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Third edition of the Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture

Guidance note for Programme Managers and Engineers

A NUMERICAL GUIDE TO VOLUME 2 OF THE GUIDELINES AND PRACTICAL ADVICE ON HOW TO TRANSPOSE THEM INTO NATIONAL STANDARDS[1]

INTRODUCTION

In 2006, the World Health Organization published the third edition of the Guidelines, in collaboration with FAO and UNEP. The third edition consist of four volumes; volume 2, explained in this guidance note, addresses methods, procedures and guideline values for the safe use of wastewater in agriculture. In essence, the Guidelines are a code of good management practice. Volume 2 aims to ensure that health risks associated with the use of wastewater for irrigating crops (including food crops that are or may be eaten uncooked) are assessed and managed. Other than the 1989 second edition, this new edition therefore offers much more than a set of guideline values.

The new approach will challenge programme managers and engineers responsible for wastewater treatment and use who need to know how to use the recommended methods and procedures to design wastewater use systems that do not adversely affect public health. They will have to learn about and understand in detail the 'numerical' recommendations in the Guidelines so that the wastewater use systems they design are safe. However, it is not straightforward for these professionals to comprehend these numerical recommendations simply by reading the Guidelines – it requires a considerable amount of study and there are several concepts (for example, disability-adjusted life years) and topics (quantitative microbial risk analysis) with which few are familiar. They need a 'Guide to the Guidelines'. The purpose of this Guidance Note is to provide programme managers and engineers with a succinct overview of new concepts and topics.

NUMERICAL GUIDE TO THE 2006 GUIDELINES

Tolerable additional disease burden and risks of disease and infection

The Guidelines define a globally acceptable level of health protection. This level is based on the convention that the additional disease burden arising from working in wastewater-irrigated fields or consuming wastewater-irrigated crops should not exceed a loss of 10^{-6} disability-adjusted life years (DALYs) per person per year (pppy) (see Box 1 for a brief explanation of the DALY concept). WHO applied this level of health protection in its 2004 guidelines on drinking-water quality (WHO, 2004). Thus, international consensus is that the health risks resulting from wastewater use in agriculture are the same as those from consuming safe drinking-water. Consumers expect the food they eat to be as safe as the water they drink.

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What is new in the third edition of the Guidelines is that countries can determine the level of tolerable additional disease burden that realistically can be achieved in the national socio-economic context. If these health-based targets are higher than the internationally recommended level in the WHO guidelines, then authorities must ensure that the process of establishing the level is transparent, that a sound monitoring process of the various risk management interventions is in place and that real efforts are made to improve the level within a reasonable time horizon.

In the context of wastewater use in agriculture, the diseases of interest are caused by viral, bacterial and protozoan organisms whose transmission pathways include wastewater use in agriculture (intestinal worm infections are discussed below under 'Helminth eggs'). The recommended tolerable additional disease burden of 10^{-6} DALY loss pppy is 'translated' into tolerable disease and infection risks as follows:

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

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

BOX 1. Disability-adjusted Life Years (DALYs)

DALYs are a measure of population health expressed as burden of disease due to specific diseases or risk factors. DALYs attempt to measure the time lost because of disability or death from a disease compared with a long life free of disability in the absence of the disease. DALYs are calculated by adding the years of life lost to premature death (YLL) to the years lived with a disability (YLD). Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. YLD are calculated from the number of cases multiplied by the average duration of the disease and a severity factor ranging from 1 (death) to 0 (perfect health) based on the disease (e.g., watery diarrhoea has a severity factor from 0.09 to 0.12 depending on the age group) (Murray and Lopez, 1996; Prüss and Havelaar, 2001).

DALYs are an important tool for comparing health outcomes because they account for not only acute health effects but also for delayed and chronic effects, including morbidity and mortality (Bartram *et al.*, 2001). Thus, when risk is described in DALYs, different health outcomes (e.g., cancer vs giardiasis) can be compared and risk management decisions prioritized. Thus the DALY loss per case of Campylobacteriosis in Table 1 includes the appropriate allowance for the occurrence of Guillain-Barré syndrome (which is a an inflammatory disorder of the peripheral nerves, potentially leading to paralysis and occurring in about 1 in 1000 cases of Campylobacteriosis).

The tolerable additional disease burden of 10^{-6} DALY loss pppy adopted in the Guidelines means that a city of one million people collectively suffers the loss of one DALY per year. The highest DALY loss per case of diarrhoeal disease in Table 1 is 2.6×10^{-2}, for rotavirus disease in developing countries. Assuming that the recommendations in the Guidelines are completely followed, this means that the tolerable number of cases of rotavirus disease, caused by the consumption of wastewater-irrigated food in this developing-country city of one million people is:

$$\frac{\text{1 DALY loss per year}}{2.6 \times 10^{-2}\ \text{DALY loss per case}} = \text{38 cases per year}$$

The chance of an individual living in this developing-country city of one million becoming ill with rotavirus diarrhoea in any one year is (38×10^{-6}) – i.e., 3.8×10^{-5}, which is the tolerable rotavirus disease risk per person per year in developing countries determined in Table 1.

Three 'index' pathogens were selected: rotavirus (a virus), *Campylobacter* (a bacterium) and *Cryptosporidium* (a protozoan). Table 1 gives the DALY losses per case of rotavirus diarrhoea, *Campylobacter*iosis and cryptosporidiosis and the corresponding disease/infection ratios.

From the data in Table 1 a 'design' value of 10^{-3} pppy was chosen for the tolerable risk of rotavirus infection; the corresponding tolerable rotavirus disease risk is 10^{-4} pppy. The latter is extremely safe as it is three orders-of-magnitude lower than the actual incidence of diarrhoeal disease in the world (Table 2), and thus there is at least some level of inherent protection against disease outbreaks (i.e., epidemics, rather than endemic disease levels).

TABLE 1. DALY losses, disease risks, disease/infection ratios and tolerable infection risks for rotavirus, *Campylobacter* and *Cryptosporidium*

Pathogen		DALY loss per case of disease[a]	Tolerable disease risk pppy equivalent to 10^{-6} DALY loss pppy[b]	Disease/infection ratio	Tolerable infection risk pppy[c]
Rotavirus:	(1) IC[d]	1.4×10^{-2}	7.1×10^{-5}	0.05[e]	1.4×10^{-3}
	(2) DC[d]	2.6×10^{-2} [d]	3.8×10^{-5}	0.05[e]	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}

[a] Values from Havelaar and Melse (2003).

[b] Tolerable disease risk = 10^{-6} DALY loss pppy ÷ DALY loss per case of disease.

[c] Tolerable infection risk = disease risk ÷ disease/infection ratio.

[d] IC, industrialized countries; DC, developing countries.

[e] For developing counties the DALY loss per rotavirus death has been reduced by 95 percent as ~95 percent of these deaths occur in children under the age of 2 who are not exposed to wastewater-irrigated foods. The disease/infection ratio for rotavirus is low as immunity will have developed by the age of 3.

TABLE 2. Diarrhoeal disease (DD) incidence pppy in 2000 by region and age[a]

Region	DD incidence in all ages	DD incidence in 0–4 year olds	DD incidence in 5–80+ year olds
Industrialized countries	0.2	0.2–1.7	0.1–0.2
Developing countries	0.8–1.3	2.4–5.2	0.4–0.6
Global average	0.7	3.7	0.4

[a] Source: Mathers *et al.* (2002).

Quantitative microbial risk analyses

The Guidelines adopt a standard QMRA approach to risk analysis (Haas *et al.*, 1999) combined with 10,000-trial Monte Carlo simulations (Mara *et al.*, 2007). The basic equations are:

(a) Exponential dose-response model (for *Cryptosporidium*): $P_I(d) = 1 - \exp(-rd)$ (1)

(b) β-Poisson dose-response model (for rotavirus and *Campylobacter*): $P_I(d) = 1 - [1 + (d/N_{50})(2^{1/\alpha} - 1)]^{-\alpha}$ (2)

(c) Annual risk of infection: $P_{I(A)}(d) = 1 - [1 - P_I(d)]^n$ (3)

Where:

$P_I(d)$ is the risk of infection in an individual exposed to (here: following ingestion of) a single pathogen dose d,

$P_{I(A)}(d)$ is the annual risk of infection in an individual from n exposures per year to the single pathogen dose d,

N_{50} is the median infective dose, and α and r are pathogen 'infectivity constants'.

For rotavirus $N_{50} = 6.17$ and $\alpha = 0.253$; for *Campylobacter* $N_{50} = 896$ and $\alpha = 0.145$; and for *Cryptosporidium* $r = 0.0042$ (Haas *et al.*, 1999).

Box 2 gives an example of how these equations are used, and Box 3 details how Monte Carlo simulations are made.

BOX 2. Use of the QMRA equations for unrestricted irrigation

This example illustrates how the QMRA equations (equations 1–3) are used to determine the pathogen reduction (in log units[a]) required to protect human health in the case of unrestricted irrigation. The exposure scenario is the consumption of wastewater-irrigated lettuce.

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

2. Quantitative microbial risk analysis: consumer exposure to pathogens is calculated by using the following illustrative parameter values in the QMRA equations:

- 5000 rotaviruses per litre of untreated wastewater,
- 10 ml of treated wastewater remaining on 100 g lettuce after irrigation, and
- 100 g lettuce consumed per person every second day throughout the year.

The rotavirus dose per exposure (*d*) is the number of rotaviruses on 100 g lettuce at the time of consumption. The dose is determined by QMRA as follows:

(a) Conversion of the tolerable rotavirus infection risk of 10^{-3} pppy ($P_{I(A)}(d)$ in equation 3) to the risk of infection per person per exposure event ($P_I(d)$ in equations 1 and 2) – i.e., per consumption of 100 g lettuce, which takes place every two days throughout the year, so *n* in equation 3 is 365/2:

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

(b) Calculation of the dose per exposure event from equation 2 (the β-Poisson dose-response equation, which is used for rotavirus):

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

i.e.:

$$d = \{[1- P_I(d)]^{-1/\alpha} -1\}/\{N_{50}/(2^{1/\alpha} -1)\}$$

The values of the 'infectivity constants' for rotavirus are $N_{50} = 6.17$ and $\alpha = 0.253$. Thus:

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

3. 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 or 5×10^{-3} per litre. The number of rotaviruses in the raw wastewater is 5000 per litre and therefore the required pathogen reduction in log units[a] is:

$$\log(5000) - \log(5 \times 10^{-3}) = 3.7 - (-2.3) = 6$$

[a] A 1-log unit reduction is a reduction of 90%, 2 log units a reduction of 99%, 3 log units a reduction of 99.9%, and so on (thus a 'log unit' is strictly a '$\log_{10}$ unit'). Here, the required 6-log unit reduction is a reduction of 99.9999% (where each '9' is a significant figure).

BOX 3. Monte Carlo risk simulations

The specimen calculations in Box 2 use 'fixed' values for each parameter (e.g., 10 ml of wastewater remaining on 100 g of lettuce after irrigation [Shuval *et al.* (1997) measured a mean volume of 10.8 ml]. However, there is usually some degree of 'uncertainty' about the precise values of the parameters used in these QMRA equations. This uncertainty is taken into account by assigning to each parameter a range of values (e.g., 10–15 ml of wastewater remaining on 100 g of lettuce after irrigation), although a fixed value can be assigned to any parameter if so wished.

A computer program then selects at random a value for each parameter from the range of values specified for it and then determines the resulting risk. The program repeats this process a large number of times (a total of 10,000 times for the simulations reported herein) and then determines the median risk. This large number of repetitions removes some of the uncertainty associated with the parameter values and makes the results generated by multi-trial Monte Carlo simulations much more robust, although of course only as good as the assumptions made.

A. RESTRICTED IRRIGATION

Exposure scenario

The model scenario developed for restricted irrigation is the involuntary ingestion of soil particles by those working in wastewater-irrigated fields or by young children playing in them. This is a likely scenario as wastewater-saturated soil would contaminate workers' or children's fingers. Some pathogens could be transmitted to their mouths and hence ingested. The quantity of soil involuntarily ingested in this way has been reported (but not specifically for this restricted-irrigation scenario) as up to ~100 mg per person per day of exposure (Haas *et al.* 1999; WHO 2001). Two 'sub-scenarios' were investigated: (a) highly mechanized agriculture and (b) labour-intensive agriculture. The former represents exposure in industrialized countries where farm workers typically plough, sow and harvest using tractors and associated equipment and can be expected to wear gloves and be generally hygiene-conscious when working in wastewater-irrigated fields. The latter represents farming practices in developing countries in situations where tractors are not used and gloves (and often footwear) are not worn, and where hygiene is commonly not promoted.

Risk simulations

Labour-intensive agriculture. The results of the Monte Carlo-QMRA risk simulations are given in Table 3 for various wastewater qualities (expressed as single log ranges of *E. coli* numbers per 100 ml) and for 300 days exposure per year (the footnote to the Table gives the range of values assigned to each parameter). From Table 3 it can be seen that the median rotavirus infection risk is ~10^{-3} pppy for a wastewater quality of 10^3–10^4 *E. coli* per 100 ml.

Thus, the tolerable rotavirus infection risk of 10^{-3} pppy is achieved by a 4-log unit reduction – i.e., from 10^7–10^8 to 10^3–10^4 *E. coli* per 100 ml, so that the required wastewater quality is ≤10^4 *E. coli* per 100 ml (at this level the risk in Table 3 is 4.4×10^{-3} pppy, which is slightly high; however, the risk is proportional to the number of days of exposure per year, here taken as 300; in practice, therefore, the risk will be closer to 10^{-3} pppy).

TABLE 3. Restricted irrigation – labour-intensive agriculture with exposure for 300 days per year: median infection risks from ingestion of wastewater-contaminated soil estimated by 10,000-trial Monte Carlo simulations[a]

Soil quality (*E. coli* per 100 g)[b]	Median infection risk pppy		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7–10^8	0.99	0.50	1.4×10^{-2}
10^6–10^7	0.88	6.7×10^{-2}	1.4×10^{-3}
10^5–10^6	0.19	7.3×10^{-3}	1.4×10^{-4}
10^4–10^5	2.0×10^{-2}	7.0×10^{-4}	1.3×10^{-5}
10^4	4.4×10^{-3}	1.4×10^{-4}	3.0×10^{-6}
10^3–10^4	1.8×10^{-3}	6.1×10^{-5}	1.4×10^{-6}
100–1000	1.9×10^{-4}	5.6×10^{-6}	1.4×10^{-7}

[a] 10–100 mg soil ingested per person per day for 300 days per year; 0.1–1 rotavirus and *Campylobacter*, and 0.01–0.1 *Cryptosporidium* oocyst, per 10^5 *E. coli*; N_{50} = 6.7 ± 25% and α = 0.253 ± 25% for rotavirus; N_{50} = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*, r = 0.0042 ± 25% for *Cryptosporidium*. No pathogen die-off (taken as a worst case scenario).

[b] The wastewater quality is taken to be the same as the soil quality – i.e., the soil is assumed, as a worst case scenario, to be saturated with the wastewater.

Highly mechanized agriculture. The simulated risks for various wastewater qualities and for 100 days exposure per year are given in Table 4, which shows that the median rotavirus infection risk is ~10^{-3} pppy for a wastewater quality of 10^5 *E. coli* per 100 ml. Thus, a 3-log unit reduction, from 10^7–10^8 to 10^4–10^5 *E. coli* per 100 ml is required to achieve the tolerable rotavirus infection risk of 10^{-3} pppy, and the required wastewater quality is ≤10^5 *E. coli* per 100 ml.

Note that the median risks for *Campylobacter* and *Cryptosporidium* are all lower than those for rotavirus.

TABLE 4. Restricted irrigation – highly mechanized agriculture with exposure for 100 days per year: median infection risks from ingestion of wastewater-contaminated soil estimated by 10,000-trial Monte Carlo simulations[a]

Soil quality (*E. coli* per 100 g)[b]	Median infection risk pppy		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7–10^8	0.50	2.1×10^{-2}	4.7×10^{-4}
10^6–10^7	6.8×10^{-2}	1.9×10^{-3}	4.7×10^{-5}
10^5–10^6	6.7×10^{-3}	1.9×10^{-4}	4.6×10^{-6}
10^5	1.5×10^{-3}	4.5×10^{-5}	1.0×10^{-6}
10^4–10^5	6.5×10^{-4}	2.3×10^{-5}	4.6×10^{-7}
10^3–10^4	6.8×10^{-5}	2.4×10^{-6}	5.0×10^{-8}
100–1000	6.3×10^{-6}	2.2×10^{-7}	≤1×10^{-8}

[a] 1–10 mg soil ingested per person per day for 100 days per year; 0.1–1 rotavirus and *Campylobacter*, and 0.01–0.1 *Cryptosporidium* oocyst, per 10^5 *E. coli*; N_{50} = 6.7 ± 25% and α = 0.253 ± 25% for rotavirus; N_{50} = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*. No pathogen die-off (taken as a worst case scenario).

[b] The wastewater quality is taken to be the same as the soil quality – i.e., the soil is assumed, as a worst case scenario, to be saturated with the wastewater.

Note that the median risks for *Campylobacter* and *Cryptosporidium* are all lower than those for rotavirus.

B. UNRESTRICTED IRRIGATION

Exposure scenario

The exposure scenarios used for unrestricted irrigation are the consumption of wastewater-irrigated lettuce (Shuval *et al.*, 1997) and the consumption of wastewater-irrigated onions (a leaf and a root vegetable, respectively).

Risk simulations

The results of the Monte Carlo-QMRA risk simulations are given in Table 5 for various wastewater qualities (expressed as single log ranges of *E. coli* numbers per 100 ml) (the footnote to the Table gives the range of values assigned to each parameter). From Table 5 it can be seen that the median rotavirus infection risk is 10^{-3} pppy for a wastewater quality of 10^3–10^4 *E. coli* per 100 ml, so the tolerable rotavirus infection risk of 10^{-3} pppy is achieved by a 4-log unit reduction, from 10^7–10^8 to 10^3–10^4 *E. coli* per 100 ml, so that the required wastewater quality is ≤10^4 *E. coli* per 100 ml (at 10^4 per 100 ml the risk in Table 5 is 2.2×10^{-3} pppy which is close enough to 10^{-3} pppy). This 4-log unit reduction by treatment is supplemented by the 2–3 log unit reduction due to rotavirus die-off between the last irrigation and consumption assumed in these risk simulations (see footnote to Table 5), so giving a total pathogen reduction of 6–7 log units (cf. the specimen calculations in Box 2).

This 4-log unit reduction by treatment for unrestricted irrigation is also protective of the fieldworkers (see 'Labour-intensive agriculture' above).

TABLE 5. Unrestricted irrigation: median infection risks from the consumption of wastewater-irrigated lettuce estimated by 10,000-trial Monte Carlo simulations[a]

Wastewater quality (*E. coli* per 100 ml)	Median infection risk pppy Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7–10^8	0.99	0.28	0.50
10^6–10^7	0.65	6.3×10^{-2}	6.3×10^{-2}
10^5–10^6	9.7×10^{-2}	2.4×10^{-3}	6.3×10^{-3}
10^4–10^5	9.6×10^{-3}	2.6×10^{-4}	6.8×10^{-4}
10^4	2.2×10^{-3}	1.3×10^{-4}	4.5×10^{-4}
10^3–10^4	1.0×10^{-3}	2.6×10^{-5}	3.1×10^{-5}
100–1000	8.6×10^{-5}	3.1×10^{-6}	6.4×10^{-6}
10–100	8.0×10^{-6}	3.1×10^{-7}	6.7×10^{-7}

[a] 100 g lettuce eaten per person per 2 days; 10–15 ml wastewater remaining on 100 g lettuce after irrigation; 0.1–1 rotavirus and *Campylobacter*, and 0.01–0.1 oocyst, per 10^5 *E. coli*; 10^{-2}–10^{-3} rotavirus and *Campylobacter* die-off, and 0–0.1 oocyst die-off, between last irrigation and consumption; N_{50} = 6.7 ± 25% and α= 0.253 ± 25% for rotavirus; N_{50} = 896 ± 25% and α= 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*.

Note that the median risks for *Campylobacter* and *Cryptosporidium* are all lower than those for rotavirus.

Table 6 gives the required total log unit reductions for unrestricted irrigation of lettuce and onions for various levels of tolerable rotavirus infection risk: 10^{-2}, 10^{-3} and 10^{-4} pppy (these Monte Carlo simulations are the reverse of those in Tables 3–5 as they first set the risk and then determine the required total pathogen reduction). Table 6 shows that (a) the consumption of root crops requires a 1-log unit pathogen reduction greater than the consumption of non-root crops, and (b) the required pathogen reductions change by an order of magnitude with each order-of-magnitude change in tolerable risk.

Post-treatment health-protection control measures

Die-off is not the only way by which pathogen numbers are reduced after treatment. The main post-treatment health-protection control measures and the log unit pathogen reductions they achieve are listed in Table 7. These log unit reductions are extremely reliable: in essence they always occur. Hygiene education may be required in some societies to ensure that salad crops and vegetables when eaten raw are always washed in clean water prior to consumption, but this is not (at least in hygiene education terms) an arduous task. On the other hand, root crops (such as onions, carrots) are always peeled before they are eaten.

TABLE 6. Unrestricted irrigation: required pathogen reductions for various levels of tolerable risk of infection from the consumption of wastewater-irrigated lettuce and onions estimated by 10,000-trial Monte Carlo simulations[a]

Tolerable level of rotavirus infection risk (pppy)	Corresponding required level of rotavirus reduction (log units)	
	Lettuce	Onions
10^{-2}	5	6
10^{-3}	6	7
10^{-4}	7	8

[a] 100 g lettuce and onions eaten per person per 2 days; 10–15 ml and 1–5 ml wastewater remaining after irrigation on 100 g lettuce and 100 g onions, respectively; 0.1–1 and 1–5 rotavirus per 10^5 *E. coli* for lettuce and onions, respectively; N_{50} = 6.17 ± 25% and α = 0.253 ± 25%.

TABLE 7. Post-treatment health-protection control measures and pathogen reductions

Control measure	Pathogen reduction (log units)	Notes
Drip irrigation	2–4	2-log unit reduction for low-growing crops, and 4-log unit reduction for high-growing crops.
Pathogen die-off	0.5–2 per day	Die-off after last irrigation before harvest (value depends on climate, crop type, etc.).
Produce washing	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.

Thus, for a tolerable rotavirus infection risk of 10^{-3} pppy, the 4-log unit reduction by treatment must be supplemented by post-treatment control measures totalling 2 log units for non-root crops and 3 log units for root crops – for example, a 1-log unit reduction due to die-off and a 1-log unit reduction by produce washing (or a 2-log unit reduction due to die-off) for non-root crops; and a 1-log unit reduction due to die-off and a 2-log unit reduction by produce peeling for root crops. This then gives the required total log unit reduction of 6 for non-root crops and 7 for root crops. However, it is likely that there will always be at least a 2-log unit reduction due to die-off in warm-climate countries (rather than the 1-log unit reduction assumed above), so that there will always be a factor of safety of at least one order-of-magnitude.

Helminth eggs

The Guidelines' recommendation is that wastewater used in agriculture should contain ≤1 human intestinal nematode egg per litre. This is the same as was recommended in the 1989 Guidelines (WHO, 1989), but with one important difference: when children under the age of 15 are exposed (by working or playing in wastewater-irrigated fields) additional measures are needed, such as regular deworming (by their parents or at school). The helminths referred to here are the human intestinal nematodes: *Ascaris lumbricoides* (the human roundworm), *Trichuris trichiura* (the human whipworm), and

Ancylostoma duodenale and *Necator americanus* (the human hookworms); details of the diseases they cause and their life cycles are given in Feachem *et al.* (1983).

Horticulture

Horticulture under rigorously controlled conditions (for example: horticultural workers wear boots and gloves and are trained to be highly hygiene-conscious) is essentially the same as the subscenario of highly mechanized agriculture considered above under 'Restricted irrigation'. Therefore to protect the health of the horticultural workers a pathogen reduction by treatment of 3 log units is required. In order to protect the health of the consumers, an additional pathogen reduction of 3 log units has to be provided by the post-treatment control measures for non-root crops (Table 7). For root crops the additional reduction is 4 log units.

Wastewater treatment

In most developing countries waste stabilization ponds are the most appropriate option for wastewater treatment (von Sperling and de Lemos Chernicharo, 2005; Mara, 2004). In warm climates a series of ponds comprising an anaerobic pond, a secondary facultative pond and a single maturation pond can produce an effluent with $\leq 10^4$ *E. coli* per 100 ml (and also with ≤1 helminth egg per litre). The anaerobic ponds can be covered and the biogas collected and used for such purposes as cooking or electricity generation (DeGarie *et al.*, 2000). This is another form of wastewater use.

In England the guidelines for the microbiological quality of 'ready-to-eat' foods (such as prepared sandwiches and salads on sale in local shops and supermarkets) state that a level of up to 10,000 faecal coliforms per 100 g is "acceptable" (Gilbert *et al.*, 2000). Lettuce is a common component of many ready-to-eat foods, so it makes little sense to irrigate lettuces with wastewater treated to a higher quality than that required of the lettuces themselves.

TRANSPOSITION OF THE GUIDELINES INTO NATIONAL STANDARDS

The WHO 2006 Guidelines are recommendations of good practice. In themselves they have no legal status in any jurisdiction. Governments can choose to adopt or adapt and adopt (or, of course, even ignore) the Guidelines, and they can decide whether to transpose them into legally enforceable national standards or to keep them only as recommendations of good practice. The government departments normally involved in this decision-making process are Ministries or Departments of Health, Water, Environment, Agriculture and Finance, including the part of government responsible for food safety.

There are two basic decisions to be made, as follows:

(a) Decision #1: are the Guidelines to be transposed into national standards or only endorsed as recommendations for good national practice?

(b) Decision #2: Is the tolerable additional burden of disease of 10^{-6} DALY loss pppy appropriate for local conditions? This is an important decision as the value used for this controls the tolerable disease and infection risks pppy (Table 1) and thus the degree (and hence cost) of wastewater treatment needed to ensure that these risks are not exceeded. Is a value of 10^{-5} DALY loss pppy locally more appropriate?

The following points should be taken into consideration in making the second decision:

(a) A stricter requirement would not normally be needed since, as noted above, a DALY loss of 10^{-6} pppy is the value used by WHO (2004) in its drinking-water quality guidelines. Thus the consumption of wastewater-irrigated food is as safe as drinking fully treated drinking water if the recommendations in the 2006 Guidelines are followed.

(b) A less stringent requirement results in higher tolerable disease and infection risks pppy. For example, a tolerable additional disease burden of 10^{-5} DALY loss pppy would increase the disease and infection risks in Table 1 by a factor of 10, resulting in a tolerable rotavirus disease risk of 10^{-3} pppy, which is still two orders of magnitude lower than the current global incidence of diarrhoeal disease of 0.1–1 pppy (Table 2). The corresponding tolerable rotavirus infection risk is 10^{-2} pppy and therefore the required effluent qualities discussed above become one order-of-magnitude less stringent (for example, for restricted irrigation with labour-intensive agriculture, the required wastewater quality is $\leq 10^5$ *E. coli* per 100 ml, rather than $\leq 10^4$ per 100 ml). Governments may decide that this level of health protection (i.e., 10^{-5} DALY loss pppy) is sufficient if the local incidence of diarrhoeal disease is high (i.e., closer to 1 pppy than to 0.1 pppy). [Countries with a high diarrhoeal disease incidence include, of course, many developing countries, but also Australia (~0.9 pppy) (Hall *et al.*, 2006) and the United States (~0.8 pppy) (Mead *et al.*, 1999)].

(c) An alternative basis for choosing 10^{-5} (rather than 10^{-6}) DALY loss pppy might be that the additional cost of wastewater treatment to meet the 10^{-6} DALY loss pppy is not affordable (or the extra money would be better spent on something else). This could be a decision for the medium-to-long term (especially if the local incidence of diarrhoeal disease is high) or for the short-to-medium term (unaffordable now, but the intention would be to upgrade treatment to meet the 10^{-6} DALY loss pppy in the near future).

(d) As treatment is required more to protect the fieldworkers (it is the only health-protection measure available for restricted irrigation), a decision could be taken to adopt a 10^{-5} DALY loss pppy for the fieldworkers (for whom additional measures should be required, such as the provision of oral rehydration salts and access to medical assistance by their employers), whilst maintaining a 10^{-6} DALY loss pppy for unrestricted irrigation (i.e., adopting this level of health protection for consumers) by ensuring that an additional 1-log unit pathogen reduction is provided by the post-treatment health-protection control measures (see Table 7).

Thus there are three options and these are summarized in Table 8, together with their requirements for treatment and post-treatment health-protection control measures. This Table can easily be modified if the less stringent additional disease burden is 10^{-4} (rather than 10^{-5}) DALY loss pppy; this approach could be used as the first step in areas where there is currently extensive use of untreated wastewater for irrigation.

Food exports

The international trade in food is governed by the 'Agreement on the Application of Sanitary and Phytosanitary Measures' (WTO, 1999), which applies to all members of the World Trade Organization. Food-importing countries are entitled to take legitimate measures to protect their citizens from hazards in imported foods, provided that such measures are not unjustifiably restrictive of trade. The basic purpose of such measures is to protect consumers in food-importing countries against diseases that may be endemic in food-exporting countries and to which such consumers may have little or no immunity or resistance.

The irrigation of export food crops with wastewater would be generally only acceptable to the importing country if all the recommendations in these Guidelines are followed. For example, EUREPGAP, a European organization for sustainable agriculture and the certification of food imports into the European Union, prohibits the use of untreated wastewater for crop irrigation but has accepted the use of wastewater treated in accordance with the WHO 1989 guideline values (EUREPGAP, 2004) and makes reference to the third edition of Guidelines (EUREPGAP, 2006).

TABLE 8. Summary of requirements for wastewater treatment and post-treatment health-protection control measures for restricted and unrestricted irrigation for health protection levels of 10^{-6} and 10^{-5} DALY loss per person per year

Health protection level	Irrigation and farming system	Wastewater treatment requirements	Post-treatment health-protection control measures (Table 7)
1. 10^{-6} DALY loss pppy	(a) Restricted irrigation		
	(i) Labour-intensive agriculture	4-log unit pathogen reduction (i.e., to ≤10^4 *E. coli* per 100 ml)	Not applicable.
	(ii) Highly mechanized agriculture	3-log unit pathogen reduction (i.e., to ≤10^5 *E. coli* per 100 ml)	Not applicable
	(b) Unrestricted irrigation		
	(i) Labour-intensive agriculture	4-log unit pathogen reduction (i.e., to ≤10^4 *E. coli* per 100 ml)	Provision of additional 2-log unit pathogen reduction for non-root crops and 3-log unit reduction for root crops
	(ii) Highly mechanized agriculture	3-log unit pathogen reduction (i.e., to ≤10^5 *E. coli* per 100 ml)	Provision of additional 3-log unit pathogen reduction for non-root crops and 4-log unit reduction for root crops
2. 10^{-5} DALY loss pppy	(a) Restricted irrigation		
	(i) Labour-intensive agriculture	3-log unit pathogen reduction (i.e., to ≤10^5 *E. coli* per 100 ml)	Not applicable.
	(ii) Highly mechanized agriculture	2-log unit pathogen reduction (i.e., to ≤10^6 *E. coli* per 100 ml)	Not applicable
	(b) Unrestricted irrigation		
	(i) Labour-intensive agriculture	3-log unit pathogen reduction (i.e., to ≤10^5 *E. coli* per 100 ml)	Provision of additional 2-log unit pathogen reduction for non-root crops and 3-log unit reduction for root crops
	(ii) Highly mechanized agriculture	2-log unit pathogen reduction (i.e., to ≤10^6 *E. coli* per 100 ml)	Provision of additional 3-log unit pathogen reduction for non-root crops and 4-log unit reduction for root crops
3. 10^{-6} DALY loss pppy for consumers, and 10^{-5} DALY loss pppy for fieldworkers	Unrestricted irrigation: labour-intensive agriculture	3-log unit pathogen reduction (i.e., to ≤10^5 *E. coli* per 100 ml	Provision of additional 3-log unit pathogen reduction for non-root crops and 4-log unit reduction for root crops

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Note: this 'Guide to the Guidelines' is based mainly on WHO (2006) and Mara *et al.* (2007).

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