# Quantitative Microbial Risk Assessment (QMRA)

## A methodological framework for estimating health risks associated with the reuse of treated wastewater


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# What is Risk ?

- ✓ **Risk** is a measure of the **probability** and **consequence** of uncertain future events.
- ✓ It is associated with the **chance** and **severity** of an undesirable outcome.
- ✓ Risk involves exposure to:
  - **Losses**
  - **Damages**
  - **Health effects**
  - **Other undesirable consequences**

… now you know why the **risk** of travelling by plane is extremely low because although the consequences from a fatal accident are **very high** the probability to take place is extremely **low** !!!

**Exercise : Think about an activity with high risk having low consequence but high probability**

- ✓ The degree of risk varies and can be influenced by factors such as **uncertainty**, **probability of occurrence**, and **applied control measures**.
- ✓ It is important to make **informed decisions** to minimize the risks concerning the human health and the environment.

***Risk = Probability · Consequence***

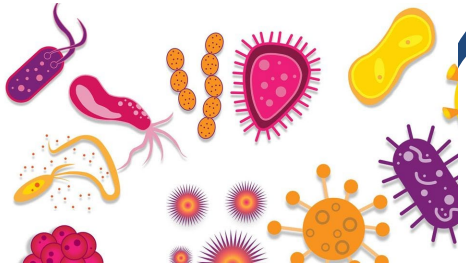
# What is Quantitative Microbial Risk Assessment (QMRA)?

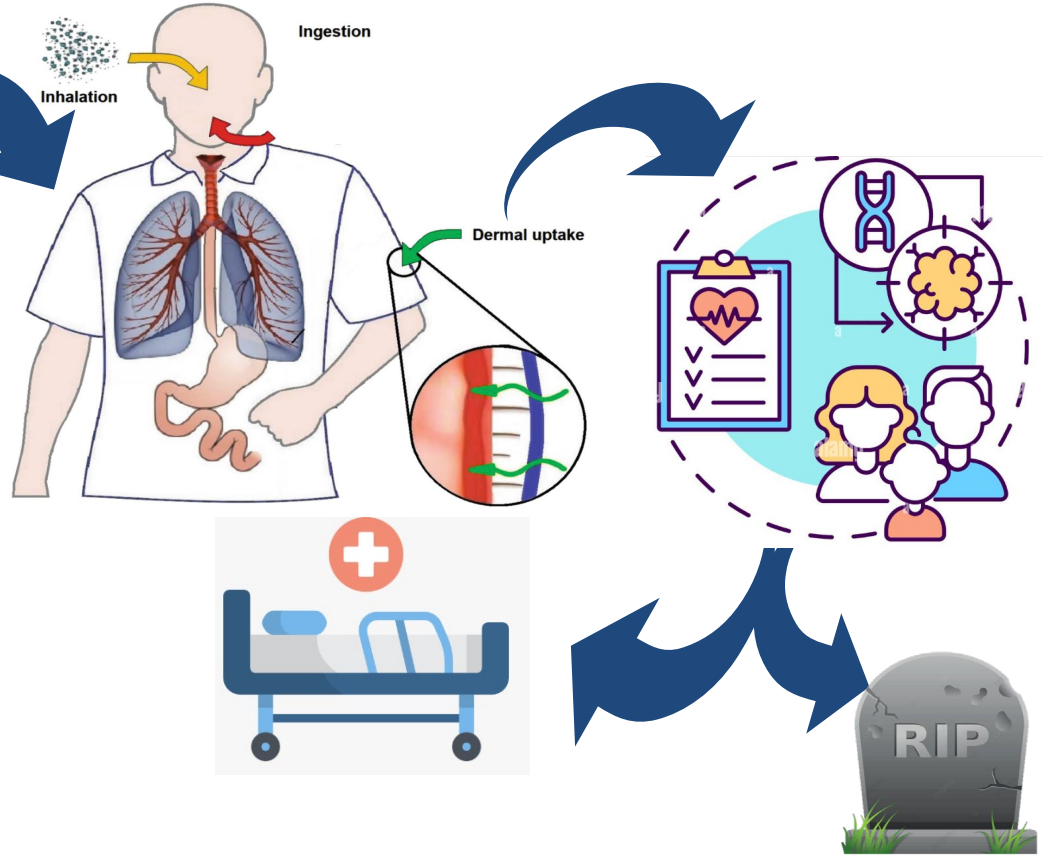
- ✓ QMRA is a **methodological approach** which can be applied to **estimate** the **health risks** associated with faecal pathogens present in drinking water, in wastewater, in recreational water and in different water reuse or recycling scenarios.
- ✓ QMRA is based on:
  - ✓**The quality data from the water source**
  - ✓**The information from the treatment barriers**
  - ✓**The characteristics of specific pathogens**
- ✓ QMRA uses mathematical methodology and relevant information to derive **disease burden estimates** associated with exposure to pathogens from water sources.


# What are the risk associated with the use of reclaimed water?

# Which are the main steps of Quantitative Microbial Risk Assessment (QMRA)?

- ✓ QMRA follows a **common approach** in risk assessment, which includes **four discrete** components:
  1. Hazard identification
  2. Exposure assessment
  3. Health effects assessment
  4. Risk characterization






- ✓ QMRA provides a scientific basis for risk management decisions and can be used in Decision Support Systems (DSS).
- ✓ As a risk-based approach, QMRA can be used to:
  - Assess existing water treatment systems, using site-specific water quality data
  - Determine the need for additional treatment barriers
  - Evaluate the impact of source water quality to the overall risk

# 1 Hazard identification – Problem formulation

- ✓ The first step of QMRA is hazard identification, a **qualitative** process of identifying hazards to the water system or to human health from microorganisms as well as the description of the spectrum of human illness and disease associated with the specific microorganisms.
- ✓ ***Microbial Hazards:*** Originate from pathogenic microorganisms (pathogens) that may have an ***adverse impact on the health*** of the people who use the water or come in contact with it.
- ✓ ***Hazardous events:*** Events that may introduce pathogens into the water supply or events that may fail to remove them.

  These events may occur at every stage of the water supply chain e.g.

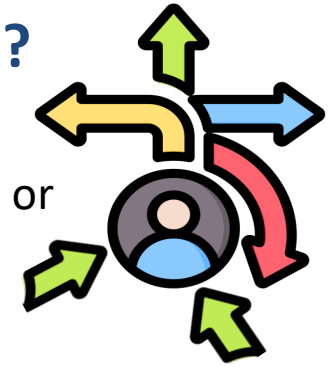
  - At the source (e.g. rain events that flush human or animal faecal waste into the water supply, or the reuse of treated wastewater in various water reuse scenarios)
  - In treatment (e.g. failures in filtration or disinfection units)
  - In the distribution network (e.g. improper repair work introducing microbial contamination)
  - Power supply failure in WWT units, pumps failure etc.

# 1 Hazard identification – Problem formulation

## ✓ Which hazards should be considered ?

- ✓ It is not possible to consider all water-related human pathogens in a QMRA.
- ✓ Therefore, ***reference pathogens*** are chosen that, if controlled, would ideally ensure control of all pathogens of concern.
- ✓ Reference pathogens should be selected taking into account local conditions, including relevance to the exposure pathway(s), source water characteristics and the incidence and severity of waterborne disease.

## ✓ Which exposure pathways – Which hazardous events should be considered ?



- ✓ The overall pathway from pathogen occurrence to human exposure should be identified.
- ✓ Specific hazardous events (i.e. an incident or situation that can lead to the presence of the hazard) or scenarios that are identified.

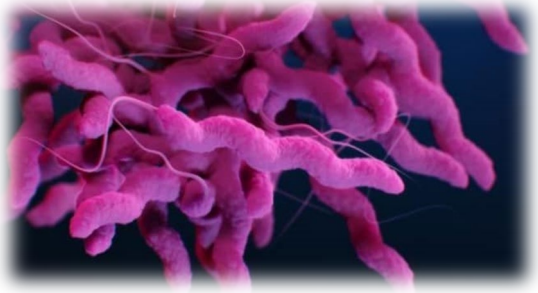
## ✓ Which health outcomes should be considered ?

- ✓ The human health outcomes that are of interest are identified.
- ✓ Depending on the purpose of the assessment, the human health outcomes may include ***infection***, ***illness***, ***illness and sequelae***, or ***a measure of disease burden that aggregates the impact of all of these outcomes***.

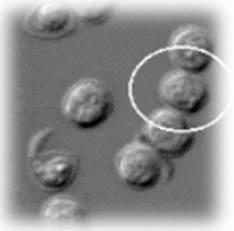
## ✓ What level of certainty is needed for risk management ?

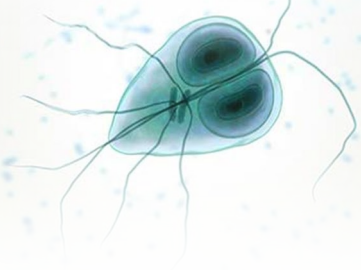
# 1 Hazard identification - Common pathogens in water

- **Bacteria**
  - *Campylobacter jejuni*
  - *Salmonella enterica*
  - *Escherichia coli* O157
  - *Vibrio cholerae*
  - *Pseudomonas aeruginosa*
  - *Legionella* spp.
  - *Aeromonas* spp.
  - *Mycobacterium* spp.

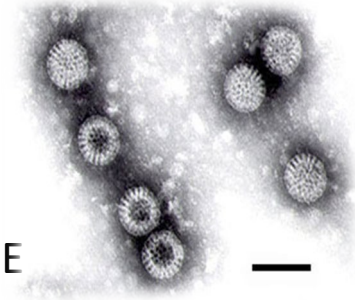


- **Protozoan Parasites**
  - *Cryptosporidium parvum and hominis* (oocysts)
  - *Giardia lamblia*
  - *Entamoeba histolytica*
  - *Naegleria fowleri*

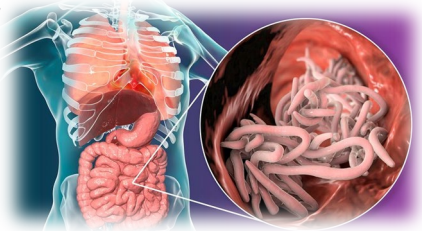




- **Viruses**
  - Adenovirus
  - Norovirus
  - Rotavirus
  - Hepatitis A and E
  - Enteroviruses (Echovirus-12, Coxsackievirus B4 )



- **Helminths (Parasitic Worms)**
  - *Schistosoma* spp.
  - *Dracunculus medinensi*
  - *Ascaris lumbricoides*



*Most common **reference** pathogens*

# 1 Hazards associated with drinking water or wastewater reuse

- ✓ The various hazards that can be caused by the water usage can have **completely different health outcomes**.
- ✓ Some outcomes are **mild** (e.g. **nausea, vomiting**), whereas others can be **severe** (e.g. **cholera, haemolytic uraemic syndrome associated with *Escherichia coli* O157 or cancer**).

- ✓ Some outcomes are **acute** (e.g. **diarrhoea**), whereas others are **delayed** (e.g. **infectious hepatitis or cancer**).
- ✓ Some especially relate to certain **age ranges** and **groups** (e.g. infection with hepatitis E virus has a very high mortality rate among pregnant women).

- ✓ In addition, a hazard may **cause multiple effects**
  - ✓ *Enterovirus may cause mostly gastrointestinal illness, but also severe health outcomes, including **meningitis, sepsis, myocarditis, poliomyelitis, link with type I diabetes**.*
  - ✓ *Campylobacter may cause self-limiting diarrhoea. Sequelae include **Guillain-Barré syndrome (GBS)**, **reactive arthritis (ReaA)** and **inflammatory bowel disease**.*

# Guillain-Barré syndrome (GBS)

## CAUSES OF
## GUILLAIN BARRE SYNDROME

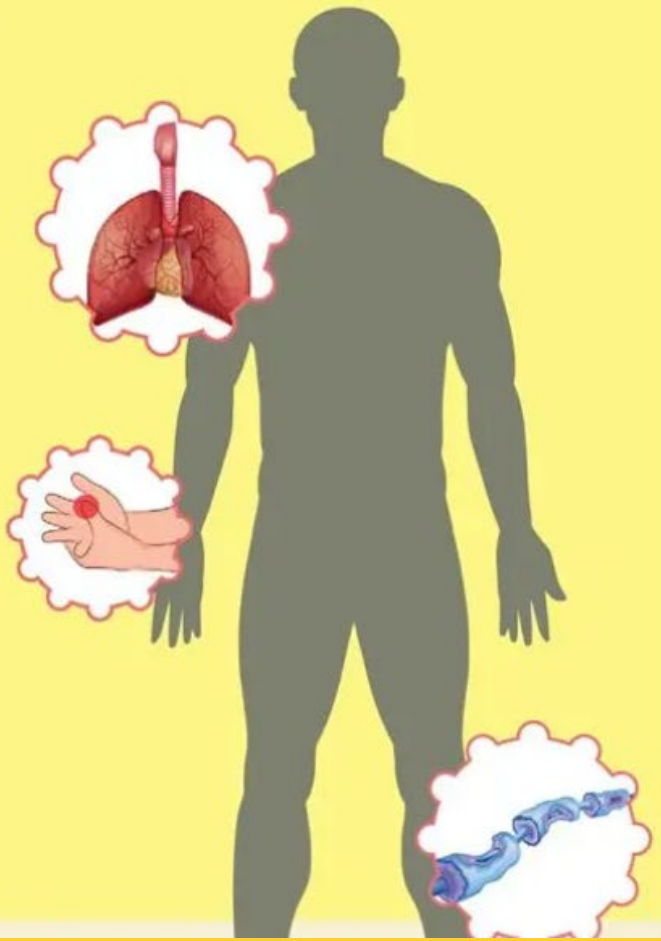
- **It is an Autoimmune disease where the body's immune system mistakenly attacks and damages its nerve cells.**

- Usually develops a few days after recovering from a Gastrointestinal or respiratory tract infection caused by some specific microorganisms Such as:

- **Gastrointestinal Tract infection due to:**

1. Campylobacter Jejuni infection (Most common)
   As per some studies, every 1 in 20 people suffering from Guillain Barre Syndrome (GBS) has a history of recent Campylobacter Jejuni Infection.

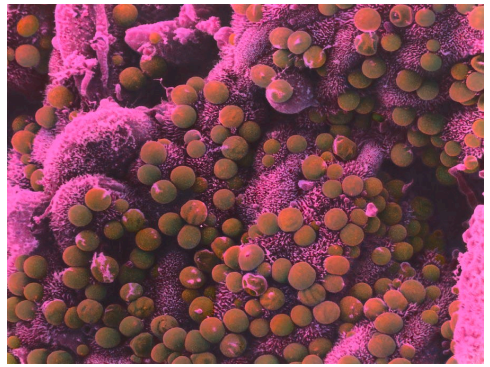
Rarely Gastrointestinal infections with few other bacteria can also be a culprit.



# Protozoa

- ✓ ***Cryptosporidium parvum*** and ***Giardia lamblia*** have been selected as the **reference** protozoa for risk assessment because of their
  - ✓ **High prevalence rates**
  - ✓ **Potential to cause widespread disease**
  - ✓ **Resistance to chlorine disinfection**
  - ✓ **The availability of a dose–response model for each organism**
- ✓ Ideally, a reference protozoa will represent
  - ✓ **Worst-case combination of high occurrence**
  - ✓ **High concentration and long survival time in source water**
  - ✓ **Low removal and/or inactivation during treatment and**
  - ✓ **High pathogenicity for all age groups**

*Giardia lamblia*



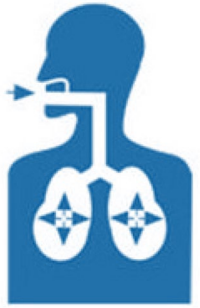
*Cryptosporidium parvum*

These organisms can cause serious illness in immunocompetent and immunocompromised individuals. Illness caused by *Cryptosporidium* is more serious because it is capable of causing death, particularly in immunocompromised individuals, and extraintestinal damages can occur (i.e., in lungs, at pancreas, etc.)

The presence and types of *Giardia* and *Cryptosporidium* in a given water source are variable.
Faeces from humans and other animals are the main sources of enteric protozoa.

# 2 Exposure assessment

- ✓ Human exposure assessment consists of:
  - (a) **Identification of exposed populations (receptors)** and **exposure routes**
  - (b) **Estimation of the rate at which humans are exposed to the contaminant**
- ✓ Human exposure can occur via a number of pathways. The most significant include **ingestion**, **inhalation**, **skin absorption**.
- ✓ Ingestion can include the consumption of contaminated food or water and from the accidental ingestion of water or soil.
- ✓ Inhaled contaminants may be present in either gaseous form or as suspended particulate matter (spray).
- ✓ Dermal absorption can arise from immersion in contaminated air or water (bathing, swimming) or as a result of physical contact with contaminated soil or water (i.e. plant watering, gardening etc.).


# Paris 2024 Summer Olympic Games

## German Olympian 'vomits nine times' after swimming in Seine

Beck hits out at organisers for staging events in Paris river, having become latest athlete to get sick post-competition

Telegraph Sport

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PARIS 2024


Leonie Beck says she vomited and suffered diarrhoea following the marathon swim in Paris Credit: Sarah Stier/Getty Images

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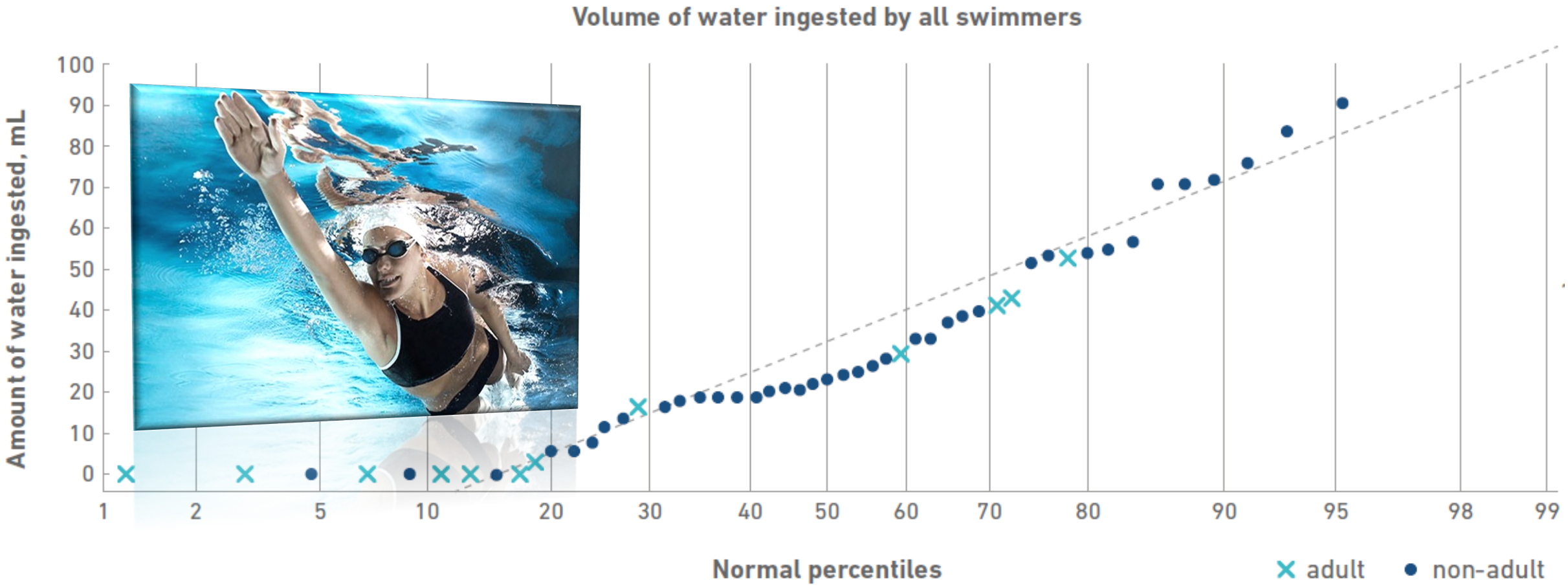
- ✓ Ahead of the 2024 Olympics, the city of Paris spent $1.5 billion to clean up the Seine, where swimming had been banned since 1923.
- ✓ Three German swimmers became ill after competing in the open water races at the Paris Olympics, though it was not immediately clear if the long-polluted Seine River was responsible for their sickness.
- ✓ However, **Leonie Beck**, a German athlete, who finished 9$^{th}$ in the 10-kilometer event, posted a picture of herself on Instagram giving a thumbs up but looking ill. "**Vomited 9 times yesterday + diarrhea**" she wrote …
- ✓ Recall that the games had been postponed due to the rain in the previous days.

# Ingested water from swimmers in recreational water




***Source***: *A. P. Dufour, T. D. Behymer, R. Cantú, M. Magnuson, L. J. Wymer; Ingestion of swimming pool water by recreational swimmers. J Water Health 1 June 2017; 15 (3): 429–437. doi: https://doi.org/10.2166/wh.2017.255*

# 2 Exposure dose

**Exposure dose per event** = **Concentration of pathogens in the exposure medium (C)** x **The amount of material ingested or inhaled per event (q)**

Number of pathogens per event = Number of pathogens/L or Number of pathogens/$m^3$ x L or $m^3$

# 2 Defining the exposure pathway

## ✓ Sources

- ✓ The initial point of pathogen quantification. It may not always be possible or appropriate to quantify the concentration directly at the point of exposure.
- ✓ For drinking-water, the source could be the untreated source water, the treated drinking-water, or even upstream faecal sources
- ✓ For wastewater reuse scenarios, pathogens have been quantified in faecal sources, raw sewage and treated effluent.

## ✓ Control measures (barriers)

- ✓ Environmental (e.g. residence time, sunlight, overland transport),
- ✓ Engineered (e.g. drinking-water treatment stages or wastewater treatment barriers)
- ✓ Regulatory (e.g. withholding periods for crops) controls that are expected to lead to a loss or inactivation of pathogens.

## ✓ Mechanisms of exposure (intake)

- ✓ The pathway by which human exposure may result, which, depending on the context, may include intentional drinking, unintentional ingestion (e.g. during recreational swimming), aerosol ingestion and food consumption.

# 3 Health effects assessment

- ✓ The **health impact data** for the identified hazards for the specific study population are compiled. Special consideration may be given to **vulnerable portions of the population (children, pregnant women, elderly people and immunocompromised individuals)** and to the **fraction of exposed people in the total population.**
- ✓ The following components should be considered:
  - ✓ **Dose–response relationship**: Application of a dose–response model is the ***critical link between pathogen exposure and estimated health outcomes*** (either infection or illness). A model usually is selected from published literature data.
  - ✓ **Probability of illness:** Not all infected individuals will develop symptoms. When using an infection-based dose–response model, it may be necessary to estimate the probability of illness once infected.
  - ✓ **Probability of sequelae:** Sequelae are severe, secondary and/or chronic health effects that may occur following initial infection. Quantifying total disease burden involves giving consideration to the likelihood and consequences of these more severe health outcomes for the given population.
  - ✓ **Disease burden:** The **DALY** is the metric used in WHO guidelines for overall community health burden. For water-associated diseases, it incorporates the total impact of all health outcomes. The advantage of using DALYs is that it allows the consideration of different impacts on both the quantity and quality of life.

# 4 Risk characterization

- **Quantitative measures of risk**: The risk may be quantified in many different metrics from the information collected during the exposure and health effects assessments, including the probability of infection, probability of illness, expected number of illness cases and DALYs. The time scale of risk may be for a single exposure, a series of independent exposures or a year. The population may be the total population or the exposed fraction of the population.
- **Variability and uncertainty**: In **deterministic modelling** the risk may be characterized by a single point estimate, such as the mean, minimum or worst case scenario, while in **stochastic modelling** by probability distributions that take into consideration the range of likely values and the probability of each of those values occurring.
- **Sensitivity analysis**: The investigation of how variability and uncertainty in the input parameters influence the variability and uncertainty in the risk outcome can be used to explore how the model components or variables, such as pathogen concentrations, efficacy of intervention measures, dose–response parameters, morbidity ratio, etc., interact and which is most important to the outcome. In particular, sensitivity analysis allows the most important sources of variability and uncertainty to be identified, which can be used to target where management should focus, where control measures should be taken and where additional data should be collected.

# 4 Variability and Uncertainty

- **Variability** and **uncertainty** are common elements of all types of risk assessment.
- **Variability** refers to how system elements change over time and space.
- **Uncertainty** refers to a lack of knowledge regarding system elements. Most of the times knowledge about model inputs is limited or absent. Building QMRA models involves subjective choices and assumptions to fill in the gaps of limited data sets.
- Examples of common sources of variability in water safety management are:
  - Pathogen concentrations in raw wastewater
  - Performance of engineered and natural treatment barriers
  - Pathogen concentrations in treated sewage effluent
  - Exposure doses and frequencies
- Some common uncertainty considerations that arise in water-related QMRA studies include:
  - Uncertainty due to absence of specific information
  - Uncertainty regarding the representativeness of experimental data
  - Uncertainty regarding selection of statistical distribution

# 4 Exposure Assessment Tools – Deterministic vs. Stochastic approach

- **Deterministic**
  - Point estimates.
  - Initial exposure assessments, including screening-level assessments.
  - This approach uses point values and simple models to produce a point estimate of exposure (either high-end or typical exposure i.e. conservative or even worst-case values).
  - Deterministic assessments are simple to carry out, often use readily available data, and produce results that are straightforward to interpret.
  - However, the use of single-point estimates does not address **variability** and **uncertainty.**
- **Stochastic**
  - Probability or frequency distributions for source concentrations or exposure factors.
  - More information and assumptions are required, and stochastic analyses are more difficult to perform.
  - Provides better understanding of uncertainty and variability.
  - Simulations using Monte Carlo method.

# 4 The multi-barrier concept

- **The multi-barrier concept** utilizes multiple systems working together to ensure the safety of water.
- For drinking water such barriers include:
  - Source water protection
  - Proper selection and operation of water treatment systems
  - Management of distribution systems to maintain treated water quality
  - Routine monitoring for verification of water quality
  - Use of qualified personnel with proper education

# 4 Log reduction – Log Removal Value (LRV)

- ✓ Microbial reduction in QMRA is most often quantified in terms of $\log_{10}$ reduction
  - ✓ 1 log unit 90% reduction
  - ✓ 2 log units 99% reduction
  - ✓ 3 log units 99.9% reduction
  - ✓ 4 log units 99.99% reduction
  - ✓ 5 log units 99.999% reduction
  - ✓ …

$$\text{Log Removal} = -\text{Log}_{10}\left(\frac{C_{outflow}}{C_{inflow}}\right)$$

- ✓ The reduction in microbial concentration across a barrier is usually defined by a **single** $\log_{10}$ reduction value or a **distribution** of $\log_{10}$ reductions.
- ✓ The total $\log_{10}$ reduction of a treatment train is assumed to be the **sum** of the $\log_{10}$ of each individual components.
- ✓ In the United States, treatment of all surface water supplies must be filtered and disinfected to ensure a four-log reduction of enteric viruses (99.99%) and a three-log (99.9%) reduction of *Cryptosporidium oocysts.* These removals are designed to reduce the yearly risk of infection from waterborne disease to 1:10,000/year (= $10^{-4}$).

**Exercise 2. *What is the % reduction of the initial number of pathogens if we achieve a 2.3 LRV?***

# Reductions of bacteria, viruses and protozoa achieved by water treatment technologies at drinking-water treatment plants for large communities (*Source: WHO Guidelines for drinking-water quality, 2022 )*

| Treatment process | Enteric pathogen group | Minimum removal (LRV) | Maximum removal (LRV) | Notes |
|---|---|---|---|---|
| **Pretreatment** | | | | |
| Roughing filters | Bacteria | 0.2 | 2.3 | Depends on filter medium, coagulant |
| Storage reservoirs | Bacteria | 0.7 | 2.2 | Residence time > 40 days |
| | Protozoa | 1.4 | 2.3 | Residence time 160 days |
| Bank filtration | Viruses | > 2.1 | 8.3 | Depends on travel distance, soil type, pumping rate, pH, ionic strength |
| | Bacteria | 2 | > 6 | |
| | Protozoa | > 1 | > 2 | |
| **Coagulation, flocculation and sedimentation** | | | | |
| Conventional clarification | Viruses | 0.1 | 3.4 | Depends on coagulation conditions |
| | Bacteria | 0.2 | 2 | |
| | Protozoa | 1 | 2 | |
| High-rate clarification | Protozoa | > 2 | 2.8 | Depends on use of appropriate blanket polymer |
| Dissolved air flotation | Protozoa | 0.6 | 2.6 | Depends on coagulant dose |
| Lime softening | Viruses | 2 | 4 | Depends on pH and settling time |
| | Bacteria | 1 | 4 | |
| | Protozoa | 0 | 2 | |
| **Filtration** | | | | |
| Granular high-rate filtration | Viruses | 0 | 3.5 | Depends on filter media and coagulation pretreatment; filtered water turbidity of ≤ 0.3 NTU in 95% of samples (and none to exceed 1 NTU) associated with 1–2 log reduction of viruses and 3 log reduction of *Cryptosporidium*[a] |
| | Bacteria | 0.2 | 4.4 | |
| | Protozoa | 0.4 | 3.3 | |
| Slow sand filtration | Viruses | 0.25 | 4 | Depends on presence of schmutzdecke, grain size, flow rate, operating conditions (mainly temperature, pH); filtered water turbidity of ≤ 1NTU in 95% of samples (and none to exceed 5 NTU) associated with 1–2 log reduction of viruses and 2.5–3 log reduction of *Cryptosporidium*[a] |
| | Bacteria | 2 | 6 | |
| | Protozoa | 0.3 | > 5 | |
| Precoat filtration | Viruses | 1 | 1.7 | If filter cake is present |
| | Bacteria | 0.2 | 2.3 | Depends on chemical pretreatment |
| | Protozoa | 3 | 6.7 | Depends on media grade and filtration rate |
| Membrane filtration: microfiltration, ultrafiltration, nanofiltration, reverse osmosis | Viruses | < 1 | > 6.5 | Varies with membrane pore size (microfilters, ultrafilters, nanofilters and reverse osmosis filters), integrity of filter medium and filter seals, and resistance to chemical and biological ("grow-through") degradation; maximum reductions associated with filtered water turbidity of < 0.1 NTU[a] |
| | Bacteria | 1 | > 7 | |
| | Protozoa | 2.3 | > 7 | |
| **Primary disinfection**[b,c] | | | | |
| Chlorine | Viruses | 2 ($Ct_{99}$ 2–30 min·mg/l; 0–10 °C; pH 7–9) | | Free chlorine × contact time predicts efficacy; not effective against *Cryptosporidium* oocysts. Turbidity and chlorine-demanding solutes inhibit this process; hence, turbidity should be kept below 1 NTU to support effective disinfection. Where this is not practical, turbidities should be kept below 5 NTU with higher chlorine doses or contact times.[a] In addition to initial disinfection, the benefits of maintaining free chlorine residuals throughout distribution systems at or above 0.2 mg/l should be considered |
| | Bacteria | 2 ($Ct_{99}$ 0.04–0.08 min·mg/l; 5 °C; pH 6-7) | | |
| | Protozoa | 2 ($Ct_{99}$ 25–245 min·mg/l; 0–25 °C; pH 7–8; mainly *Giardia*) | | |
| Chlorine dioxide | Viruses | 2 (Ct99 2–30 min·mg/l; 0–10 °C; pH 7–9) | | |
| | Bacteria | 2 ($Ct_{99}$ 0.02–0.3 min·mg/l; 15–25 °C; pH 6.5–7) | | |
| | Protozoa | 2 ($Ct_{99}$ 100 min·mg/l) | | |

# 4 Risk of infection

- ✓ The United States Environmental Protection Agency (USEPA) as well as the Dutch Drinking Water Act of 2001 sets a health-based target for a risk of **less than one infection per 10,000 individuals (1/10,000 = 0.0001 = $10^{-4}$) per year**.
- ✓ For drinking water this means that if 10,000 people each consume on average 1 L of tap water per day, **only** one individual may be infected by a waterborne pathogen.
- ✓ Many other water authorities adopt this risk limit also.

# 4 Risk of illness

- ✓ Microbial risk can also be expressed as a **risk of illness**, which is usually a percentage (fraction) of the risk of infection.
- ✓ For example, about 70% of people develop illness after infection by *Cryptosporidium*
- ✓ However, the **severity of illness** caused by microbial infection in humans varies depending on factors such as **age** and **physical condition**.

# 4 Other risk characterization benchmarks

- ✓ In order to support public health priority setting, a **common metric** is required that can be applied to **all types of hazard** and takes into account **different health outcomes**, including **probabilities**, **severities** and **duration of effects**.
- ✓ The **Disability-Adjusted Life Years (DALY)** used from World Health Organization (WHO) provides this metric. WHO established a risk endpoint (Disease Burden) of **$10^{-6}$ DALY per person per year as a health target.**
- ✓ Compared with the USEPA approach, this method **requires the input of information on infection–illness ratios and on the impact or burden of illness**.
- ✓ The $10^{-6}$ DALY tolerable burden of disease target may not be achievable or realistic in some locations and circumstances. Where the overall burden of disease by multiple exposure routes (water, food, air, direct personal contact, etc.) is very high, setting a $10^{-6}$ DALY per person per year level of disease burden from waterborne exposure alone will have little impact on the overall disease burden.
- ✓ Setting a less stringent level of acceptable risk, such as $10^{-5}$ or $10^{-4}$ DALY per person per year, from waterborne exposure may be more realistic, yet still consistent with the goals of providing high-quality, safe water.

# 4 How DALYs work ?

- ✓ WHO has used DALYs quite extensively to evaluate public health priorities and to assess the disease burden associated with environmental exposures, particularly for microbial hazards.
- ✓ DALYs are preferred because it considers both the probability of **experiencing an illness, injury** or **even death**, and the impact of the associated health effect.
- ✓ DALY is used to provide a single number to capture all of the **health costs** caused by the illness.
- ✓ **One DALY can be thought of as one lost year of "healthy" life.**
- ✓ The tolerable burden of disease from WHO is defined as an upper limit of $10^{-6}$ DALY per person per year (pppy). This upper-limit DALY *is approximately equivalent* to a $10^{-5}$ excess lifetime risk of cancer (i.e. 1 excess case of cancer per 100 000 people ingesting drinking-water at the water quality target daily over a 70-year period)
- ✓ Expressing health-based targets for chemical hazards in DALYs has the advantage of **enabling comparisons** with microbial risks. However, use of the DALY approach **for chemicals** has been limited in practice due to gaps in knowledge.
- ✓ **To calculate DALYs we need to calculate two other components first**
  **(a) The years lived with a disability (YLD) and (b) The years of life lost (YLL)**

# 4 Calculating years lived with a disability or illness (YLD)

- ✓ To calculate the years lived with a disability (YLD), the outcome fraction is multiplied by the severity weight and the duration of the illness for each illness outcome that is attributed to the pathogen. These products are then summed to give the YLD per case of illness.

$$\text{YLD} = \text{Number of incident cases} \cdot \text{Severity weight} \cdot \text{Duration of disability or illness}$$

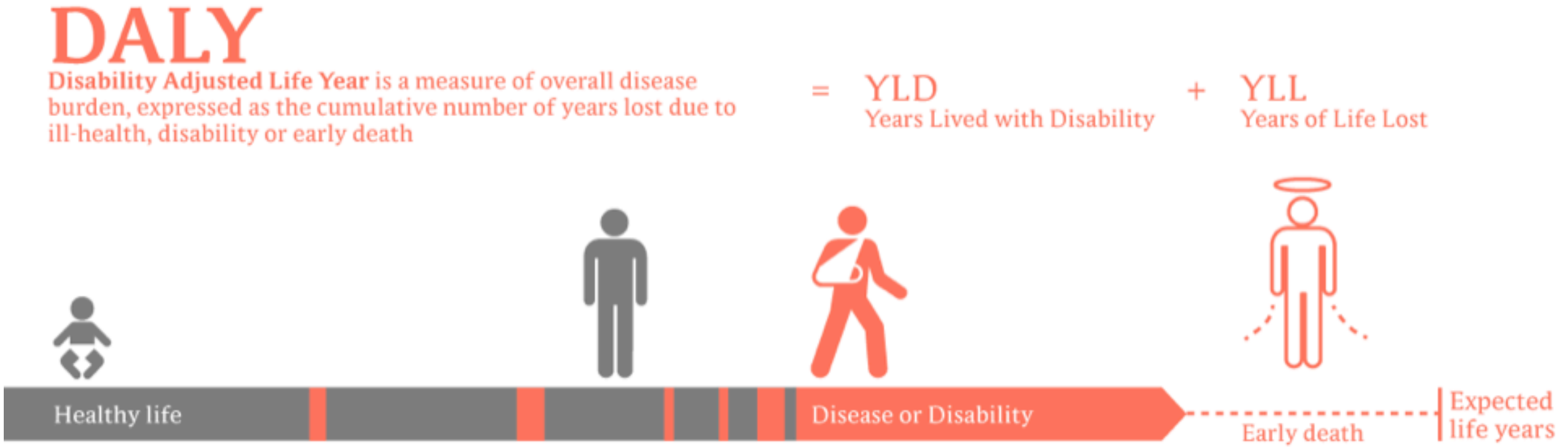
# 4 Calculating years of life lost (YLL)

- ✓ Since premature death eliminates potential years of healthy living, the YLL is calculated as **the difference between the age at death and the full life expectancy for the population**, multiplied by the **severity weight (here equals 1)** associated with loss of life and the fraction of ill individuals who died.

$$\text{YLL} = \text{Number of deaths attributable to the disease} \cdot \text{Severity weight} \cdot (\text{Life expectancy} - \text{Age at death})$$

- ✓ Usually a combined life expectancy i.e. the average of male and female life expectancies of about **81 years** is used, as the reference pathogens do not have gender specific health outcomes.
- ✓ For *Cryptosporidium*, *Giardia*, *rotavirus*, and *E.coli O157*, the weighted median age of about **39 years** is used as the age at death.
- ✓ This assumes that there is no difference in fatality rates between the age categories. For *Campylobacter*, death primarily occurs in the elderly population. Therefore, the age at death is assumed to be the median age of the eldest population category (i.e. about **73 years**).

# DALY - Infographics




Source: Interpretation of metrics: DALYs and damage to human health
*https://pre-sustainability.com/articles/metrics-interpretation-daly-and-damage-to-human-health/*

# How DALYs per case is calculated

- **Exercise** : A woman aged 53 died after 10 days in hospital after infection by *E.coli O157* having consumed contaminated water.
  - Which is the calculated years lived with a disability or illness (YLD) ?
  - Which is the calculated years of life lost (YLL) ?
  - Which is the calculated DALYs

Assuming that the severity weight of 0.23 characterizes the infection from *E.coli O157*

**YLD = 1 x 0.23 x 10 / 365 = 0.006 years**

**YLL = 1 x 1 x (81-53) = 28 years**

**DALYs = YLD + YLL = 0.006 + 28 = 28.006 years**

**If the woman had recovered from her illness the DALYs would be only 0.006 years ($6 \times 10^{-3}$) !**

**Exercise :** *Question to think about …* ***Can YLL be negative value*** *?*

# How DALYs/person/year is calculated (pppy)

- **Exercise 4** Within the last year in a small community of 10,000 inhabitants 5 were suffering from mild diarrhea and 2 from severe diarrhea after drinking contaminated tap water following a flood incident. Calculate the DALY/person/year for this case.
- Assuming that:
  - **Mild diarrhea** (severity rating of 0.1**) lasting 3 days** per case;
  - **Severe diarrhea** (severity rating of 0.23) **lasting 7 days** per case;
  - **No death incidents were reported due to the contamination of water**

$$\text{Years Lived with a Disability or illness (YLD)} = \text{Number of cases x Disability weight x Duration (expressed in years)}$$

$$\text{Years of Life Lost (YLL)} = \text{Number of deaths x Life expectancy at the age of death (expressed in years)}$$

$$\text{DALYs / person / year} = \frac{\text{Total DALYs (YLD + YLL)}}{\text{Population x Time (expressed in years)}}$$

$$\text{DALYs / person / year} = \frac{\left(5 \times 0.1 \times 3/365\right) + \left(2 \times 0.23 \times 7/365\right) + 0}{10{,}000 \text{ x } 1}$$

$$= 4.1 \cdot 10^{-7} + 8.8 \cdot 10^{-7} = 12.9 \cdot 10^{-7} = 1.29 \cdot 10^{-6}$$

# 4 The Dose – Response relationship

- ✓ Various models exist for the dose–response relationship for infection and the dose–response relationship for illness when infected.
- ✓ The most commonly applied models are based on the single-hit theory where every ingested pathogen particle is assumed to act independently and has an individual probability to cause infection.

# 4 The Exponential Dose - Response Model

$$P_{inf} = 1 - e^{(-r \cdot d)}$$

- ✓ Describes the probability of an exposed individual becoming infected ($P_{inf}$ ) given an expected dose (***d***).
- ✓ The parameter ***r*** in this model characterizes the likelihood of a host-organism interaction that will result in infection.
- ✓ The relatively simple mathematical form of the exponential dose response model can, to some extent, obscure the fact that it is the result of the combination of two other probability functions:
  - ✓ (1) a Poisson distributed probability of ingesting one or more organisms capable of causing an infection given the number of infectious organisms present in the water that is consumed, and
  - ✓ (2) a Binomially distributed probability of one or more of the ingested infectious organisms interacting with the host and causing an infection given the number of organisms ingested.

# The Beta-Poisson Dose - Response Model

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

$$P_{inf} = 1 - \left[1 + \frac{d}{N_{50}}\left(2^{1/\alpha} - 1\right)\right]^{-\alpha}$$

- ✓ Describes the probability of an exposed individual becoming infected ($P_{inf}$ ) given an expected dose ($d$).
- ✓ $\alpha$, $\beta$ parameters of the equation.
- ✓ $N_{50}$ median infectious dose.

# Converting probability of illness per event to the annual probability of illness

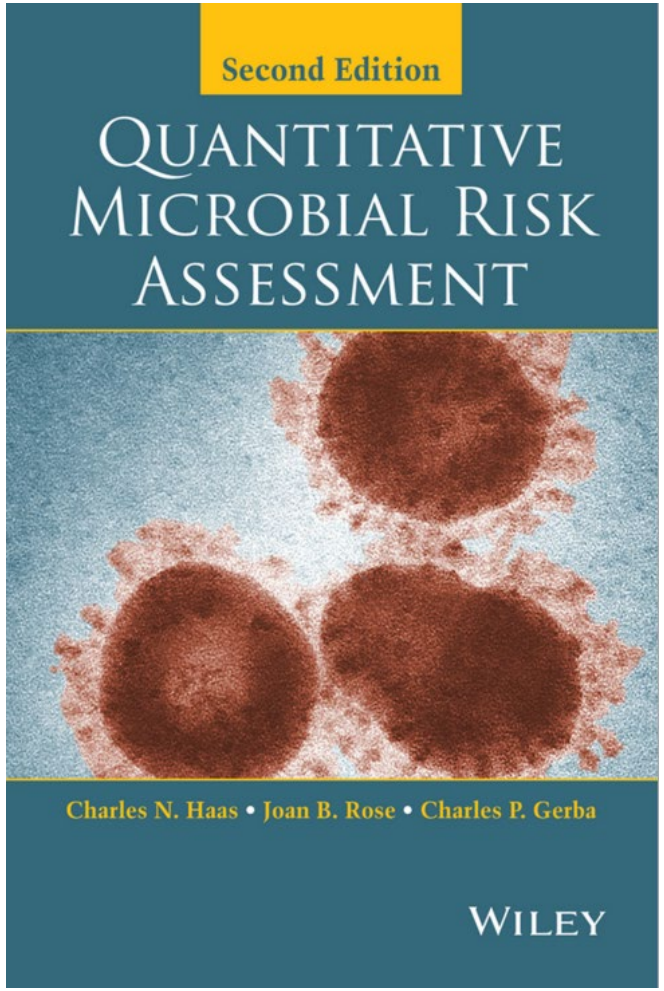
$$P_{ill\ per\ event} = Ratio\ of\ infection\ to\ illness \cdot P_{inf\ per\ event}$$

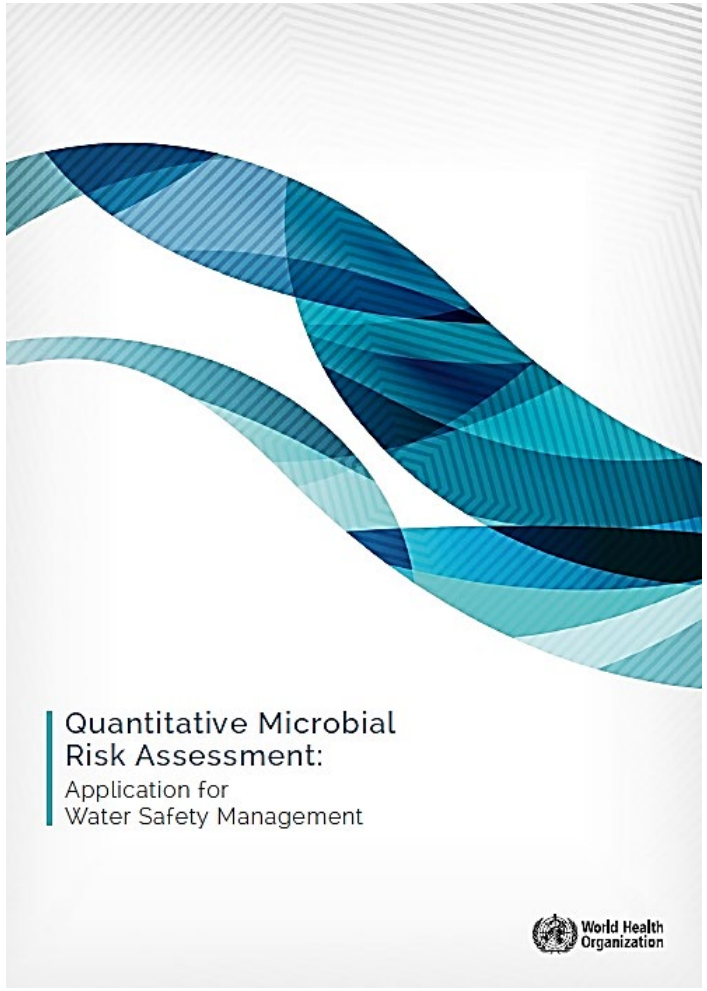
$$P_{ill\ per\ year} = 1 - (1 - Pill_{\ per\ event})^{n}$$

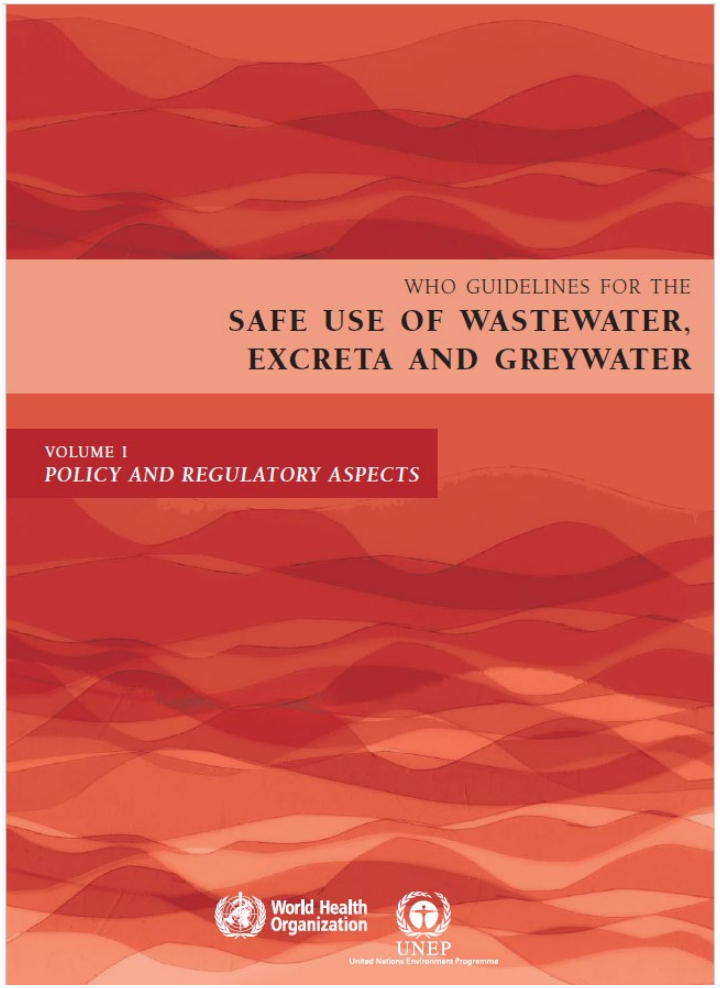
where ***n*** is the number of repeated exposures per year in the same risk

# A short tutorial …

# QMRA - Suggested readings



# Conclusions

- ✓ QMRA provides a **clear** and **transparent** approach for comparing system risks with a health outcome target, making it possible to evaluate whether a system or pathway is safe.
- ✓ QMRA can help **identify effective measures** that can be implemented to reduce the risk below health-based targets.
- ✓ QMRA needs reliable input data, such as pathogen concentrations in different water matrices, data on pathogen removal by different barriers under different conditions, data on exposure volumes and dose–response relationship data.

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