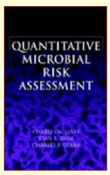
WASTEWATER REUSE 3
Quantitative microbial risk analysis

1.	 **Natural Wastewater Treatment & Reuse** **WASTEWATER REUSE 3 Quantitative Microbial Risk Analysis (QMRA)** Professor Mara	We're now going to look at a very important and useful technique in wastewater reuse: quantitative microbial risk analysis, or QMRA.
2.	**Quantitative Microbial Risk Analysis** **Probability of infection from a single dose *d* of a pathogen, $P_I(d)$** • Two dose–response models: **1. Exponential dose-response model** $P_I(d) = 1 - \exp(-rd)$ ① $= rd$ when $rd \ll 1$ *r* is a 'pathogen infectivity' constant: *Cryptosporidium*: $r = 4.2 \times 10^{-3}$; *Giardia*: $r = 0.0199$	QMRA enables us to determine the probability (or risk) of infection occurring in a community or an individual as a result of exposure to a single dose *d* of a pathogen, and we term this risk $P_I(d)$. We have to use a dose-response model, and the model we use for protozoan pathogens, such as *Cryptosporidium* and *Giardia*, is the exponential dose-response model, which is: $P_I(d) = 1 - e^{-rd}$ which we'll call equation ①. When *rd* is very small the equation becomes: $P_I(d) = rd$ *r* is a pathogen infectivity constant, and its value for *Cryptosporidium* is 4.2×10^{-3} and for *Giardia* 0.0199.
3.	For a **community** $P_I(d)$ is the proportion of the community infected as a result of all members of the community being individually exposed to *d* pathogens. For an **individual** $P_I(d)$ is the probability (risk) of infection as a result of exposure to *d* pathogens. From ①: $d = -r^{-1}\ln[1 - P_I(d)]$ ②	For a community $P_I(d)$ is the proportion of the community that becomes infected as a result of all members of the community having been exposed to a single dose *d* of a pathogen; and for an individual $P_I(d)$ is the probability or risk of infection as a result of having been exposed to the single dose *d*. We can rearrange equation ① in terms of *d*, as shown on the slide, and we'll call this equation 'equation ②'.

4.	When $P_I(d) = 0.5$ (50% of community infected) $d = N_{50}$, the median infectious dose. From ①: $N_{50} = -\ln(0.5)/r = 0.69/r$ ③ **2. Beta-Poisson dose response model** $P_I(d) = 1 - [1 + (d/N_{50})(2^{1/\alpha} - 1)]^{-\alpha}$ ④ N_{50} and α are pathogen constants:	When $P_I(d)$ = 0.5 (that is, 50% of an exposed community becomes infected), d = N_{50}, the median infective dose which, from equation ①, is 0.69/r, and this is equation ③. The second dose-response model, which we use for bacterial and viral pathogens, is the beta-Poisson model, which is given by equation ④ on the slide. N_{50} and α are pathogen constants,
5.	**β-Poisson pathogen infectivity constants** **Pathogen** / **N_{50}** / **α** Rotavirus 6.17 0.253 *Campylobacter* 896 0.145 *Vibrio cholerae* 243 0.25 *Shigella* 1,120 0.21 *Salmonella* 23,600 0.313 *S. typhi* 3.6×10^6 0.109	and their values for some of the more common excreted pathogens are given in this table.
6.	From ④: $d = \{[1 - P_I(d)]^{-1/\alpha} - 1\}/\{N_{50}/(2^{1/\alpha} - 1)\}$ ⑤ Equations 1–5 are for **single** exposures to a pathogen dose *d*.  Reference text – Haas, Rose and Gerba, (Wiley, 1999):	We can rearrange equation ④ in terms of *d*, as shown on the slide, and this gives equation ⑤. The equations we've used so far, equations ① – ⑤, are all for **single** exposures to a pathogen dose *d*.
7.	**❀ MULTIPLE EXPOSURES ❀** eg, from drinking treated drinking water, *or* from consuming wastewater-irrigated salad crops or raw vegetables ❑ Annual risk of infection from *n* multiple exposures per year to pathogen dose *d*: $P_{I(A)}(d) = 1 - [1 - P_I(d)]^n$ ⑥ risk from single exposure days of exposure per year	However, in real life, we are often subjected to **multiple** exposures – we drink drinking water every day, and we might eat wastewater-irrigated foods several times a week. So we need to be able to determine the **annual** risk of infection from *n* exposures per year to a pathogen dose *d*. And this is given by equation ⑥ on the slide. This says that the annual risk of infection, $P_{I(A)}(d)$ is given by: $1 - [1 - P_I(d)]^n$

8.	$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n$ $[1 - P_I(d)]$ = risk of ***not*** becoming infected from 1 exposure $[1 - P_I(d)]^n$ = $1 - [1 - P_I(d)]^n$ =	So how does this come about? Well, as we have seen, $P_I(d)$ is the risk of becoming infected as a result of a single exposure to the pathogen dose d. Therefore $[1 - P_I(d)]$ is the risk of *not* becoming infected as a result of a single exposure to the pathogen dose d.
9.	$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n$ $[1 - P_I(d)]$ = risk of ***not*** becoming infected from 1 exposure $[1 - P_I(d)]^n$ = risk of ***not*** becoming infected from n exposures per year $1 - [1 - P_I(d)]^n$ =	So $[1 - P_I(d)]^n$ is the risk of *not* becoming infected as a result of n exposures to the pathogen dose d.
10.	$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n$ $[1 - P_I(d)]$ = risk of ***not*** becoming infected from 1 exposure $[1 - P_I(d)]^n$ = risk of ***not*** becoming infected from n exposures per year **Therefore:** $1 - [1 - P_I(d)]^n$ = annual risk of infection from n exposures per year	Thus $1 - [1 - P_I(d)]^n$ is the annual risk of *becoming* infected as a result of n exposures per year to the pathogen dose d.
11.	From ⑥: $P_I(d) = 1 - [1 - P_{I(A)}(d)]^{1/n}$ ⑦ **********	We can express equation ⑥ in terms of $P_I(d)$, as shown on the slide, and this is equation ⑦.

12.	From ⑥: $P_I(d) = 1 - [1 - P_{I(A)}(d)]^{1/n}$ ⑦ ********** **INFECTION AND DISEASE** ➢ Only a proportion of infected individuals will develop clinical disease: $P_D(d) = a[P_I(d)]$ ⑧ $0 < a < 1$	In normal, casual speech we often use the terms 'infection' and 'disease' to mean the same thing; but they are different. Not everyone who is infected will become ill, so, the *disease* risk $P_D(d)$ is equal to a constant a × the *infection* risk $P_I(d)$ [this is equation ⑧], and a has a value somewhere between 0 and 1.
13.	**Application of QMRA to drinking water quality** WHO in its 2004 ***Guidelines for Drinking Water Quality*** uses a 'tolerable' risk of waterborne disease from drinking fully treated drinking water of: 10^{-3} per person per year 	So what's the use of QMRA? Well, we can apply it to drinking water, for example. The World Health Organization uses a 'tolerable' risk of waterborne disease of 10^{-3} per person per year. This means that it's OK if one person in a thousand becomes ill each year from drinking fully treated drinking water.
14.	QMRA can answer such questions as: **What is the maximum permissible number of rotaviruses per litre of treated drinking water?** 	We can use QMRA to answer questions like 'What is the maximum permissible number of rotaviruses per litre of treated drinking water?'. In other words we can use QMRA to set rational drinking water quality requirements, or standards.
15.	ie, $P_{I(A)}(d) = 1 \times 10^{-3}$ From ⑦ with n = 365: $P_I(d)$ (ie, single exposure) = 2.7×10^{-6}	If we take $P_{I(A)}(d)$ as 10^{-3} per person per year, then, from equation ⑦ with n as 365 (as we drink drinking water every day), we can calculate $P_I(d)$ as 2.7×10^{-6} per person per exposure event.

16.	ie, $P_{I(A)}(d) = 1 \times 10^{-3}$ From ⑦ with n = 365: $P_I(d)$ (ie, single exposure) = 2.7×10^{-6} **ROTAVIRUS:** From eq. ⑤ with N_{50} = 6.17 and α = 0.253: $d = 4.5 \times 10^{-6}$ Assume this dose is in 2 litres of treated drinking water. Therefore max. conc. of rotaviruses per litre of treated drinking water is: ~2×10^{-6}, or: **~2 rotaviruses per million litres**	So, we can now use equation ⑤, with N_{50} = 6.17 and α = 0.253 for rotavirus, to calculate the single rotavirus dose d, and this works out as 4.5×10^{-6}. Suppose that this dose d is in 2 litres of water. Therefore, assuming that people drink 2 litres of water a day, the maximum permissible concentration of rotaviruses in drinking water is around 2×10^{-6} per litre; that's roughly 2 rotaviruses per million litres of treated drinking water.
17.	 Application of QMRA to wastewater reuse: next presentation	In the next presentation we will discuss how QMRA can be applied to wastewater reuse, including the irrigation of, as shown here, salad crops and vegetables that may be eaten uncooked.