QUANTITATIVE MICROBIAL RISK ANALYSIS: THE 2006 WHO GUIDELINES AND BEYOND

HOW TO USE THE QMRA-MONTE CARLO COMPUTER PROGRAMS IN WASTEWATER-USE PLANNING AND PROJECT DESIGN





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Contents

►Notes:

1. 'Restricted ' irrigation refers to the irrigation of all crops, except those that are eaten or may be eaten uncooked. 'Unrestricted' irrigation refers to the irrigation of all crops, including those that are eaten or may be eaten uncooked.

2. The abbreviation 'pppy' stands for 'per person per year'; FC for 'faecal coliforms', and MC for 'Monte Carlo'.

► FIRST OF ALL

Read the companion document *Quantitative Microbial Risk Analysis: The 2006 WHO Guidelines and Beyond – An Introduction* (contained in the .zip file from which you downloaded this document) to familiarise yourself with QMRA (e.g., the dose-response equations, calculation of annual risks, exposure scenarios used in unrestricted and restricted irrigation, etc).

1. HOW TO DETERMINE ROTAVIRUS, *CAMPYLOBACTER* AND *CRYPTOSPORIDIUM* INFECTION RISKS

The two computer programs 'P1. QMRA-MC_UnrestrictedIrrigation_2.xls' and 'P2. QMRA-MC_ Restricted Irrigation_2.xls' are contained in the .zip file from which you obtained this document. Both these programs incorporate the improved Karavarsamis and Hamilton method for determining annual infection risks (details are given in *QMRA: The 2006 WHO Guidelines and Beyond – An Introduction*).

1.1 UNRESTRICTED IRRIGATION

(i) Open the program 'P1. QMRA-MC_UnrestrictedIrrigation_2.xls'.

►If you are using Excel 2003, click 'Enable macros'; or, if you are using Excel 2007, click 'Options' and then check 'Enable this content' and click 'OK'. If the Excel security setting on your computer is set too high, you will not get these options – go to page 19 to see how to change the Excel security setting to the level required to allow the program to run.

(ii) Make sure you're on the first sheet – 'QMRABetaP'. This is what you should now see… … … … … … →

This is what you see … … … … … … … … →

What you have to do now is to fill in the yellow cells (there may be some existing values in the yellow cells; if there are, simply overwrite them with the values below).

Try these parameter ranges:

(a) FC count per 100 ml: 10^3–10^4
(b) No. of pathogens per 10^5 FC: 0.1–1
(c) Water on 100 g lettuce (mL): 10–15
(d) Quantity of lettuce consumed (g/day): 50–150
(e) Reduction factor [die-off]: 0–0
(f) Exposure (every n days): 1–3
(g) Disease/infection ratio: 1–1
(h) Variation from default value (±%): 25

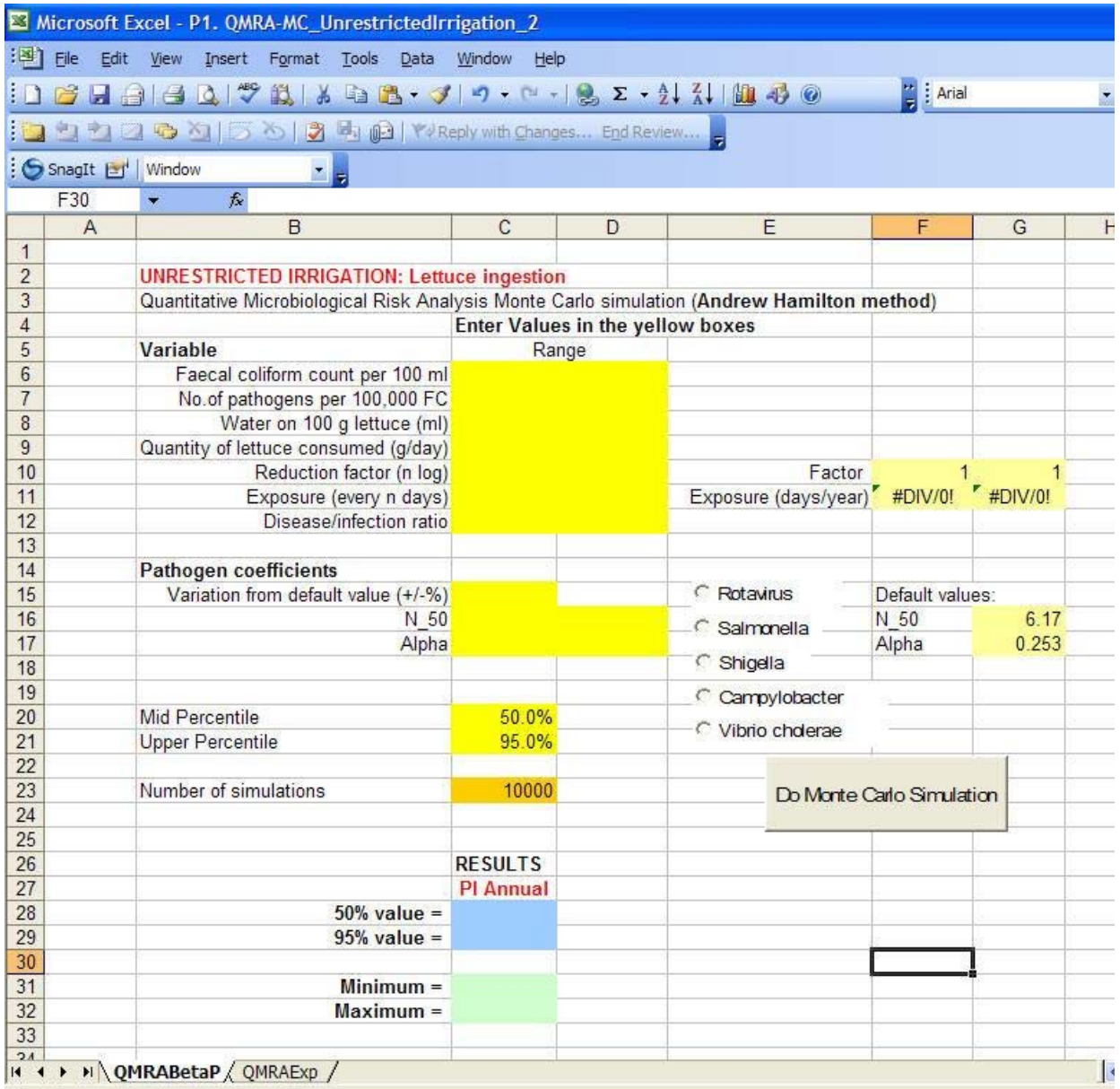
Check 'rotavirus'.

The entries for 'Mid Percentile', 'Upper Percentile' and 'Number of simulations' should be as shown (if not, change them to these values).

Click any empty cell to confirm your choices.

Click the 'Do Monte Carlo Simulation' box and wait until entries appear in the coloured cells under 'RESULTS'.

The screen should now look like this ↓



The screen should now look like this … →

You have determined the rotavirus infection risk* in a person who eats 50–150 g of lettuce every 2–3 days. The lettuce has been irrigated with treated wastewater containing 10^3–10^4 FC (or *E. coli*) per 100 mL. There are 0.1–1 rotavirus in the wastewater for every 10^5 FC (or *E. coli*) and the rotavirus N_{50} and alpha values are 6.17 ± 25% and 0.253 ± 25%. You have assumed there is no pathogen die-off (Reduction factor = 0–0)

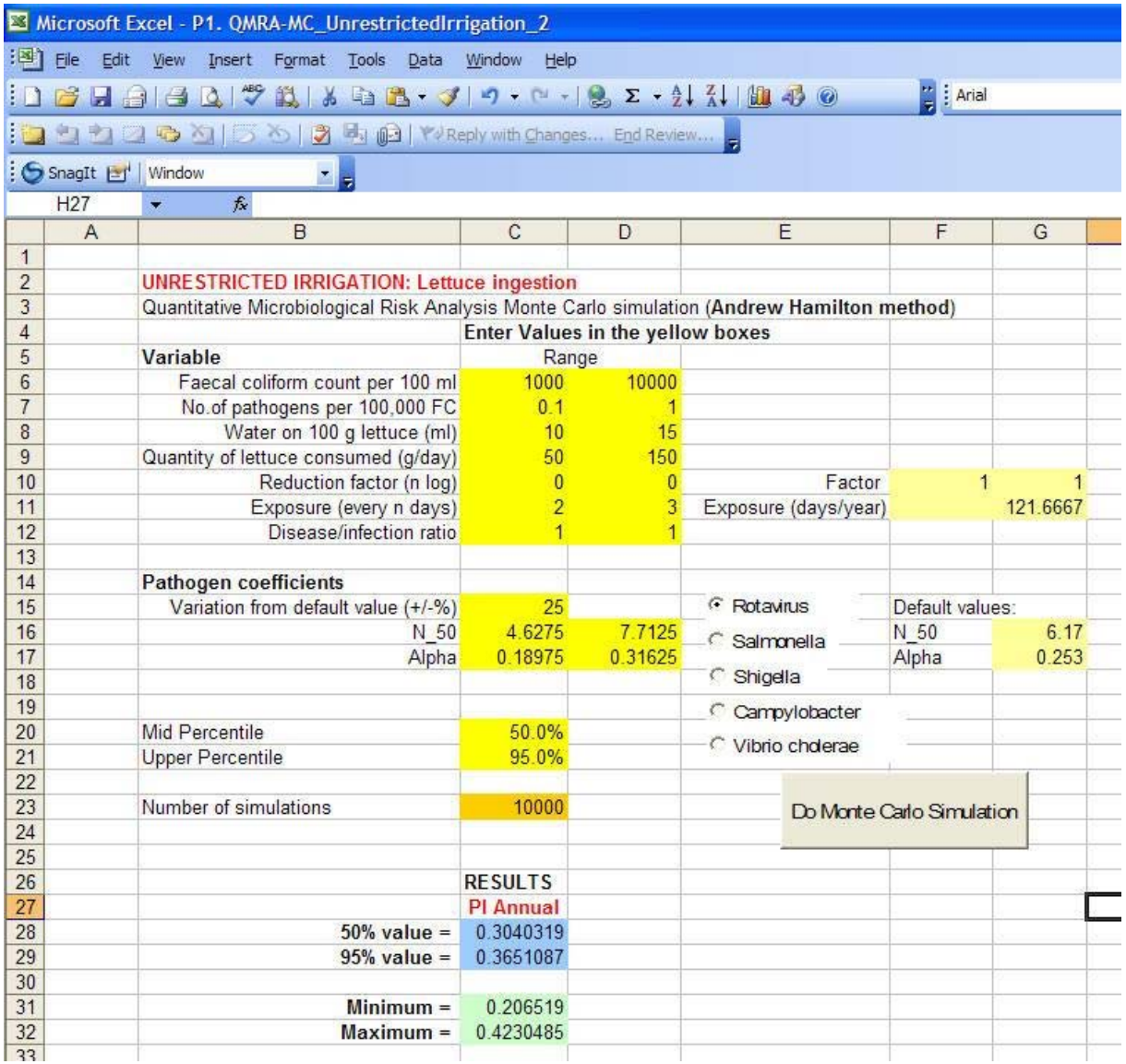
The displayed RESULTS (to 2 significant figures) are:

(a) 50% value (i.e., the median rotavirus infection risk): 0.30 pppy

(b) 95%value (i.e., the 95-percentile rotavirus infection risk): 0.37 pppy

Your values may be slightly different as no two runs yield exactly the same results.

***Setting the Disease/infection ratio to 1 in both yellow cells means that the infection risk is the same as the disease risk, so you are effectively determining the rotavirus infection risk.**



	A	B	C	D	E	F	G
1							
2		UNRESTRICTED IRRIGATION: Lettuce ingestion					
3		Quantitative Microbiological Risk Analysis Monte Carlo simulation (Andrew Hamilton method)					
4			Enter Values in the yellow boxes				
5		Variable	Range				
6		Faecal coliform count per 100 ml	1000	10000			
7		No.of pathogens per 100,000 FC	0.1	1			
8		Water on 100 g lettuce (ml)	10	15			
9		Quantity of lettuce consumed (g/day)	50	150			
10		Reduction factor (n log)	0	0	Factor	1	1
11		Exposure (every n days)	2	3	Exposure (days/year)		121.6667
12		Disease/infection ratio	1	1			
13							
14		Pathogen coefficients					
15		Variation from default value (+/-%)	25		◉ Rotavirus	Default values:	
16		N_50	4.6275	7.7125	○ Salmonella	N_50	6.17
17		Alpha	0.18975	0.31625	○ Shigella	Alpha	0.253
18							
19					○ Campylobacter		
20		Mid Percentile	50.0%		○ Vibrio cholerae		
21		Upper Percentile	95.0%				
22							
23		Number of simulations	10000		Do Monte Carlo Simulation		
24							
25							
26			RESULTS				
27			PI Annual				
28		50% value =	0.3040319				
29		95% value =	0.3651087				
30							
31		Minimum =	0.206519				
32		Maximum =	0.4230485				
33							

1.1 UNRESTRICTED IRRIGATION, continued

What you can do now:

(a) *Campylobacter*

Repeat the risk simulation you have just done − but this time for *Campylobacter* by selecting 'Campylobacter'. The RESULTS should be around 0.014 pppy for the median *Campylobacter* infection risk and 0.018 pppy for the 95-percentile infection risk.

(b) *Cryptosporidium*

Select the second sheet 'QMRAexp' and enter in the yellow boxes the same ranges for each parameter as for rotavirus and *Campylobacter* − except for 'No. of pathogens per 10^5 FC', for which enter 0.01−0.1; select 'Cryptosporidium', click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box. The RESULTS should be around 2.3×10^{-4} pppy for the median *Cryptosporidium* infection risk and 2.9×10^{-4} pppy for the 95-percentile infection risk.

1.2 RESTRICTED IRRIGATION

(i) Open the program 'P2. QMRA-MC_RestrictedIrrigation_2.xls'. If you are using Excel 2003, click on 'Enable macros'; or, if you are using Excel 2007, click on 'Options' and then check 'Enable this content' and click on 'OK' (this is important: the program won't run if you don't do this – see also page 19).

(ii) Make sure you're on the first sheet – 'QMRABetaP'.

(iii) Enter the ranges of parameter values given on the next page and what you will then see on your monitor or laptop screen is … … … … … … … … … … … … … … … … …. … … … … … … … … … … … →

►Enter these parameter ranges in the yellow cells:

(a) FC count per g soil: 10–100 (i.e., 10^3–10^4 per 100 g)*
(b) No. of pathogens per 10^5 FC: 0.1–1
(c) Quantity of soil ingested (g/day): 0.01–0.1 (i.e., 10–100 mg/day)*
(d) Exposure (days/year): 300 (this is a 'fixed' value)
(g) Disease/infection ratio: 1–1
(h) Variation from default value (±%): 25

*NOTE that in (a) the soil quality is entered as 'per gram' and NOT 'per 100 g'; and in (b) the quantity of soil ingested is in 'g/day' and NOT 'mg/day'. See also the Note on the next page.

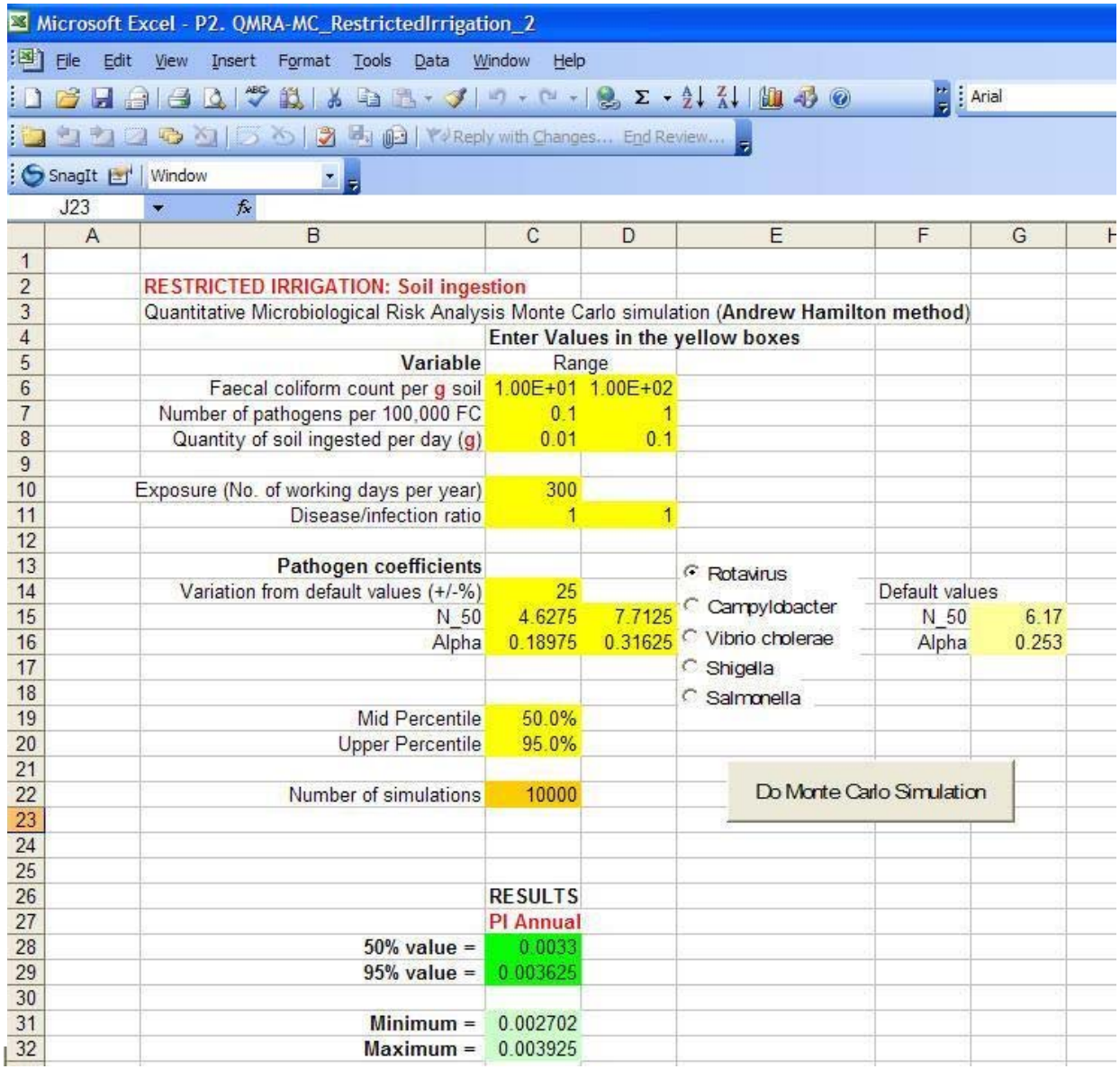
►Select 'Rotavirus'.

►The entries for 'Mid Percentile', 'Upper Percentile' and 'Number of simulations' should be as shown (if not, change them to these values).

►Click any empty cell to confirm your choices. Then click the 'Do Monte Carlo Simulation' box and wait until entries appear in the coloured cells under 'RESULTS'.

The screen should now look like this …. →

RESULTS: the median rotavirus infection risk is 3.3×10^{-3} pppy and the 95-percentile risk 3.6×10^{-3} pppy.



1.2 RESTRICTED IRRIGATION, continued

Note: as a worst-case scenario it is assumed that the soil quality (expressed as FC per 100 g) is the same as the wastewater quality (FC per 100 mL) – i.e., the assumption is that the soil is fully saturated with the wastewater.

What you can do now:

(a) *Campylobacter*

Repeat the risk simulation you have just done – but this time for *Campylobacter* by selecting 'Campylobacter'. The RESULTS should be around 1.3×10^{-4} pppy for the median *Campylobacter* infection risk and 1.3×10^{-4} pppy for the 95-percentile infection risk.

(b) *Cryptosporidium*

Select the second sheet 'QMRAexp' and enter in the yellow boxes the same ranges for each parameter as for rotavirus and *Campylobacter* – except for 'No. of pathogens per 10^5 FC', for which enter 0.01–0.1; select 'Cryptosporidium', click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box. The RESULTS should be around 2.1×10^{-6} pppy for the median *Cryptosporidium* infection risk and 2.3×10^{-6} pppy for the 95-percentile infection risk.

Note: The two computer programs 'P1. QMRA-MC_UnrestrictedIrrigation_2.xls' and 'P2. QMRA-MC_Restricted Irrigation_2.xls' also allow you to calculate disease and/or infection risks due to *Salmonella*, *Shigella*, *Vibrio cholerae* and *Giardia*.

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2. HOW TO DETERMINE NOROVIRUS INFECTION RISKS

The following two computer programs

- **P3. QMRA-MC_UnrestrictedIrrigation_Norovirus_2.xls, and**
- **P4. QMRA-MC_RestrictedIrrigation_Norovirus_2.xls**

are contained in the .zip file from which you obtained this document. Both programs incorporate the improved Karavarsamis and Hamilton method for determining annual infection risks.

2.1 UNRESTRICTED IRRIGATION

(i) Open the program 'P3. QMRA-MC_UnrestrictedIrrigation_Norovirus_2.xls'. If you are using Excel 2003, click 'Enable macros'; or, if you are using Excel 2007, click 'Options' and then check 'Enable this content' and click 'OK' (this is important: the program won't run if you don't do this – see also page 19).

(ii) Enter exactly the same ranges of parameter values as you did for rotavirus, *Campylobacter* and *Cryptosporidium* in the program 'P1. QMRA-MC_UnrestrictedIrrigation_2.xls', click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box.

The RESULTS should be around 0.21pppy for the median norovirus infection risk and 0.25 pppy for the 95-percentile infection risk.

2.2 RESTRICTED IRRIGATION

(i) Open the program 'P4. QMRA-MC_RestrictedIrrigation_Norovirus_2.xls'. If you are using Excel 2003, click 'Enable macros'; or, if you are using Excel 2007, click 'Options' and then check 'Enable this content' and click 'OK' (this is important: the program won't run if you don't do this – see also page 19).

(ii) Enter exactly the same ranges of parameter values as you did for rotavirus, *Campylobacter* and *Cryptosporidium* in the program 'P2. QMRA-MC_RestrictedIrrigation_2.xls', click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box.

The RESULTS should be around 0.21pppy for the median norovirus infection risk and 0.23 pppy for the 95-percentile infection risk.

3. HOW TO DETERMINE *ASCARIS* INFECTION RISKS

The following two computer programs

- **P5. QMRA-MC_UnrestrictedIrrigation_Ascaris.xls, and**
- **P6. QMRA-MC_RestrictedIrrigation_Ascaris.xls**

are contained in the .zip file from which you obtained this document. Both programs incorporate the improved Karavarsamis and Hamilton method for determining annual infection risks.

3.1 UNRESTRICTED IRRIGATION

(i) Open the program 'P5. QMRA-MC_UnrestrictedIrrigation_Ascaris.xls'. If you are using Excel 2003, click 'Enable macros'; or, if you are using Excel 2007, click 'Options' and then check 'Enable this content' and click 'OK' (this is important: the program won't run if you don't do this – see also page 19).

(ii) Enter 0.1–1 for 'Number of Ascaris eggs per litre of treated wastewater' and exactly the same ranges for the other parameters as you did for rotavirus, *Campylobacter* and *Cryptosporidium* in the program 'P1. QMRA-MC_UnrestrictedIrrigation_2.xls'; click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box. The RESULTS should be around 0.026 pppy for the median *Ascaris* infection risk and 0.034 pppy for the 95-percentile infection risk.

3.2 RESTRICTED IRRIGATION

(i) Open the program 'P6. QMRA-MC_RestrictedIrrigation_Ascaris.xls'. If you are using Excel 2003, click 'Enable macros'; or, if you are using Excel 2007, click 'Options' and then check 'Enable this content' and click 'OK' (this is important: the program won't run if you don't do this – see also page 19).

(ii) Enter 0.0001–0.001 for 'Number of Ascaris eggs per g soil' (i.e., 0.1–1 per kg soil) and exactly the same ranges for the other parameters as you did for rotavirus, *Campylobacter* and *Cryptosporidium* in the program 'P2. QMRA-MC_RestrictedIrrigation_2.xls'; click any empty cell to confirm your choices, and then click the 'Do Monte Carlo Simulation' box. The RESULTS should be around 1.5×10^{-3} pppy for the median *Ascaris* infection risk and 1.7×10^{-3} pppy for the 95-percentile infection risk.

4. HOW TO USE THE QMRA-MC RESULTS IN WASTEWATER-USE PLANNING AND PROJECT DESIGN

The main purpose of using these QMRA-MC computer programs is to determine the total pathogen reductions required to protect the health of those who work in wastewater-irrigated fields and that of those who consume wastewater-irrigated foods. In the case of unrestricted irrigation the total pathogen reduction determined by QMRA is achieved by a combination of wastewater treatment and post-treatment health-protection control measures of the kind shown in Table 1. In the case of restricted irrigation the total pathogen reduction determined by

Table 1. Post-treatment health-protection control measures and associated log unit pathogen reductions

Control measure	Pathogen reduction (log units)	Notes
Drip irrigation	2–4	2-log unit reduction for low-growing crops, 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	3	Washing salad crops, vegetables and fruit in weak disinfectant and rinsing with clean water.
Produce peeling	2	Fruits, root crops.

QMRA has to be achieved wholly by wastewater treatment as there is no other way to protect the health of the fieldworkers. In practice the degree of wastewater treatment required for unrestricted irrigation is the same as that for restricted irrigation because there are fieldworkers whose health can only be protected by this level of treatment. The balance of the total required pathogen reduction is achieved by an appropriate selection of the post-treatment health-protection control measures detailed in Table 1.

4.1 CASE STUDY A: RESTRICTED IRRIGATION

Suppose (a) wastewater is to be used to irrigate sugar cane for ethanol production; and (b) your Ministry of Health has set the maximum tolerable additional burden of disease in those working in the wastewater-irrigated cane fields as 1×10^{-4} DALY loss pppy. This maximum DALY loss of 10^{-4} pppy 'translates' into a maximum tolerable norovirus infection risk of 0.13 pppy and into a maximum tolerable *Ascaris* infection risk of 1.2×10^{-2} pppy.[1]

In practice locally appropriate parameter ranges have to be selected for use in the QMRA-MC programs. Here it is assumed that the ranges used in sections 2.2 (for norovirus) and 3.2 (for *Ascaris*) are appropriate – even the number of days worked per year in the cane fields (300) as, in southwest Colombia at least, cane is harvested throughout the year.

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[1] See *QMRA: The 2006 WHO Guidelines and Beyond – An Introduction* for an explanation of DALYs (disability-adjusted life years) and justification of a maximum DALY loss of 1×10^{-4} pppy. This document also shows how this DALY loss is 'translated' into a maximum tolerable infection risk.

The programs 'P4. QMRA-MC_RestrictedIrrigation_Norovirus_2.xls' and 'P6. QMRA-MC_Restricted Irrigation_Ascaris.xls' are used and Tables 2 and 3 generated – this is quite straightforward: in the case of norovirus the program is run four times, each time with a different range of soil quality: 10^7–10^8, 10^6–10^7, 10^5–10^6 and 10^4–10^5 FC per 100 g soil – but enter these ranges in the program as 10^5–10^6, 10^4–10^5, 10^3–10^4 and 10^3–10^4 FC per g soil. In the case of *Ascaris* the program is also run four times, again with different ranges of soil quality: 100–1000, 10–100, 1–10 and 0.1–1 eggs/kg soil – but enter these ranges in the program as 1–0.1, 0.01–0.1, 0.001–0.01 and 0.0001–0.001 eggs per g soil) [see the Notes on pages 7 and 8].

The tables should look like this … →

Thus a 2-log unit reduction is required for norovirus if a norovirus risk of 0.19 pppy is acceptable (it is only slightly higher than the tolerable risk of 0.13 pppy given above, and it means that an individual will have norovirus diarrhoea on average once every five years, rather than once every 7–8 years). For *Ascaris* a 2-log unit reduction results in an infection risk of 1.5×10^{-2} pppy which is close to the value of 1.2×10^{-2} pppy given above.

►So wastewater treatment is required to achieve 2-log unit reductions of both norovirus and *Ascaris*.

Table 2 – Restricted irrigation:
Median norovirus infection risks from the involuntary ingestion of 10–100 mg of wastewater-saturated soil per day for 300 days per year estimated by 10,000 Karavarsamis-Hamilton MC simulations.

Soil quality (faecal coliforms per 100 g soil)	Median norovirus infection risk pppy
10^7–10^8	1
10^6–10^7	0.88
10^5–10^6	0.19
10^4–10^5	2.0×10^{-2}

Table 3 – Restricted irrigation:
Median *Ascaris* infection risks from the involuntary ingestion of 10–100 mg of wastewater-saturated soil per day for 300 days per year estimated by 10,000 Karavarsamis-Hamilton MC simulations.

Soil quality (*Ascaris* eggs per kg soil)	Median *Ascaris* infection risk pppy
100–1000	0.75
10–100	0.14
1–10	1.5×10^{-2}
0.1–1	1.5×10^{-3}

4.2 CASE STUDY B: UNRESTRICTED IRRIGATION

Suppose (a) wastewater is to be used to irrigate lettuce; and (b) your Ministry of Health has set the maximum tolerable additional burden of disease in those working in wastewater-irrigated fields and in those consuming wastewater-irrigated foods as 1×10^{-4} DALY loss pppy. As in the case of restricted irrigation, this maximum DALY loss of 10^{-4} pppy 'translates' into a maximum tolerable norovirus infection risk of 0.13 pppy and into a maximum tolerable *Ascaris* infection risk of 1.2×10^{-2} pppy.[2]

Fieldworker protection

The fieldworkers are assumed to be as exposed as the sugar-cane fieldworkers in Case Study A. Thus wastewater treatment is required to achieve a 2-log unit reduction of both norovirus and *Ascaris*.

Consumer protection

The consumers are protected by wastewater treatment (2-log unit pathogen reduction) and by a locally appropriate selection of the post-treatment health-protection control measures detailed in Table 1. Thus the total log unit pathogen reduction has to be determined so that the log unit reduction to be achieved by these post-treatment health-protection control measures can be ascertained.

The required total log unit pathogen reduction is determined by using the two programs 'P3. QMRA-MC_UnrestrictedIrrigation_Norovirus_2.xls' and 'P5. QMRA-MC_UnrestrictedIrrigation_Ascaris.xls' with locally appropriate ranges of the parameter ranges have to be selected for use in these QMRA-MC programs. Here it is assumed that the ranges used in section 2.1 (for norovirus) and section 3.1 (for *Ascaris*) are appropriate – except for lettuce consumption: lettuce is not a normal part of the local diet,

[2] See Footnote #1 on page 13.

although people do eat it in sandwiches and other fast foods at the rate of 5–10 g per day on 3–5 days a week.

Tables 4 and 5 are now generated – again this is quite straightforward: in the case of norovirus the program is run four times, each time with a different range of wastewater quality (10^5–10^6, 10^4–10^5, 10^3–10^4 and 10^2–10^3 FC per 100 mL);[3] and in the case of *Ascaris* also four times (100–1000, 10–100, 1–10 and 0.1–1 eggs/L).

The tables should look like this … →

The results in Table 4 indicate that a 3-log unit reduction is required for norovirus (from 10^7–10^8 FC per 100 mL (raw wastewater) to 10^4–10^5 FC per 100 mL, at which level the norovirus infection risk is 0.10 pppy – i.e., just below the maximum tolerable risk of 0.13 pppy given in section 4.1. For *Ascaris* the results in Table 5 show that a 3-log unit reduction (from 100–1000 eggs/L to 0.1–1 egg/L) results in an infection risk of 6.0×10^{-4} pppy which well below the maximum tolerable risk of 1.2×10^{-2} pppy given in section 4.1.

Wastewater treatment achieves a 2-log unit reduction of norovirus and *Ascaris*, so an additional 1 log unit reduction has to be achieved by post-treatment health-protection control measures (Table 1) – produce washing in clean water will reliably achieve this (produce disinfection, which is routinely practised in some communities, would achieve a very safe additional reduction of 3 log units).

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[3] Wastewater qualities of 10^7–10^8 and 10^6–10^7 FC per 100 mL are not considered as the resulting infection risks can be safely assumed to be too high.

Table 4 – Unrestricted irrigation:
Median norovirus infection risks from the consumption of 5–10 mg of wastewater-irrigated lettuce on 3–5 days per week estimated by 10,000 Karavarsamis-Hamilton MC simulations

Wastewater quality (FC per 100 mL)	Median norovirus infection risk pppy
10^5–10^6	0.66
10^4–10^5	0.10
10^3–10^4	1.1×10^{-2}
10^2–10^3	1.1×10^{-3}

Table 5 – Unrestricted irrigation:
Median *Ascaris* infection risks from the consumption of 5–10 mg of wastewater-irrigated lettuce on 3–5 days per week estimated by 10,000 Karavarsamis-Hamilton MC simulations

Wastewater quality (*Ascaris* eggs per L)	Median *Ascaris* infection risk pppy
100–1000	0.42
10–100	5.7×10^{-2}
1–10	5.9×10^{-3}
0.1–1	6.0×10^{-4}

►**So the QMRA-MC risk simulations have indicated the degree of wastewater treatment required for both restricted and unrestricted irrigation and, for unrestricted irrigation, the additional log unit pathogen reduction to be achieved by an appropriate selection of post-treatment health-protection control measures.**

Excel macro security settings

Excel 2003

If, when you open one of the QMRA-MC programs, you do not see this Security Warning dialogue box … … … … … … … … .. … … .. … → the macro security level is set too high.

To correct this:

(1) open the program and click on 'Tools' and then on 'Options';

(2) click the 'Security' tab and then on 'Macro Security';

(3) you will now see this 'Security' dialogue box … … … … … … .. … →

(4) click the 'Security Level' tab (if necessary), then select the 'Medium' setting and click 'OK'.

Reference: 'Change the security level for macro virus protection', online at: http://office.microsoft.com/en-us/excel/HP052356701033.aspx.

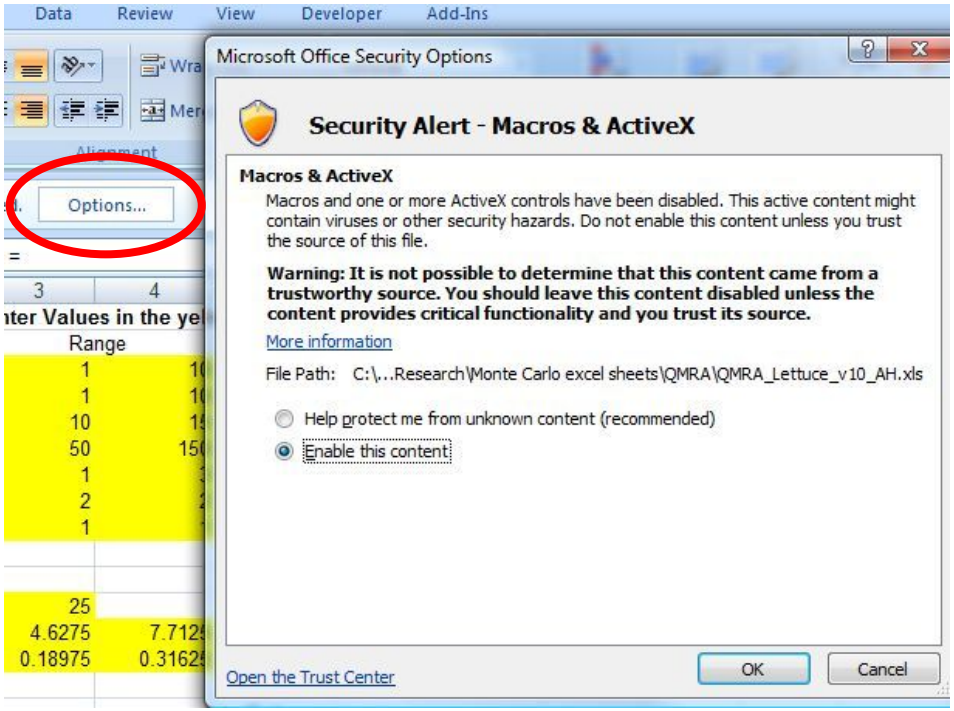
See next page for Excel 2007.

Excel macro security settings, continued

Excel 2007

If, when you open one of the QMRA-MC programs, you do not see this 'Options' box … … … … … ↘ (and hence are unable to get the Security Alert dialogue box shown), the macro security level is set too high.

To set the security setting to the correct level:
(1) open the program and click on the Microsoft Office Button in the top right corner;
(2) click 'Excel Options' at the bottom right of the dialogue box;
(3) click 'Trust Center' in the left-hand menu;
(4) click 'Trust Center Settings…'
(5) click 'Macro Settings', select 'Disable all macros with notification', and click 'OK'.



Reference: 'Change the security level for macro virus protection', online at: http://office.microsoft.com/en-us/excel/HP052356701033.aspx.

… and Finally, in case you're interested:

Why "Monte Carlo"?

"**Monte Carlo methods are useful for modeling phenomena with significant uncertainty in inputs, such as the calculation of risk.** … Physicists at Los Alamos Scientific Laboratory [in the 1940s] were investigating radiation shielding and the distance that neutrons would likely travel through various materials. Despite having most of the necessary data, such as the average distance a neutron would travel in a substance before it collided with an atomic nucleus or how much energy the neutron was likely to give off following a collision, the problem could not be solved with analytical calculations. John von Neumann and Stanislaw Ulam suggested that the problem be solved by modeling the experiment on a computer using chance. Being secret, their work required a code name. Von Neumann chose the name "Monte Carlo". The name is a reference to the Monte Carlo Casino in Monaco where Ulam's uncle would borrow money to gamble. … Monte Carlo methods were central to the simulations required for the Manhattan Project,[1] though were severely limited by the computational tools at the time. Therefore, it was only after electronic computers were first built (from 1945 on) that Monte Carlo methods began to be studied in depth. In the 1950s they were used at Los Alamos for early work relating to the development of the hydrogen bomb, and became popularized in the fields of physics, physical chemistry, and operations research."

Source: http://en.wikipedia.org/wiki/Monte_Carlo_method

[1] The Manhattan Project was the codename for the project which developed the first atomic bomb during World War II.