2006 WHO Guidelines for Safe Reuse of Wastewater

About WHO

World Health Organization

- WHO is the directing and coordinating authority for health within the United Nations system.

- Provides leadership on global health matters, setting norms and standards

- The Guideline is recognized as representing the **position of the United Nation** systems on issues of wastewater reuse.

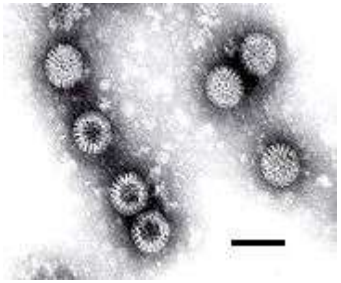
Wastewater reuse in relation to MDG

Wastewater reuse can help to grow more food (water + nutrients)

However it should be done safely (public health and environment)

Risks involved in wastewater reuse

➢**Bacteria**: *Campylobacter* and *Salmonella* (diarrhea), *Vibrio cholerae* (cholera).



➢**Viruses**: *Rotavirus* (diarrhea among infants), *Norovirus* (diarrhea all ages)

➢**Protozoa**: *Giardia lamblia, and Cryptosporidium* (severe diarrhea)

➢**Helminths**: Worms such as *Ascaris lumbricoides*. Eggs are in the feces and may survive for several years

➢ **Groups exposed to health risks associated with the use of wastewater for irrigation:**

- consumers,
- farm workers and their families, and
- nearby communities

➢ **Unrestricted irrigation**: For irrigation of crops eaten raw

➢ **Restricted irrigation**: Crops not for direct human consumption

The 1973 WHO Guidelines (based on USA-Californian standards), but…..

- "recognized that the extremely strict Californian standards were not justified by the available epidemiological evidence", and made the following recommendations:
  - for both restricted and unrestricted irrigation: "no chemicals which lead to undesirable residues in crops or fish"
  - additionally for unrestricted irrigation : ≤100 total coliforms per100 mL,
  - and additionally for restricted irrigation – (a) (crops not for direct human consumption): "freedom from gross solids, and significant removal of parasite eggs"; and (b) either ≤100 total coliforms per 100 mL or "significant removal of bacteria".

The 1989 WHO guidelines

- Based largely on epidemiological evidence (**actual** risk) as follows:
  - Restricted irrigation: ≤1 human intestinal nematode (helminths) egg per liter
  - Unrestricted irrigation: ≤1 human intestinal nematode egg per liter and ≤1000 fecal coliforms per 100 mL

Incorporated distinction between **actual** and **potential** risks and introduced 'health-protection control measures' (crop restriction, drip irrigation and human exposure control) which could be used, either singly or in combination, when wastewater treatment does not, or is unable to, achieve ≤1 egg per liter and ≤1000 fecal coliforms per 100 mL

Actual and potential health risks

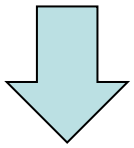
- An actual risk to public health occurs as a result of wastewater irrigation when all of the following four conditions are satisfied:
  1. either an **infective dose** of the pathogen reaches the wastewater-irrigated field or the pathogen multiples in the field to form an **infective dose**
  2. the infective dose **reaches a human** host
  3. the host becomes **infected**, and
  4. the infection **causes disease** or further transmission
- Actual risks can thus only be determined from epidemiological studies.
- If conditions **1-3** are satisfied but not condition 4, then the risk is only a **potential** risk.

Critics guidelines WHO 1989

- Requirement for wastewater treatment ≤ 1000 fecal coliforms per 100 mL, especially in low- and middle income countries can not be met => **illegal irrigation, no control**.
- Fecal coliforms level in European rivers from 1,000 to 10,000/100ml. **No health risk reported**! (UNEP/WHO 1996)
- Guidelines are not just numbers
  = good practice + microbial water quality standards
- Low-cost effective treatment technologies needed
- Risk reduction strategies necessary (and possible) where wastes receive no or inadequate treatment

WHO realizes

- Reuse of wastewater, greywater and excreta in agriculture and aquaculture is practiced worldwide on a large scale, however often without sufficient health protection measures
- WHO recognizes the importance of reuse of wastewater, greywater and excreta for sustainable food production and improved livelihood
- WHO provides guidance on health protection measures for safe reuse



Objective new targets: <u>maximize the protection of human health and the beneficial use of important resources</u>

Approaches to microbial risk control

- There have been three basic approaches to the control of microbial risks:
  - Based on **potential risks**, such as the very strict Californian standards and the even stricter US EPA/USAID guidelines
  - Based on **actual risks**, such as the 1989 WHO Guidelines
  - Based on **tolerable or acceptable risks**: quantitative microbial risk analysis (QMRA), such as the 2006 WHO Guidelines

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http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html

Update from the 1989 (and 1973) guidelines

Source: Werner (2005)

2006 WHO Guideline for the safe use of wastewater

- Guidelines are a code of good management practice.

- Ensure that **health risks (pathogens)** associated with the use of wastewater for irrigation crops (including food crops eaten uncooked) are assessed and managed.

- Offers much more than a set of guideline values

- Include **health-based targets (DALY)**, which correspond to the tolerable burden of disease that would result from agricultural wastewater use.

- **Models (QMRA)** used to **calculate the required levels of pathogens reduction** to meet the targets for different types or irrigation scenarios employing different degrees of wastewater treatment and non/treatment.

- **Pathogen reduction** can be **achieved** with different combinations of health protection control measures (risk reduction achieved **by wastewater treatment** and by including **post-treatment health-protection** control measures)

- Provide a framework that supports the establishment of national standards and regulations for agricultural wastewater use.

WHO 2006 – Approach for microbial risks

1. To define a tolerable health-based targets (**DALY – disability-adjusted life years**), from which it is possible….
2. To derive tolerable risks of **disease** and **infection** to set health-based targets for pathogen reductions,
3. To determine the required pathogen reduction(s) (**QMRA**)
4. To determine how the required pathogen reductions can be achieved (**multiple-barrier approach**), and
5. To put in place a system for verification monitoring

1. Define a tolerable health-based target

➢ **Health-based target**: Establish a defined level of health protection for a given exposure. Measure of disease = **DALY** (disability-adjusted life years) **"LIFE LOST"**

- **DALYs** are a measure of **population health** in terms of the burden due to a specific disease or risk factor
- **DALYs** attempt to measure **healthy years of life lost** because of disability or death from a disease
- **DALYs** account for not only acute health effects but also for **delayed and chronic effects**

1. Define a tolerable maximum additional burden of disease

2006 WHO suggests health-based target <= 10^{-6} DALY pppy

• Only one of a million human life years expectancy will be lost due to the potential additional disease from wastewater/excreta reuse

• Same protection level as used in the WHO guideline for drinking water (people expect food they eat to be as safe as water they drink)

1. Define a tolerable maximum additional burden of disease

Table 2.4 Health-based targets and helminth reduction targets for treated wastewater use in agriculture

Type of irrigation	Health-based target for viral, bacterial and protozoan pathogens	Microbial reduction target for helminth eggs
Unrestricted	$\leq 10^{-6}$ DALY per person per year[a]	≤1 per litre (arithmetic mean)[b,c]
Restricted	$\leq 10^{-6}$ DALY per person per year[a]	≤1 per litre (arithmetic mean)[b,c]
Localized (e.g. drip irrigation)	$\leq 10^{-6}$ DALY per person per year[a]	(a) Low-growing crops:[d] ≤1 per litre (arithmetic mean) (b) High-growing crops:[d,e] No recommendation

- Helminthic risks same as 1989 WHO Guidelines. In 1989 recommendation was based on expert opinion, but in 2006 was based on epidemiological evidence.

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2. Derive tolerable disease and infection risks

The tolerable maximum additional **"LIFE LOST"** = **DALY** (disability-adjusted life years) needs to be translated to disease and infection risks pppy

DALY loss per case of disease = "health cost" of one episode of that disease.

$$\text{Tolerable disease risk pppy} = \frac{\text{Tolerable DALY loss pppy (i.e., } 10^{-6})}{\text{DALY loss per case of disease}}$$

$$\text{Tolerable infection risk pppy} = \frac{\text{Tolerable disease risk pppy}}{\text{Disease/infection ratio}}$$

2. Derive tolerable disease and infection risks

Pathogen	DALY loss per case of disease	Tolerable disease risk pppy for 10^{-6} DALY loss pppy	Disease/ infection ratio	Tolerable infection risk pppy
Rotavirus: (1) IC[a]	1.4×10^{-2}	7.1×10^{-5}	0.05	1.4×10^{-3}
(2) DC[a]	2.6×10^{-2}	3.8×10^{-5}	0.05	7.7×10^{-4}
Campylobacter	4.6×10^{-3}	2.2×10^{-4}	0.7	3.1×10^{-4}
Cryptosporidium	1.5×10^{-3}	6.7×10^{-4}	0.3	2.2×10^{-3}

10^{-3}

[a] IC, industrialized countries; DC, developing countries. The DALY loss per case of rotavirus diarrhea is higher in DC than IC because a higher proportion of children under 5 in DC become infected, the disease has a longer duration due to their lower nutritional status, and they form a higher percentage of the total population.

Source: WHO 2006b.

2. Derive tolerable disease and infection risks

2006 WHO reference pathogens

- **Rotavirus** (a viral pathogen)
- *Campylobacter (a bacterial pathogen)*
- *Cryptosporidium (a protozoan pathogen)*

➢ These pathogens were chosen as 'reference' pathogens because (i) **dose-response data were available** for them; and (ii) they are **all epidemiologically important agents of severe diarrhea**

➢ Risk of **Rotavirus** infection higher than others. **Rotavirus** infection risks used to assess safety of wastewater-irrigation practices

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3. Determine pathogen reduction (QMRA)

- Exposure scenarios:
  - **Unrestricted irrigation**: consumption of wastewater-irrigated salad crops
  - Restricted irrigation: involuntary ingestion of wastewater soil particles (fieldworkers)

QMRA example

- Consumer exposure to rotavirus infection is calculated by using the following illustrative parameter values:
  - **5000 rotaviruses** per liter of untreated wastewater
  - **10 mL** of treated wastewater remaining on **100 g** lettuce after irrigation,
  - **100 g** lettuce consumed per person every two days throughout the year.

3. Determine pathogen reduction (QMRA)

Tolerable risk of infection: the 'design' risk of rotavirus infection is taken as 10^{-3} pppy

$$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n \Rightarrow P_I(d) = 1 - (1 - 10^{-3})^{[1/(365/2)]} = 5.5 \times 10^{-6}$$

n = number of exposures per year

$P_I(d)$ = probability of infection per single exposure

The rotavirus dose per exposure (*d) is the number of rotaviruses*

3. Determine pathogen reduction (QMRA)

The rotavirus dose per exposure ***(d)*** *is the number of rotaviruses*

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

$P_I(d)$ = probability of infection per single exposure

N_{50} = number that will infect 50% of population (= 6.2)
α = constant (= 0.253)

$$d = \{[1 - (5.5 \times 10^{-6})]^{-1/0.253} - 1\} / \{6.17/(2^{1/0.253} - 1)\} = 5 \times 10^{-5} \text{ per exposure event}$$

3. Determine pathogen reduction (QMRA)

Required pathogen reduction: this dose (d) of 5×10^{-5} rotavirus is contained in the 10 ml of treated wastewater remaining on the lettuce at the time of consumption, so the rotavirus concentration is 5×10^{-5} per 10 ml – **i.e., 5×10^{-3} per liter**. The number of rotaviruses in the raw wastewater is **5000 per liter** and therefore the required total rotavirus reduction in log units is: **(6 log removal)**

$$\log\left(\frac{5000}{0.005}\right) = \log(1{,}000{,}000) = 6$$

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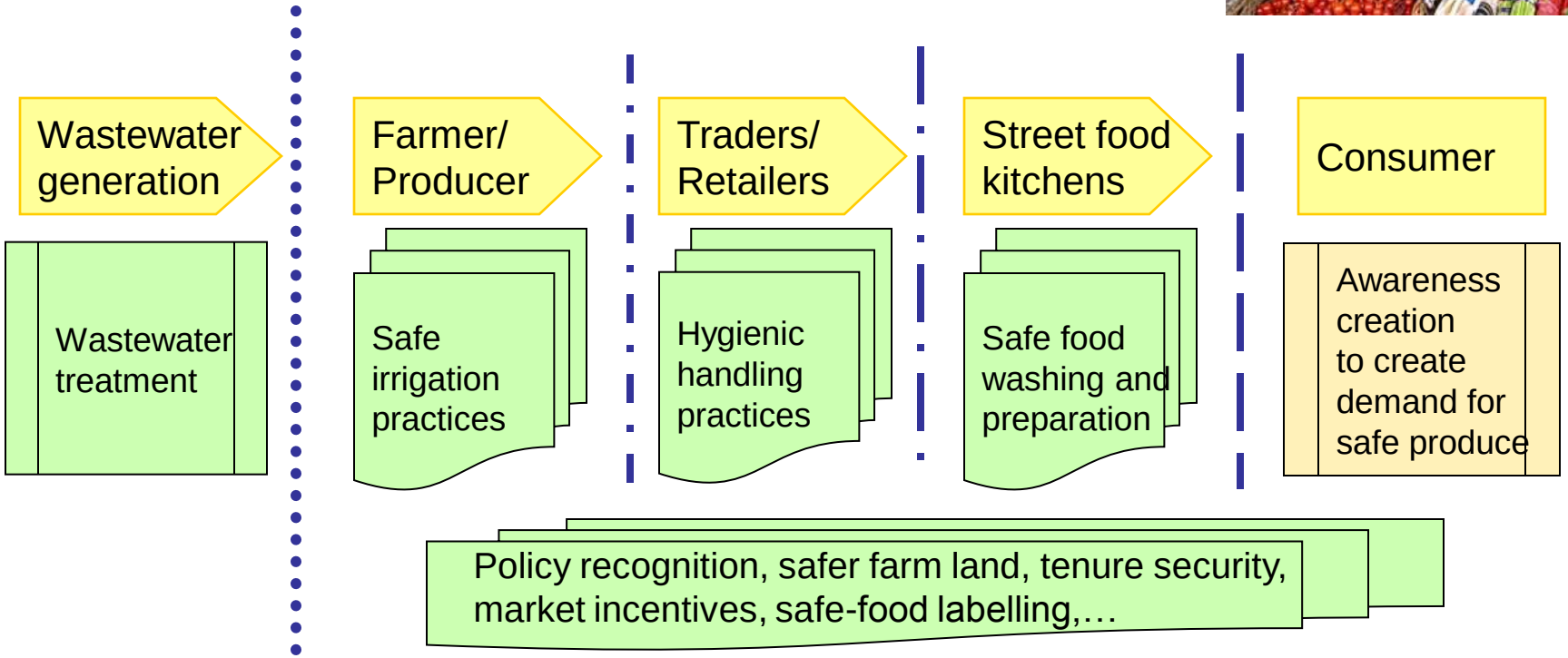
Good practices for risk reduction

WHO's *multiple barrier* approach from "Farm to Fork"



4. Pathogen reduction

Control measure	Pathogen reduction (log units)
Wastewater treatment	1−6
Localized (drip) irrigation (low-growing crops)	2
Localized (drip) irrigation (high-growing crops)	4
Spray drift control (spray irrigation)	1
Spray buffer zone (spray irrigation)	1
Pathogen die-off	0.5−2 per day
Produce washing with water	1
Produce disinfection	2
Produce peeling	2
Produce cooking	6−7

Table 4.3 Pathogen reductions achievable by various health protection measures

Control measure[a]	Pathogen reduction (log units)	Notes
Wastewater treatment	1–6	The required pathogen reduction to be achieved by wastewater treatment depends on the combination of health protection measures selected (as illustrated in Figure 4.1; pathogen reductions for different wastewater treatment options are presented in chapter 5).
Localized (drip) irrigation (low-growing crops)	2	Root crops and crops such as lettuce that grow just above, but partially in contact with, the soil
Localized (drip) irrigation (high-growing crops)	4	Crops, such as tomatoes, the harvested parts of which are not in contact with the soil
Spray drift control (spray irrigation)	1	Use of micro-sprinklers, anemometer-controlled direction-switching sprinklers, inward-throwing sprinklers, etc.
Spray buffer zone (spray irrigation)	1	Protection of residents near spray or sprinkler irrigation. The buffer zone should be 50–100 m.
Pathogen die-off	0.5–2 per day	Die-off on crop surfaces that occurs between last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc.
Produce washing with water	1	Washing salad crops, vegetables and fruit with clean water
Produce disinfection	2	Washing salad crops, vegetables and fruit with a weak disinfectant solution and rinsing with clean water
Produce peeling	2	Fruits, root crops
Produce cooking	6–7	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction.

Irrigation

Flood and furrow irrigation:
Fieldworkers and their families at highest risk

Spray irrigation:
Highest potential to spread contamination onto crop surfaces and affect nearby communities

Drip irrigation:
Offer the most health protection because wastewater is applied directly to the plants.
Most expensive to implement

Table 5.2 Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes

Treatment process	Log unit pathogen removals[a]			
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
Low-rate biological processes				
Waste stabilization ponds	1–4	1–6	1–4	1–3[b]
Wastewater storage and treatment reservoirs	1–4	1–6	1–4	1–3[b]
Constructed wetlands	1–2	0.5–3	0.5–2	1–3[b]
High-rate processes				
Primary treatment				
Primary sedimentation	0–1	0–1	0–1	0–<1[b]
Chemically enhanced primary treatment	1–2	1–2	1–2	1–3[b]
Anaerobic upflow sludge blanket reactors	0–1	0.5–1.5	0–1	0.5–1[b]
Secondary treatment				
Activated sludge + secondary sedimentation	0–2	1–2	0–1	1–<2[b]
Trickling filters + secondary sedimentation	0–2	1–2	0–1	1–2[c]
Aerated lagoon + settling pond	1–2	1–2	0–1	1–3[c]
Tertiary treatment				
Coagulation/flocculation	1–3	0–1	1–3	2[b]
High-rate granular or slow-rate sand filtration	1–3	0–3	0–3	1–3[b]
Dual-media filtration	1–3	0–1	1–3	2–3[b,d]
Membranes	2.5–>6	3.5–>6	>6	>3[b,d]
Disinfection				
Chlorination (free chlorine)	1–3	2–6	0–1.5	0–<1[b]
Ozonation	3–6	2–6	1–2	0–2[c]
Ultraviolet radiation	1–>3	2–>4	>3	0[c]

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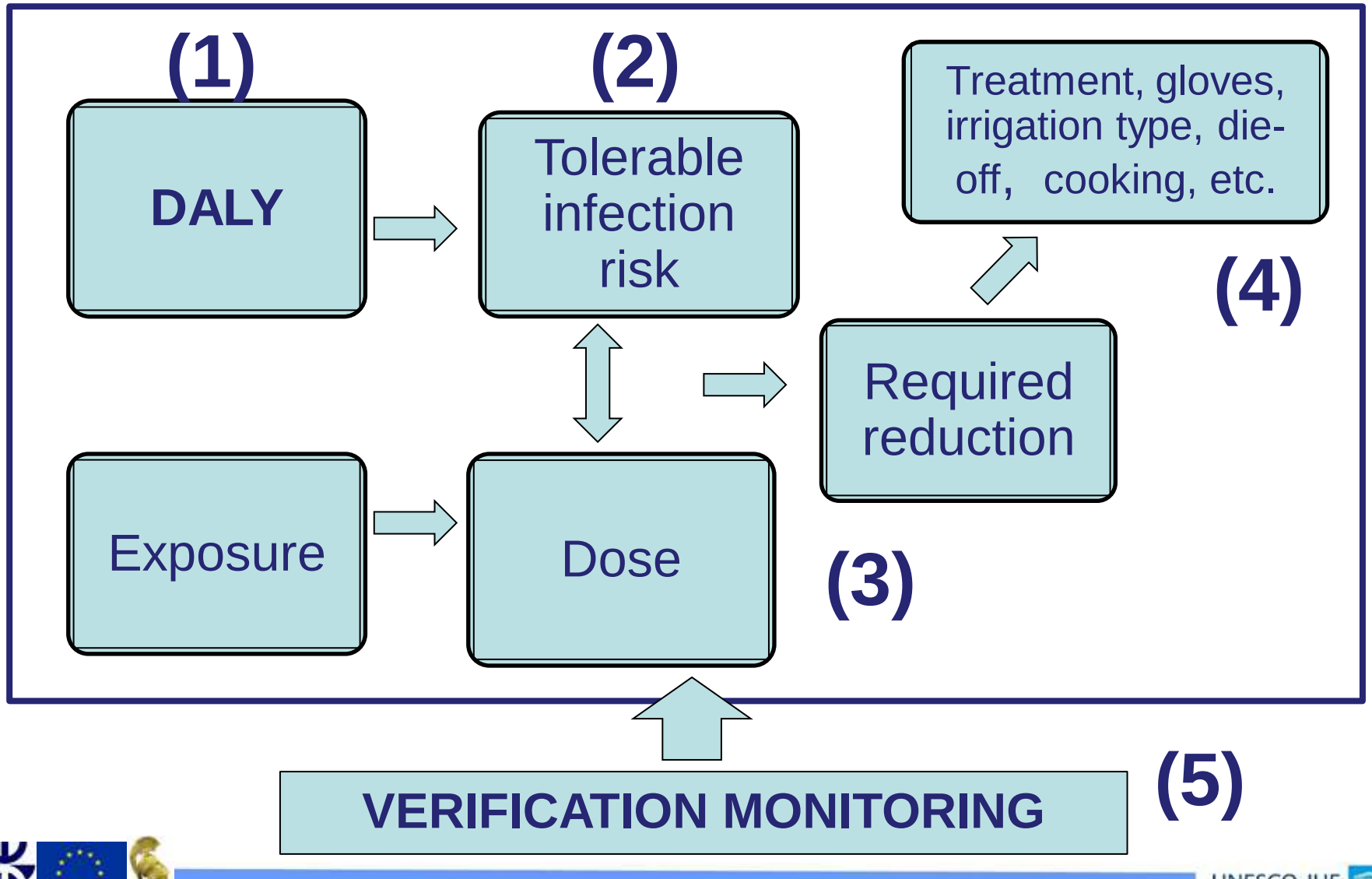
5. Verification Monitoring

1. **Determine critical control points (CCPs):**
   • Correspond to wastewater treatment plant effluent and each post-treatment health-protection control measures in operation
2. **Establish Critical Limits:**
   • The number of *E.coli* or fecal coliforms which shows unequivocally that the design removal is being achieved
3. **System to monitor the control of the CCP**
   • Involves sampling and microbiological analysis at an established frequency (weekly, or not less than monthly)

Summary overview



WHO 2006, volume 2, section 4.5

" *Wastewater treatment may be considered to be of a low priority if the local incidence of diarrheal disease is high and other water-supply, sanitation and hygiene-promotion interventions are more cost-effective in controlling transmission. In such circumstances, it is recommended that, initially, a national standard is established for a locally appropriate level of tolerable additional burden of disease based on the local incidence of diarrheal disease—for example,* $\leq 10^{-5}$ *or* ***≤10⁻⁴ DALY"***

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Update from the 1989 (and 1973) guidelines

Source: Werner (2005)

Risk management

- Risk management is the process of weighing policy alternatives and selecting the most appropriate regulatory action. Risk management is not a science; rather it combines information about risk with economic, political, legal, ethical, and value judgments to reach decisions.

Excreta (1)

Table 1. Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture

	Helminth eggs (number per gram total solids or per litre)	*E. co li* (number per 100 ml)
Treated faeces and faecal sludge	<1/g total solids	<1000 g/total solids
Greywater for use in:		
• Restricted irrigation	<1/litre	$<10^{5}$ [a] Relaxed to $<10^{6}$ when exposure is limited or regrowth is likely
• Unrestricted irrigation of crops eaten raw	<1/litre	$<10^{3}$ Relaxed to $<10^{4}$ for high-growing leaf crops or drip irrigation

[a] These values are acceptable due to the regrowth potential of *E. coli* and other faecal coliforms in greywater.

Excreta (2)

Table 2. Recommendations for storage treatment of dry excreta and faecal sludge before use at the household and municipal levels[a]

Treatment	Criteria	Comment
Storage; ambient temperature 2–20 °C	1.5–2 years	Will eliminate bacterial pathogens; regrowth of *E. coli* and *Salmonella* may need to be considered if rewetted; will reduce viruses and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers.
Storage; ambient temperature >20–35 °C	>1 year	Substantial to total inactivation of viruses, bacteria and protozoa; inactivation of schistosome eggs (<1 month); inactivation of nematode (roundworm) eggs, e.g. hookworm (*Ancylostoma*/*Necator*) and whipworm (*Trichuris*); survival of a certain percentage (10–30%) of *Ascaris* eggs (≥4 months), whereas a more or less complete inactivation of *Ascaris* eggs will occur within 1 year.
Alkaline treatment	pH >9 during >6 months	If temperature >35 °C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination.

[a] No addition of new material.

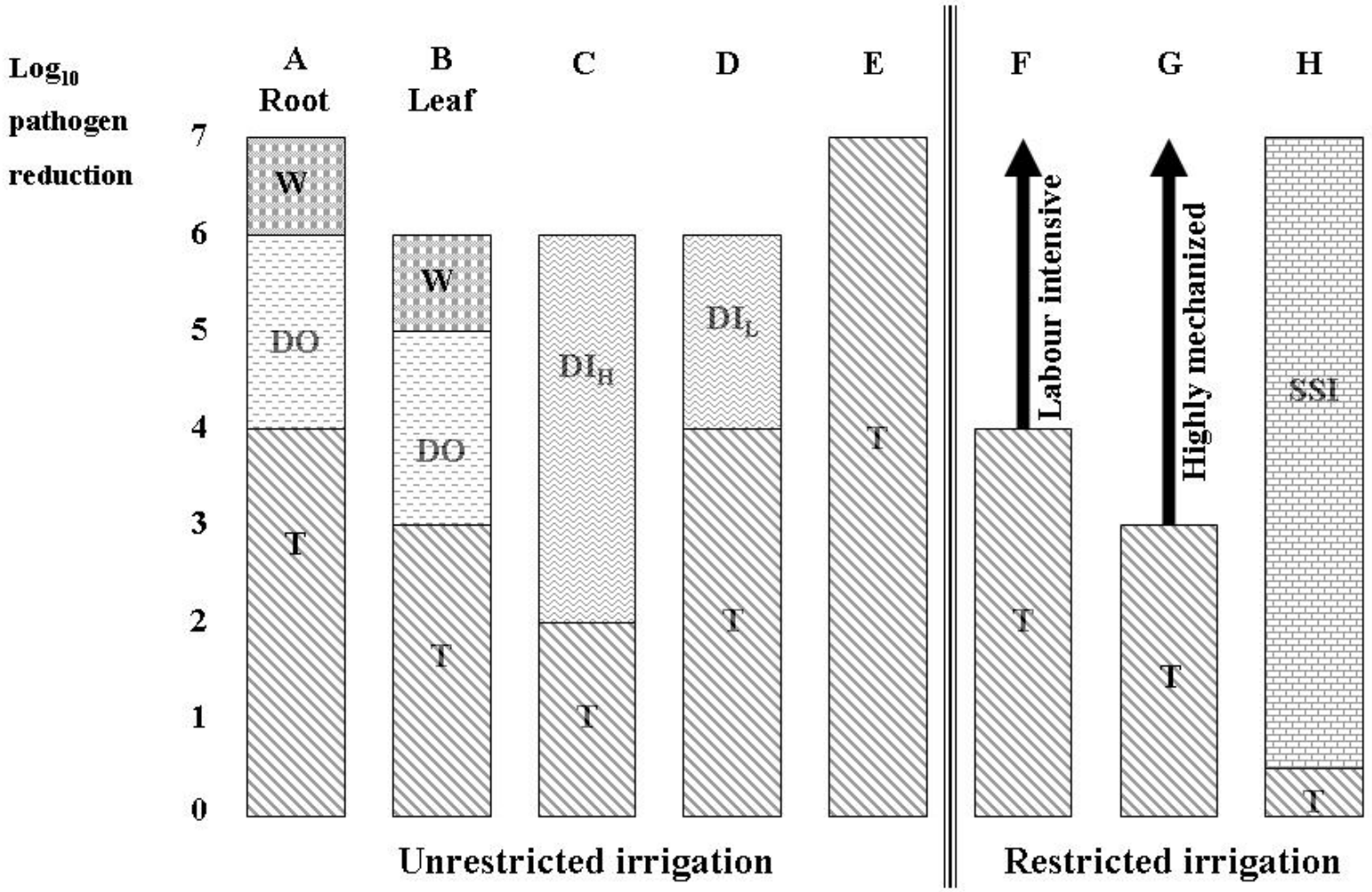
Guidance note for National Programme Managers and Engineers

http://www.who.int/water_sanitation_health/wastewater/Volume2_v2.pdf

Improving Wastewater Use in Agricultural: An Emerging Priority (World Bank)

- Examples to show how the WHO guidelines could be applied in countries at three different levels of economic development reflecting different positions on the sanitation ladder
  - Low-income countries with insufficient wastewater treatment capacities and largely uncontrolled wastewater use
  - Middle-income countries trying to move from uncontrolled to controlled wastewater use
  - High income countries where wastewater is treated and wastewater irrigation is a planned process

4. Pathogen reduction



5. Verification Monitoring

Type of irrigation	Option (Figure 4.1)	Required pathogen reduction by treatment (log units)	Verification monitoring level (*E. coli* per 100 ml)	Notes
Unrestricted	A	4	$\leq 10^3$	Root crops
	B	3	$\leq 10^4$	Leaf crops
	C	2	$\leq 10^5$	Drip irrigation of high-growing crops
	D	4	$\leq 10^3$	Drip irrigation of low-growing crops
	E	6 or 7	$\leq 10^1$ or $\leq 10^0$	Verification level depends on the requirements of the local regulatory agency[a]
Restricted	F	4	$\leq 10^4$	Labour-intensive agriculture (protective of adults and children under 15)
	G	3	$\leq 10^5$	Highly mechanized agriculture
	H	0.5	$\leq 10^6$	Pathogen removal in a septic tank