THE NEW WHO DRAFT GUIDELINES FOR WATER REUSE IN AGRICULTURE

The integration of reclaimed water in water resource management: the fostering role of the territorial region

Lloret de Mar, (Costa Brava, Girona)
18-20 October, 2005

George Kamizoulis, PhD, MPH
Senior Scientist, WHO/MED POL

The most appropriate metric of expressing burden of disease

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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). (Bartram, Fewtrell and Stenström, 2001).

The reference point for excess burden of disease used by WHO in the WHO Guidelines for Drinking Water Quality is = 10^{-6} DALY per person per year (pppy)

Corresponds to a tolerable excess lifetime risk of fatal cancer of 10^{-5} per person (an individual has a 1 in 100,000 lifetime chance of developing fatal cancer)

The same high health protection level of = 10^{-6} DALY per person per year is used for wastewater use in agriculture

DALYs, disease risks, disease/infection ratios and tolerable infection risks for rotavirus, *Campylobacter* and *Cryptosporidium*

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

IC, industrialized countries; DC, developing countries; pppy, per person per year

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

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

[c] For developing counties, the DALYs per rotavirus death have been reduced by 95%, as approximately 95% 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 is mostly developed by the age of 3.

Tolerable risk of infection of rotavirus is 10^{-3} per person per year

Following the quantitative microbial risk assessment (QMRA) calculations, it results that the rotavirus dose per consumer exposure is equivalent to 5 X 10^{-5} per exposure event

The required pathogen reduction (calculated) in log_{10} units is: 6

The approach adopted, focuses on risks from the consumption of food crops eaten uncooked and risks to fieldworks from direct contact with treated wastewater, for unrestricted and restricted, irrigation, respectively

The Monte Carlo – QMRA results for unrestricted irrigation with the relevant epidemiological evidence, show that in order to achieve = 10^{-6} DALY per person per year for rotavirus, a total pathogen reduction of 6 log units for the consumption of leaf crops (lettuce) and 7 log units for the consumption of root crops (onions) is required.

Unrestricted irrigation: median infection risks from the consumption of wastewater-irrigated onions 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}	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}**
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	4.4×10^{-4}	1.1×10^{-5}	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 α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*.

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	6.3×10^{-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}
10^3	**2.2×10^{-4}**	**5.6×10^{-6}**	**1.4×10^{-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}
1−10	1.0×10^{-6}	3.0×10^{-8}	7.0×10^{-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 α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*

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

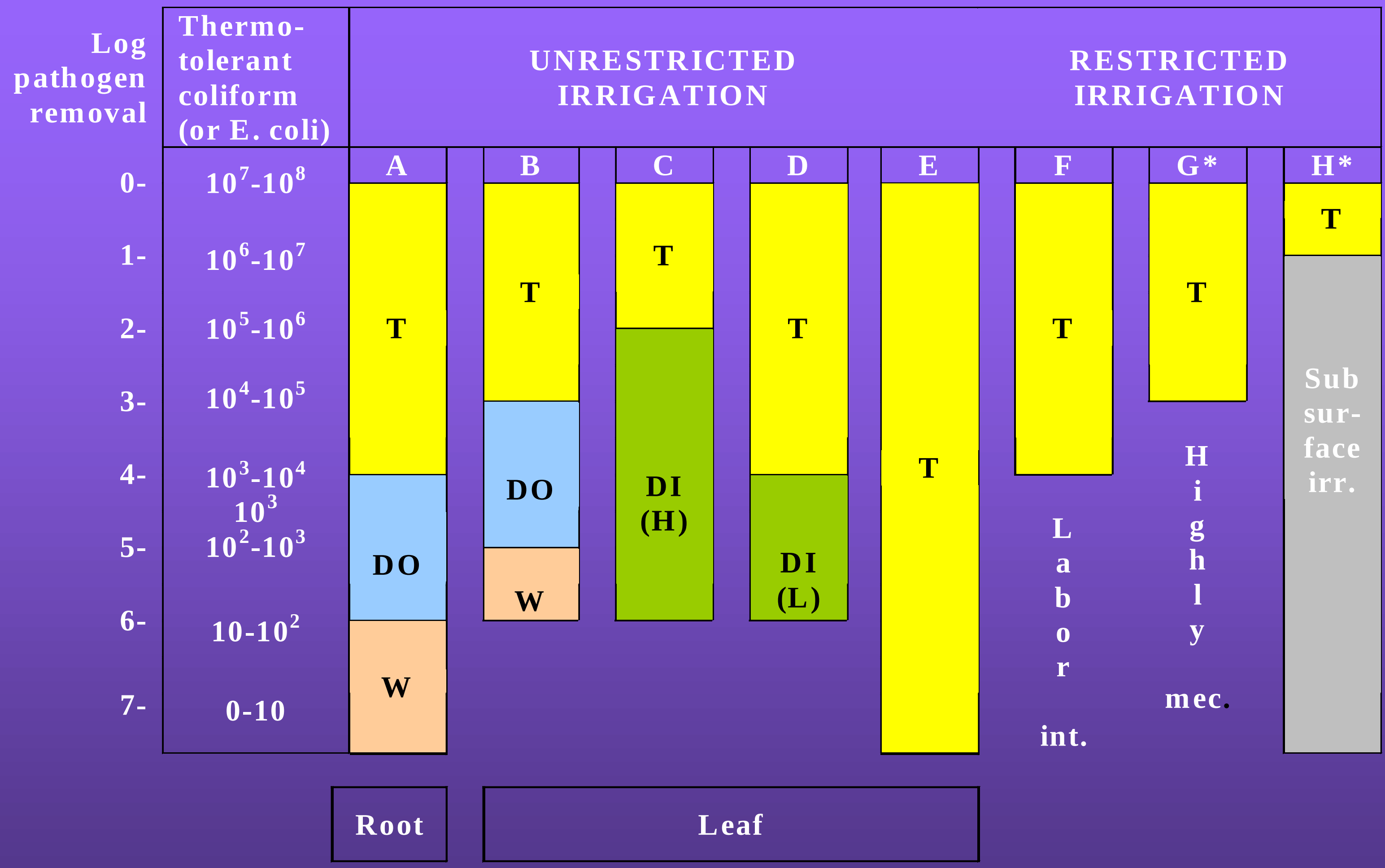
- High occurrence;
- High concentration in water to be recycled
- Low removal in treatment;
- Long survival in the environment; and
- High pathogenicity

The log units pathogen reduction by treatment is verified not by measuring pathogen numbers in samples of raw wastewater and treatment plant effluent, but by the reduction in numbers of a pathogen indicator organism.

Therefore

Escherichia coli **is recommended for this purpose, although thermotolerant coliforms may be used instead.**

Health protection measures



* = where children under 15 years are exposed
T = treatment
W = washing of produce
DO = die-off
DI = drip irrigation (L=low growing cops; H=high growing crops)

Pathogen reductions achievable by various health protection measures

Control measure	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
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.

Sources: Beuchat (1998); Petterson & Ashbolt (2003); NRMMC & EPHCA (2005).

Options for the reduction of helminth eggs by health protection measures for different helminth egg numbers in untreated wastewater and associated verification requirements

Health protection measure	Number of helminth eggs per litre of untreated wastewater	Required helminth egg reduction by treatment (log units)	Verification monitoring level (helminth eggs per litre of treated wastewater)[a]	Notes
Treatment	1000	3	≤1	Treatment should be shown to achieve this egg quality reliably
	100	2	≤1	
	10	1	≤1	
	≤1	0	N/A	The target of ≤1 egg per litre is automatically achieved.
Treatment and produce washing	1000	2	≤10	The reduction achieved by treatment is followed by a 1 log unit reduction by produce washing in a weak detergent solution and rinsing with clean water.[b]
	100	1	≤10	As above
	10	0	N/A	The required 1 log unit reduction is achieved by produce washing in a weak detergent solution and rinsing with clean water.[b]
	≤1	0	N/A	The target of ≤1 egg per litre is automatically achieved.

N/A, not applicable

[a] With waste stabilization ponds, the pond retention times can be used as a verification tool. (Currently, there are no generally valid surrogate verification tools for other treatment processes, although it may be possible to develop them locally)

[b] Valid only where this practice is common or where it can be successfully promoted and verified

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 - 90 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 - 90 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} 0.5 - 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	% 90 - 99 Log_{10} 1 - 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 - 2.0	% 95 - 99 Log_{10} 1.5 - 2

ND= No data

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

Verification monitoring of wastewater treatment (*E. coli* numbers per 100 ml of treated wastewater) for the various levels of wastewater treatment in Options A-G

Type of irrigation	Option	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

[a] For example, for secondary treatment, filtration and disinfection: 5-day biochemical oxygen demand, <10 mg/l; turbidity, <2 nephelometric turbidity units; chlorine residual, 1 mg/l; pH, 6-9; and faecal coliforms, not detectable in 100 ml.

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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}

IC, industrialized countries; DC, developing countries; pppy, per person per year

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

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

[c] For developing counties, the DALYs per rotavirus death have been reduced by 95%, as approximately 95% 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 is mostly developed by the age of 3.

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

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	Rotavirus	***Campylobacter***	***Cryptosporidium***
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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}**
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}
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*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 α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*.

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

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	Rotavirus	***Campylobacter***	***Cryptosporidium***
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10^6−10^7	0.65	6.3×10^{-2}	6.3×10^{-2}
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10^4	**2.2×10^{-3}**	**1.3×10^{-4}**	**4.5×10^{-4}**
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10^3	**2.2×10^{-4}**	**5.6×10^{-6}**	**1.4×10^{-5}**
100−1000	8.6×10^{-5}	3.1×10^{-6}	6.4×10^{-6}
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*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 α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for *Campylobacter*; *r* = 0.0042 ± 25% for *Cryptosporidium*

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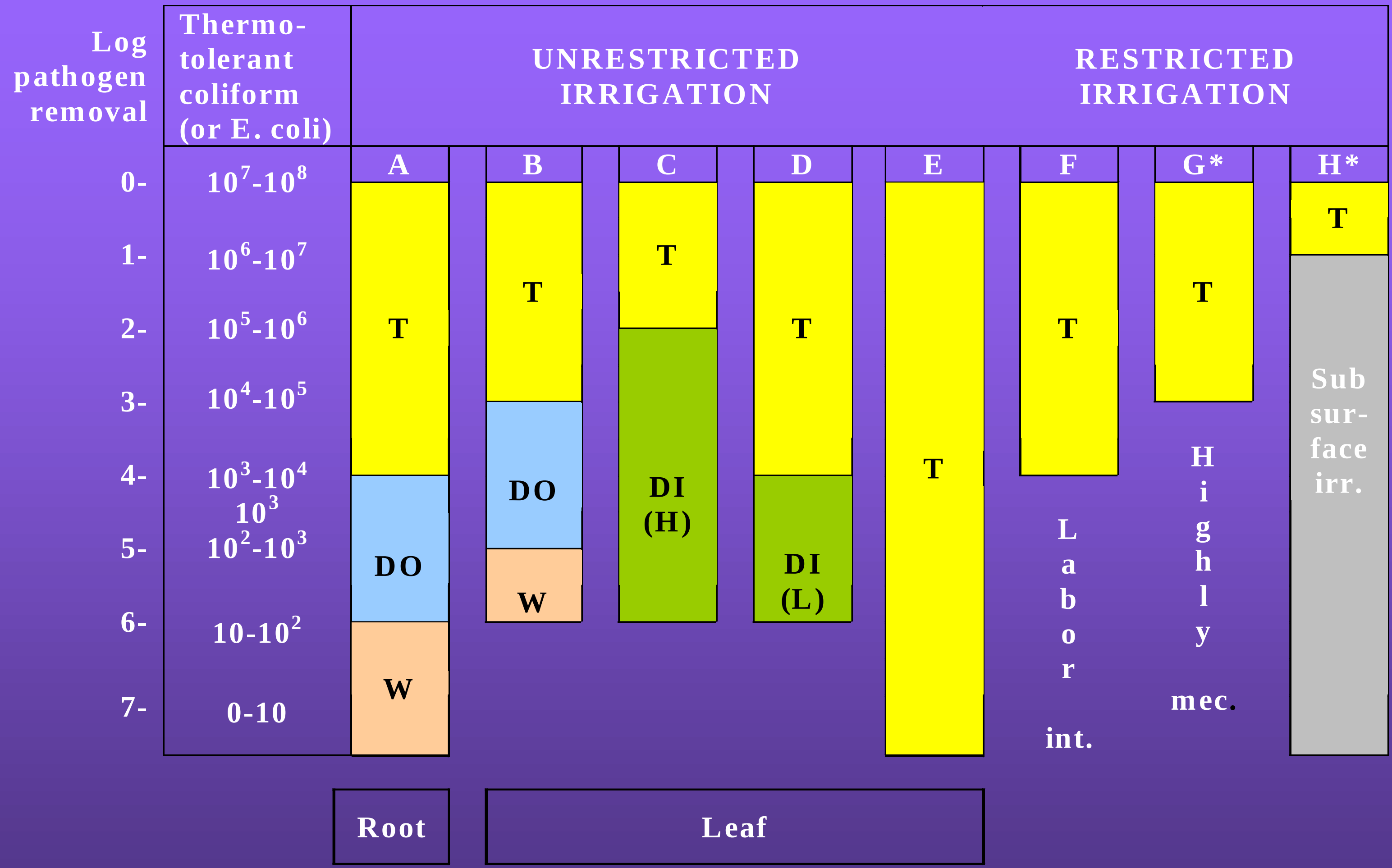
- High occurrence;
- High concentration in water to be recycled
- Low removal in treatment;
- Long survival in the environment; and
- High pathogenicity

The log units pathogen reduction by treatment is verified not by measuring pathogen numbers in samples of raw wastewater and treatment plant effluent, but by the reduction in numbers of a pathogen indicator organism.

Therefore

Escherichia coli **is recommended for this purpose, although thermotolerant coliforms may be used instead.**

Health protection measures



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Pathogen reductions achievable by various health protection measures

Control measure	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
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.

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Options for the reduction of helminth eggs by health protection measures for different helminth egg numbers in untreated wastewater and associated verification requirements

Health protection measure	Number of helminth eggs per litre of untreated wastewater	Required helminth egg reduction by treatment (log units)	Verification monitoring level (helminth eggs per litre of treated wastewater)[a]	Notes
Treatment	1000	3	≤1	Treatment should be shown to achieve this egg quality reliably
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	100	1	≤10	As above
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[a] With waste stabilization ponds, the pond retention times can be used as a verification tool. (Currently, there are no generally valid surrogate verification tools for other treatment processes, although it may be possible to develop them locally)

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Treatment Technology	Pathogen Removal Percentages/Log_{10}			
	Bacteria	Helminths	Protozoa	Viruses
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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 - 90 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 - 90 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} 0.5 - 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**	**% 90 - 99** **Log_{10} 1 - 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 - 2.0**	**% 95 - 99** **Log_{10} 1.5 - 2**

ND= No data

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

Verification monitoring of wastewater treatment (*E. coli* numbers per 100 ml of treated wastewater) for the various levels of wastewater treatment in Options A-G

Type of irrigation	Option	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

[a] For example, for secondary treatment, filtration and disinfection: 5-day biochemical oxygen demand, <10 mg/l; turbidity, <2 nephelometric turbidity units; chlorine residual, 1 mg/l; pH, 6-9; and faecal coliforms, not detectable in 100 ml.