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THE NEW DRAFT WHO GUIDELINES FOR WATER REUSE IN AGRICULTURE

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SUMMARY

WHO published in 1989 the first "Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture", that were widely used. Since that time, more experience has been gained and more evidence is produced. The new WHO guidelines on water reuse in agriculture, although still in draft form, provide all the basic information on the health risks, and how to arrive at the health based targets, by quantifying the risk and developing pathogen reduction targets. Furthermore, an analysis of the health protection measures is included, making reference to the wastewater treatment, crop restrictions, wastewater application methods and human exposure control.

Keywords: Agriculture, Guidelines, Wastewater treatment, Wastewater use, Water reuse

PREFACE

The text that follows is based on the related draft WHO guidelines and is subject to changes when the final guidelines will be produced. However, it reflects the methodology and the scientific background for the rationale followed.

MICROBIAL EVIDENCE

Untreated wastewater contains a variety of excreted organisms and pathogens, with types of numbers that vary depending upon the background levels of disease in the population. Disease outbreaks in affected populations result in increased concentrations of the causative agents in the wastewater. Table 1 below shows ranges of concentrations for different excreted organisms that can be found in wastewater, and are related to Bacteria, Intestinal helminths, Protozoa and viruses.

Table 1. Typical numbers of excreted organisms in untreated wastewaters. Sources: Yates and Gerba (1998), Faechem et al. (1983), Mara and Silva (1986); and Oragui et al. (1987).

Organism	Numbers in wastewater (per litre)
Bacteria	
Thermotolerant coliforms	10^8 -10^{10}
Campylobacter jejuni	10 - 10^4
Salmonella spp.	1 - 10^5
Shigella spp.	10 - 10^4
Vibrio cholerae	10^2 - 10^5
Intestinal helminths	
Ascaris lumbricoides	1 - 10^3
Ancylostoma/Necator	1 -10^3
Trichuris trichiura	1- 10^2
Protozoa	
Cryptosporidium parvum	1 - 10^4
Entamoeba histolytica	1 -10^2
Giardia intestinalis	10^2 - 10^5
Viruses	
Enteric viruses	10^5 - 10^6
Rotavirus	10^2 - 10^5

The above organisms are responsible for a number of risks associated with the issue of wastewater for irrigation. Following an evaluation of all the epidemiological evidence of the health effects of wastewater in agriculture, a summary of the main epidemiological evidence provides a number of health risks to consumers. There is evidence that significant risks exist of Ascaris infection for both adults and children with untreated wastewater (Khalil, 1931; Baumhogger, 1949; Krey, 1949; Shuval et al., 1984). Moreover, cholera, typhoid and shigellosis outbreaks were reported from use of untreated wastewater as well as sero-positive responses for Helicobacter pylori (untreated) (Hopkins et al., 1993). There is an increase in non-specific diarrhoea when water quality exceeds 10^4 thermotolerant coliform per 100 mL (Blumenthal et al., 2003). Regarding protozoa, there is evidence, of parasitic protozoa found on wastewater irrigated vegetable surfaces but no direct evidence of disease transmission (Carr et al., 2004). In addition to the risks on consumers, also other groups are exposed, as for example farm workers and their families, and nearby communities.

EPIDEMIOLOGICAL EVIDENCE

Since the publication of the wastewater guidelines in 1989, the health risks form wastewater use in agriculture have been investigated through quantitative microbial risk analysis (QMRA), as well as through epidemiology.

For unrestricted irrigation, Mara et al. (2005) estimated the median risks per person per year for rotavirus, Campylobacter and Cryptosporidium infections resulting from the consumption of 100 g of wastewater-irrigated lettuce on alternate days. The risks were estimated for one fixed value, 1000, and eight single-log ranges, 1-10 to 10^7-10^8, of E. coli numbers per 100 mL of wastewater (i.e., "Californian" treatment through to untreated).

The estimated risks, given in Table 2 are ~10^{-4} –10^{-6} per person per year (pppy) for a wastewater quality of 1000 E. coli per 100 mL, and ~10^{-2} –10^{-4} per person per year for a wastewater quality of 10^4-10^5 E. coli per 100 mL – i.e., the risks of eating wastewater-irrigated lettuce are not higher than 10^{-2} pppy when the wastewater quality exceeds the level of ≤1000 *E. coli* per 100 mL by one order of magnitude or more. Table 2 also shows that (a) when untreated wastewater is used, the risks are very high; and (b) even where a tolerable risk is set at 10^{-4} pppy, this can be achieved by treating the wastewater to 1000 *E. coli* per 100 mL.

Table 2. Unrestricted irrigation: median infection risks from the consumption of wastewater-irrigated lettuce estimated by 10,000-trial Monte Carlo simulations*

Wastewater quality (*E. coli* per 100 mL)	Median infection risk per person per year		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7-10^8	0.99	0.28	0.50
10^6-10^7	0.65	6.3 x 10^{-2}	6.3 x 10^{-2}
10^5-10^6	9.7 x 10^{-2}	2.4 x 10^{-3}	6.3 x 10^{-3}
10^4-10^5	9.6 x 10^{-3}	2.6 x 10^{-4}	6.8 x 10^{-4}
10^4	2.2 x 10^{-3}	1.3 x 10^{-4}	4.5 x 10^{-4}
10^3-10^4	1.0 x 10^{-3}	2.6 x 10^{-5}	3.1 x 10^{-5}
10^3	2.2 x 10^{-4}	5.6 x 10^{-6}	1.4 x 10^{-5}
100-1000	8.6 x 10^{-5}	3.1 x 10^{-6}	6.4 x 10^{-6}
10-100	8.0 x 10^{-6}	3.1 x 10^{-7}	6.7 x 10^{-7}
1-10	1.0 x 10^{-6}	3.0 x 10^{-8}	7.0 x 10^{-8}

*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 105 *E. coli;* 10^{-2}-10^{-3} rotavirus and *Campylobacter* die-off, and 0-0.1 oocyst die-off, between harvest and consumption; ID50 = 6.17 ± 25% and a = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and a = 0.145 ± 25% for *Campylobacter, r*= 0.0042 ± 25% for *Cryptosporidium*

Mara, Sleigh and Blumenthal (2005) also estimated the median risks per person per year for rotavirus, *Campylobacter* and *Cryptosporidium* infections resulting from the consumption of 100 g of raw onions per person per week for five months; these rates of consumption were based on those found in the dry season in the Mezquital Valley in Mexico, where Blumenthal et al. (2003) studied the weekly prevalence of symptomatic diarrhoeal disease. The parameter values used in the models were modified to reflect the field conditions by using different ranges of parameter values, to allow for (a) the greater number of micro-organisms expected to be on the surface of onions than on lettuce (Geldreich and Bordner (1972) found root vegetables irrigated with wastewater containing 5.8 x 10^4 thermotolerant coliform per 100 mL to have an order of magnitude more faecal bacteria than leafy vegetables); (b) the lower die-off of faecal organisms in soil than on exposed crop surfaces (Strauss, 1985); and (c) a lower volume of wastewater remaining on onions than on lettuce.

The simulated rotavirus infection risk of 0.39 per person per five months for a wastewater quality of 10^3 – 10^5 *E. coli* per 100 mL (Mara et al., 2005) shows (Table 3) very close agreement with the measured incidence of diarrhoeal disease of 0.38 per person per five months (calculated by converting prevalence values obtained in the epidemiological study to estimates of the rate of infection, using a number of assumptions). The risks calculated for *Campylobacter* and *Cryptosporidium* were lower by one and three orders of magnitude, respectively. Thus, provided that the parameter values used in the QMRA equations are carefully chosen to reflect conditions in the field, there can be agreement between QMRA-estimated infection risks and disease incidences determined from epidemiological field studies (this was also found to be the case for restricted wastewater irrigation).

Table 3 shows that the value of ≤ 1000 *E. coli* per 100 mL is protective against viral, bacterial and protozoan infections for compliance with a tolerable risk of 10^{-2} pppy; a wastewater quality of 100 *E. coli* per 100 mL would be needed to achieve a lower rotavirus infection risk of ~10^{-3}. Table 3 confirms that (a) when untreated wastewater is used, the risks are very high;

and (b) when wastewater of a quality higher than 1000 *E. coli* per 100 mL is required for unrestricted irrigation, the resulting risks are less than 10^{-3} pppy.

Table 3. Unrestricted irrigation: median infection risks from the consumption of wastewater-irrigated onions estimated by 10,000-trial Monte Carlo simulations*

Wastewater quality	Median infection risk per person per year		
(*E. coli* per 100 mL)	*Rotavirus*	*Campylobacter*	*Cryptosporidium*
10^7-10^8	1.00	0.99	3.6×10^{-2}
10^6-10^7	0.99	0.81	3.9×10^{-3}
10^5-10^6	0.99	0.17	3.2×10^{-4}
10^4-10^5	0.43	1.6×10^{-2}	3.7×10^{-5}
10^3-10^5	0.39	1.7×10^{-2}	2.8×10^{-4}
3×10^4	0.29	1.1×10^{-2}	2.3×10^{-4}
10^3-10^4	4.5×10^{-2}	2.6×10^{-5}	3.7×10^{-6}
1000	1.1×10^{-2}	1.8×10^{-3}	7.6×10^{-6}
100-1000	5.6×10^{-3}	1.0×10^{-4}	3.8×10^{-7}
100	1.2×10^{-3}	3.2×10^{-5}	8.0×10^{-8}
10-100	4.4×100^{-4}	1.1×10^{-6}	3.0×10^{-8}
1-10	5.7×10^{-5}	1.8×10^{-6}	$<10^{-8}$

*100 g of onions consumed per person once per week for five months; 1-5 mL wastewater remaining on 100 g onions after irrigation; 1-10 rotavirus and *Campylobacter,* and 0.1-1 oocyst, per 105 *E. coli;* 0.1-1 rotavirus and *Campylobacter* die-off, and 0-01-0.1 oocyst die-off, between harvest and consumption; ID50 = 6.17 ± 25% and a = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and a = 0.145 ± 25% for *Campylobacter, r*= 0.0042 ± 25% for *Cryptosporidium*

TOLERABLE RISK

In setting guidelines for the use of wastewater it would be logical to ensure that the overall levels of health protection were comparable to those for other water exposures (e.g. through drinking water or recreational water contact). This would require comparison of very different adverse health outcomes, such as cancer, diarrhoea, etc. Significant experience has now been gained in such comparisons, especially using the metric of DALYs (WHO, 2003).

DISABILITY ADJUSTED LIFE YEARS (DALYS)

DALYs are a measure of the health of a population or burden of disease due to a specific disease or risk factor. 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) (Prüss and Havelaar, 2001; Murray and Lopez, 1996). 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, Fewtrell and Strenström, 2001).

When risk is described in DALYs, different health outcomes (e.g., cancer vs giardiasis) can be compared and risk management decisions can be prioritised.

For carcinogenic chemicals in drinking water, guideline values have been set at a 10^{-5} upper-bound reference level of risk (WHO, 2004). This means that there would be a maximum of one excess case of cancer per 100,000 of the population ingesting drinking water that contained the chemical at the guideline concentration over a lifetime. The disease burden associated with this level of risk and adjusted for the severity of the illness if approximately 1 x 10^{-6} DALY (1μDALY) (WHO, 2004). This level of disease burden can be compared to a mild but more frequent illness such as self-limiting diarrhoea caused by a microbial pathogen. The estimated disease burden associated with mild diarrhoea (e.g., with a case fatality rate of ~1 x 10^{-5}) at an annual disease risk of 1 in 1000 (10^{-3}) (~1 in 10 lifetime risk) is also about 1 x 10^{-6} DALY (1μDALY) (WHO, 2004).

HEALTH BASED TARGETS (HTB)

An HBT uses the tolerable risk of disease as a baseline to set specific performance targets that will reduce the risk of disease to this level. Exposure to different concentrations of pathogens or toxic chemicals through wastewater contact or through consumption of wastewater irrigated products is associated with a certain level of risk. Reducing this risk thus involves reducing the levels of exposures to pathogens and chemicals. Therefore, the goal of HBTs in wastewater use is to reduce the exposure to pathogens or chemicals derived from the wastewater to protect public health (WHO, 2004).

The development of HBTs is based upon a reference level of risk of 10^{-6} DALYs. This is the same reference point for excess burden of disease as used by WHO in other areas of water management for health such as the WHO Guidelines for Drinking Water Quality and therefore it is appropriate for the international export of food crops irrigated with wastewater.

Assessment and Quantification of risk

Setting of health-based targets requires information on concentrations of pathogens present in source waters, dose responses and disease burdens.

Selection of reference pathogens should be based on consideration of a combination of:

- High occurrence
- High concentration in water to be recycled
- Low removal in treatment
- Long survival in the environment; and
- High pathogenicity

The goal of risk management strategies is to reduce the risk from any exposure (or the estimated number of exposures during a given period of time) to wastewater-related pathogens to a level that does not result in disease for as large a population as possible within the given constraints of the situation (i.e., technical, financial, etc.). Theses goals and the given constraints are reflected in the assessment of tolerable risk and health-based targets.

Based upon the estimated concentrations of pathogens in the raw wastewater and the volumes that people will be exposed to through different activities (i.e., contact, consumption of raw vegetables), it is possible to estimate the percentage and log reductions needed for each class of pathogen to arrive a tolerable DALY loss per person per year (percentage reductions are often described in logarithmic (log10) terms. A one log reduction equals a 90% reduction, a two log reduction equals a 99% reduction, a three log reduction equals a 99.9% reduction, etc).

HEALTH PROTECTION MEASURES

The pathogens and some chemicals present in the wastewater are the primary health hazards associated with the use of wastewater. Secondary risks may arise from the creation of habitats that facilitate the survival and breeding of vectors and a subsequent increase in the transmission of vector-borne diseases in the irrigated areas. An analysis of the system can lead to identification of the key risk points, methods of exposure and populations that might be exposed.

A variety of health protection measures are possible to make wastewater use in agriculture safer. The available measures for health protection can be grouped into four main categories:

(a) Waste treatment
(b) Crop restriction
(c) Irrigation technique and application timing, and
(d) Human exposure control

It will often be desirable to apply a combination of several methods. For example, crop restriction may be sufficient to protect consumers, but it will need to be supplemented by additional measures to protect agricultural workers. Sometimes partial treatment to a less demanding standard may be sufficient if combined with other measures.

The feasibility and efficacy of any combination will depend on many factors, which must be carefully considered before any option is put into practice. These factors will include the following: (i) Availability of resources (labour, funds, land), (ii) Existing social and agricultural practices, (iii) Market demand for wastewater irrigated products, and (iv) Existing patterns of excreta-related disease.

BARRIERS

In the use of wastewater in agriculture there are a series of control points or barriers, which can be used to mitigate risk but failure of one, although important, may not result in a negative health impact if there are other downstream control points which might eliminate the hazard. These additional barriers can reduce exposures to pathogens and are included as exposure reduction credits in the HBTs (Table 4).

- Pathogen die-off in the field or on the crop due to UV radiation, desiccation, temperature, predation, etc
- Allowing sufficient time between wastewater application and harvest to facilitate pathogen die-off on crops
- Application techniques that prevent crop contamination (local or drip irrigation)
- Types of crops, which are irrigated – crops that are not eaten or only eaten after cooking will lead to less health risk
- Protective clothing for farmers or crop handlers; and
- Washing and cooking vegetables in the home

The following provides a brief description of several technologies, review the process efficiency for pathogen and chemical removal, present information on operating considerations and describe the pros and cons of each technology in different situations (Table 5).

Crop restriction can be used to protect the health of consumers when water of sufficient quality is not available for unrestricted irrigation. Crop restriction is not an adequate single control measures and should only be considered within an integrated system of control. Crop restriction is feasible and is facilitated in several circumstances including the following: (a) Where a law-abiding society or strong law enforcement exists, (b) Where a public body controls allocation of the wastes, and has the legal authority to require that crop restrictions be followed, (c) Where an irrigation project has strong central management, (d) Where there is adequate demand for the crops allowed under crop restriction, and where they fetch a reasonable price, and (e) Where there is little market pressure in favour of excluded crops.

The choice of wastewater application method can impact the health status of farm workers, consumers, and nearby communities. Spray/sprinkler irrigation has the highest potential to spread contamination on crop surfaces and affect nearby communities. Bacteria and viruses (but not usually intestinal nematodes) can be transmitted through aerosols to nearby communities (NRMMC/EPHC, 2005).

Table 4. Percentage reduction in exposure to pathogens. Source: NRMMC/EPHC (2005); Petterson and Ashbolt (2003)

Measures				
Crop restriction	Cooking	Peeling	-	-
	99.999 – 99.9999 %	99 %	-	-
Application technique	Withholding period	Drip irrigation	DI non-contact *	Spray control
	90 % / day **	99 %	99.99 %	90 %
Exposure control	Withholding Periods-public parks (1-4 hours)	No public access during irrigation	Buffer zones (50-100m)	Sub-surface irrigation of plants/shrubs or grass
	90 %	99 %	90 %	99.999 – 99.9999 %

* DI = Drip Irrigation, this category includes crops with no ground contact, subsurface irrigation of above ground crops and drip irrigation of plants/shrubs

** Depends on weather, temperature and crop (fastest die-off on plants exposed to sun and hot, dry conditions, less for root crops and rainy weather, very rapid inactivation of viruses in warm sunny conditions as high as 2.5 logs per day).

Localized irrigation techniques (e.g., bubbler, drip, trickle) offer farm workers the most health protection because the wastewater is applied directly to the plants. Vaz da Costas Vargas et al. (1996), has shown that cessation of irrigation for 1-2 weeks prior to harvest can be effective in reducing crop contamination. Studies have indicated that each day delay between wastewater application and harvest reduces pathogens (bacteria, protozoa and viruses, no data available for helminth eggs), by at least 1 log in hot and sunny weather (Petterson and Ashbolt, 2003). This would depend upon the climatic conditions, with more rapid pathogen die-off in hot, dry weather and less in cool or wet weather without much direct sunlight.

VERIFICATION MONITORING

Verification is the use of methods, procedures or tests in addition to those used in operational monitoring to determine if the performance of the wastewater use system is in compliance with the stated objectives outlines by the health-based targets and/or whether the system needs modification and revalidation.

For microbial water quality, verification is likely to include microbiological testing. In most cases it will involve the analysis of faecal indicator microorganisms, but in some circumstances it may also include assessment of specific pathogen densities. Verification of the microbial quality of the wastewater includes testing for *Escherichia coli* or thermotolerant coliforms.

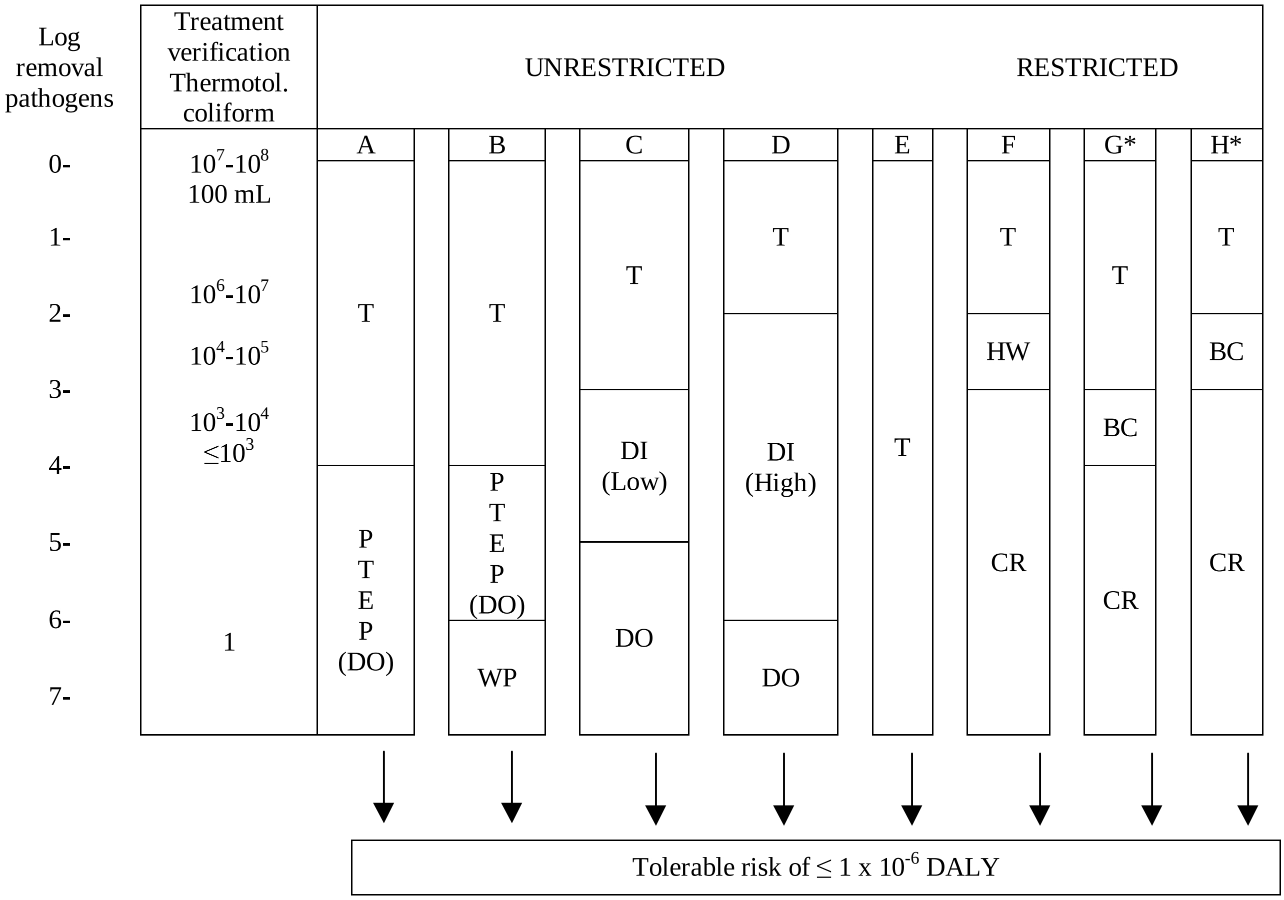
Table 5. Removal efficiencies of excreted microbes achieved by selected treatment processes

Treatment technology	**Pathogen removal percentages / log_{10}**			
	Bacteria	**Helminths**	**Protozoa**	**Viruses**
Primary treatment				
Primary sedimentation	% 50 – 90 log_{10} 0-1	% 90 log_{10} 0-1	% 27 – 64 log_{10} 0-1	% 50 – 98 log_{10} 0-1
Primary sedimentation + chemical coagulation	% 50 – 90 log_{10} 0-1	% 90 – 99.9 log_{10} 1-3	% 27 – 64 log_{10} 0-1	% 50 – 98 log_{10} 0-1
Secondary treatment				
Activated sludge or trickling filter + secondary sedimentation	% 90 – 99.9 log_{10} 1-3	% 90 – 99 log_{10} 1-2	% 45 – 97 log_{10} 0-1	% 53 – 99.9 log_{10} 0-3
Aerated lagoon + settling pond	% 90 – 99 log_{10} 1-2	% 90 – 99.9 log_{10} 1-3	% 45 – 97 log_{10} 0-1	% 90 – 99 log_{10} 1-2
Tertiary treatment / Filtration / Membrane processes				
Coagulation / Flocculation	% 30 – 99 log_{10} 0-1	% 99 log_{10} 2	% 95 – 99.99 log_{10} 1.5-4	% 90 – 99.9 log_{10} 1-3
High rate granular or slow rate sand filtration	% 50 – 99.5 log_{10} 0-2.5	% 90 – 99 log_{10} 1-2	% 50 – 99.9 log_{10} 0-3	% 20 – 99.99 log_{10} 1-4
Dual media filtration	% 30 – 90 log_{10} 0-1	% 99 – 99.9 log_{10} 2-3	% 90 – 99.9 log_{10} 1-3	% 50 – 99.9 log_{10} 0-3
Membrane processes	% 99.95 – 99.9999 log_{10} 3.5-6	% > 99.9 log_{10} > 3	% > 99.9999 log_{10} > 6	% 99.5 – 99.9999 log_{10} 2.5-6
Disinfection				
Chlorination (free chlorine)	% 99 – 99.9999 log_{10} 2-6	% ≤ 90 log_{10} 0-1	% ≤ 95 log_{10} 0-1.5	% 90 – 99.9 log_{10} 1-3
Ozone disinfection	% 99 – 99.9999 log_{10} 2-6	% ≤ 90 log_{10} 0-1	% ≤ 99 log_{10} 0-2	% 99.9 – 99.9999 log_{10} 3-6
UV disinfection	% 99 – 99.99 log_{10} 2-4	ND	% > 99.9 log_{10} > 3	% 90 – 99.9 log_{10} 1-3
Natural systems				
Waste stabilization ponds	% 90 – 99.9999 log_{10} 1-6	% 90 – 99.9 log_{10} 1-3	% 90 – 99.99 log_{10} 1-4	% 90 – 99.99 log_{10} 1-4
Wastewater storage and treatment reservoirs	% 90 – 99.9999 log_{10} 1-6	% 90 – 99.9 log_{10} 1-3	% 90 – 99.99 log_{10} 1-4	% 90 – 99.99 log_{10} 1-4
Constructed wetlands	% 50 – 99.9 log_{10} 0.5-3	% 99.9 log_{10} 3	% 50 – 99 log_{10} 0.5-2	% 95 – 99 log_{10} 1.5-2

ND = Nodata
Sources: Jiménez (2003); Yates and Gerba (1998); WHO (2004); Feachem et al. (1983), Rose et al. (1996, 1997); National Research Council (1998); Clancy et al. (1998); Lazarova et al. (2000; Sobsey (1989); Australia Environmental Health Service (2005); Karimi, Vickers and Harasick (1999).

The WHO microbial guideline values are not intended as standards for quality surveillance but as design goals to be used when planning a treatment system. Monitoring requirements should be based upon the wastewater use system and the defined National health-based targets.

Figure 1. Example for design purposes: Health based targets + advices of health protection measures



* = where children under 15 years are exposed
T = treatment
PTEP = post-treatment environmental protection
WP = washing and peeling
DO = die-off
DI = drip irrigation (L=low growing cops; H=high growing crops)
CR = crop restriction eg. industrial crops, crops eaten cooked
HW = hand washing with hygiene promotion
BC = behaviour change (tools when farming)

References

Bartram, J., L. Fewtrell and T-A Strenström (2001), Harmonised assessment of risk and risk management for water-related infectious disease: an overview. In: Fewtrell L, and Bartram J (eds), (2001). *Water Quality: Guidelines, Standards for Health; Assessment of Risk and Risk Management for Water-related Infectious Disease*. IWA on behalf o the World Health Organization, London, UK.

Baumhogger, W. (1949), Ascariasis in Darmstadt and Hesen as seen by a wastewater engineer. *Zeitschrift fur Hygiene and Infektions Krankheiten* **129**, 488-506.

Blumenthal, U.J., A. Peasey, M. Quigley and G. Ruiz-Palacios (2003), *Risk of Enteric Infections through Consumption of Vegetables with Contaminated River Water*. London School of Hygiene and Tropical Medicine, London.

Carr, R., U. Blumenthal and D. Mara (2004), Health guidelines for the use of wastewater in agriculture: developing realistic guidelines in: Scott C., Faruqui NI, Raschid-Sally L (eds.) Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities, Commonwealth Agricultural Bureau International, Orient-Longman, and International Development Research Centre, Ottawa, Canada.

Clancy, J.L., T.M. Hargy, M.M. Marshall and J.E. Dyksen (1998), UV light inactivation of Cryptosporidium oocysts. *Journal AWWA*, **90**(9), 92-102.

Feachem, R.G., D.J. Bradley, H. Garelick and D.D. Mara (1983), Sanitation and disease: health aspects of excreta and wastewater management. World Bank Studies in Water Supply and Sanitation 32. Chichester: John Wiley & Sons.

Geldreich, E.E. and R.H. Bordner (1971), Faecal contamination of fruits and vegetables during cultivation for processing and marketing: a review. *Journal of Milk and Food Technology* **34**, 184:195.

Hopkins, R.J. P.A. Vial, C. Ferrecio, J. Ovalle, P. Prado, V. Sotomayor, R.G. Russell, S.S. Wasserman, and J.G. Morris Jr (1993), Seroprevalence of *Heliobacter pylori* in Chile: *Vegetables May Serve as one Route of Transmission*. Journal of Infections Diseases **168**, 222-226.

Jiménez, B. (2003), Health risk in aquifer recharge with recycled water (chapter 3). In: Aertgeerts R. and Angelakis A. (eds.) State of the Art Report Health Risks in Aquifer Recharge Using Reclaimed Water. World Health Organization, Geneva.

Karimi, A.A., J.C. Vickers and R.F. Harasick (1999), Microfiltration goes Hollywood: the Los Angeles experience. *Journal of the American Water Works Association*, **91**(6), 90-103.

Khalil, M. (1931), The pail closet as an efficient means of controlling human helminth infections as observed in Tura prison, Egypt, with a discussion on the source of Ascaris Infection. Annals of Tropical Medicine and Parasitology **25**, 35-62

Krey, W. (1949), The Darmstadt Ascariasis epidemic and its control. *Zeitschrift fur Hygiene and Infektions Krankheiten* **129**, 507-518

Lazarova, V., P. Savoye, L. MacGovern, P. Shields, G. Tchobanoglous, R. Sakaji and M. Yates (2000), Wastewater Disinfection by UV: Evaluation of the MS2 Phages as a Biodosimeter for Plant Design. In: *Proceedings of the WateReuse Association Symposium 2000, September 12-15, 2000*, Napa. CA.

Mara, D.D. and S.A. Silva (1986), Removal of intestinal nematode eggs in tropical waste stabilization ponds: Journal of Tropical Medicine and Hygiene, 89(2):71-74.

Mara, D.D., P.A. Sleigh and U.J. Blumenthal (2005), Health risks in wastewater irrigation: comparing estimates from quantitative microbial risk analyses and epidemiological studies. *Journal of Water and Health* (submitted).

Murray C.J.L. an A.D. Lopez, eds., (1996), *The Global Burden of Disease, Vol. I.* Cambridge MA, Harvard School of Public Health on behalf of the World Health Organization and The World Bank.

National Research Council (NRC) (1998), *Issues of Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water*, Washington, DC, National Academy Press.

NRMMC/EPHC (2005), *National Guidelines for Water Recycling: Managing Health and Environmental Risks:* Natural Resource Management Ministerial Council and the Environment Protection and Heritage Council of Australia, Australia.

Oragui, J.I., T.P. Curtis, S.A. Silva and D.D. Mara (1987), Removal of excreted bacteria and viruses in deep waste stabilization ponds in northeast Brazil. Water Science and Technology **19** (Rio), 569-573.

Petterson, S.A. and N.J. Ashbolt (2003), *WHO Guidelines for the Safe Use of Wastewater and Excreta in Agriculture: Microbial Risk Assessment Section*. Unpublished document prepared for the World Health Organization, Geneva, 36 p.

Prüss, A., and A. Havelaar (2001), The Global Burden of Disease study and application sin water, sanitation, and hygiene. In: Fewtrell L., and Bartram J. (eds), 2001, *Water Quality: Guidelines, Standards for Health; Assessment of Risk and Risk Management for Water-related Infectious Disease*. IWA on behlf of the World Health Organization, London. UK.

Rose, J.B. and T.R. Slifko (1999), Giardia, Cryptosporidium, and Cyclospora and Their Impact on Foods: A Review. *Journal of Food Protection*, 1999, 62(9):1059-1070.

Rose, J.B., L.J. Dickson, S.R. Farrah and R.P. Carnahan (1996) Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility. *Water Resources,* **30**(11), 2785-2797.

Rose, J.B., M. Robbins, D. Friedman, K. Riley. S.R. Farrah and C.L. Hamann (1997), Evaluation of microbiological barriers at the Upper Occoquan Sewage Authority. *In 1996 Water Reuse Conference Proceedings, February 25-28, San Diego, California,* pp. 291-305, American Water Works Association, Denver, Colorado.

Shuval, H.I., P. Yekutiel and B. Fattal (1984), Epidemiological evidence for Helminth and Cholera transmission by vegetables irrigated with wastewater: Jerusalem – A Case Study. *Water Science and Technology* 17, 433-442.

Sleigh, P.A. and D.D. Mara (2003), Monte Carlo Program for Estimating Disease Risks in Wastewater Reuse; available at http://www.efm.leeds.ac.uk/CIVE/MCarlo.

Sobsey, M. (1989), Inactivation of Health Related Microorganisms in Water by Disinfection Processes. *Water, Science and Technology,* 21(3), 179-195.

Strauss, M. (1985), Health aspects of nightsoil and sludge use in agriculture and aquaculture – Part II: Survival of excreted pathogens in excreta and faecal sludges. IRCWDD News No. 23, pp. 4-9, EAWAG/SANDEC, Dubendorf, Switzerland.

Vaz da Costa Vargas, S., R.K.X. Batos and D.D. Mara (1996), *Bacteriological Aspects of Wastewater Irrigation.* TPHE Research Monograph N. 8 University of Leeds (Department of Civil Engineering) Leeds, England.

WHO (2003), *The World Health Report 2003, Shaping the Future*, World Health Organization, Geneva.

WHO (2004a), *Guidelines for Drinking Water Quality*, third edition. Geneva, World Health Organization.

WHO (2004b), *The World Health Report 2004 – Changing History,* World Health Organization, Geneva.

Yates, M.V. and C.P. Gerba (1998). Chapter 10: Microbial Considerations in Wastewater Reclamation and Reuse. In: Asano T. (ed). *Wastewater Reclamation and Reuse*. Lancaster, Pennsylvania, Technomic Publishing Company, pp. 1-56.