that means that for every 1,000 times (10^3) someone is exposed to the pathogen at a given dose, that person has a chance of getting sick 3 times. This can also be interpreted to mean that for every 1,000 people who are exposed to the pathogen dose, approximately 3 will get sick.

Using your results from Steps 4a (untreated biosolids) and 4b (treated biosolids), describe what those numbers mean in terms of the chance or probability that someone will get sick. Discuss your results in terms of rotavirus and the specific dose used in your calculations.

Untreated biosolids:

Treated biosolids:

Step 6 As a class discuss the following question: If you were a leader in your local, state, or national government, would you allow untreated biosolids to be applied to land? Why or why not? Include the calculations in Steps 4 and 5 in your answer.