UNSW

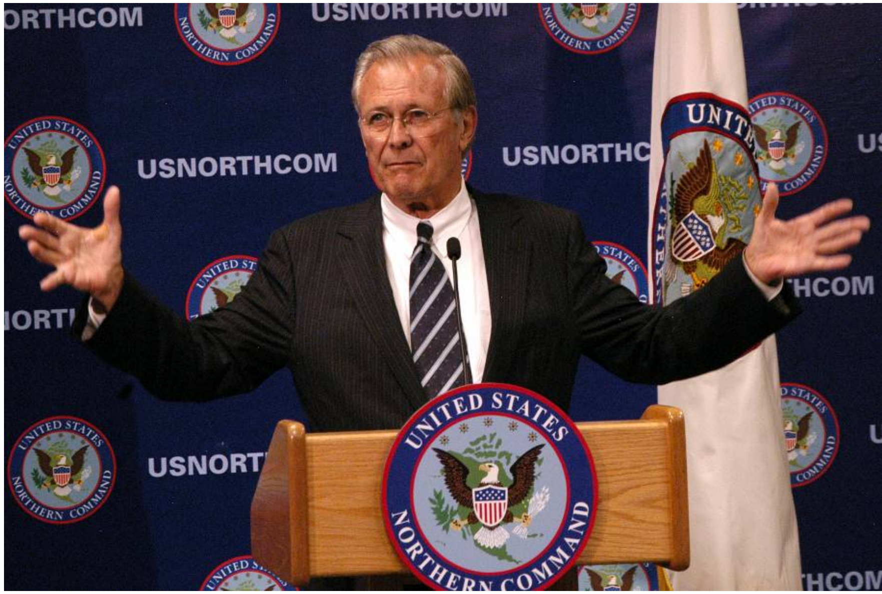
Monte Carlo Pathogen Risk Assessment Modeling in the Water Industry Using @ Risk

David J. Roser

School of Civil and Environmental Engineering UNSW

CENTRE FOR WATER & WASTE TECHNOLOGY

A Philosophy for @Risk Modellers? Rumsfeld's Postulates



- Known knowns
  - Contaminants we know we know (*Cryptosporidium)*
- Known unknowns
  - Contaminants we know we don't know (*Helicobacter)*
- Unknown unknowns
  - Contaminants we don't know we don't know (Prions??)
- Unknown knowns?
  - Contaminants we don't know we know (emergent pathogens)

Quantitative Microbial Risk Assessment (QMRA)

- @Risk Estimation of risks arising from exposure to pathogens
- @Risk Calculated for multiple exposure pathways
  - *based on **initial concentration**, **barrier reductions**, **consumption rate**, & **dose response** for **population/pathogens***
- @Risk Calculations use various PDFs to describe each stage in exposure path)
- @Risk Linked in series to get final risk estimate:
  - ***Disability Adjusted Life Years (1 μDALY)***
  - ***Infection probability (drinking 'benchmark' 10^{-4}.person^{-1}.y^{-1})***
  - ***Concentration of pathogen***

Paper Aims

For theoretical Basis for QRA/QMRA see Haas, Rose and Gerba 1999

@Risk Presentation focuses on applying QRA operationally Using @Risk as a TOOL within a larger scheme

1. Outline Infectious Disease and Water Issue
2. Why Quantitative modelling of water supply with @Risk
3. @Risk Application of Quantitative Risk Technology
4. @Risk Strategies for Addressing Use Challenges - making @Risk a Useful Day to Day Tool
5. @Risk @Risk Programming Nuts and Bolts

CENTRE FOR WATER & WASTE TECHNOLOGY

1. Infectious Diseases and Water

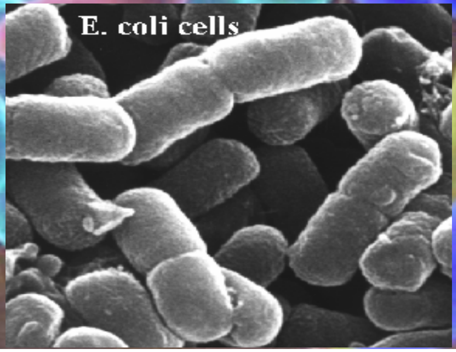
- The Culprits

- Past and Present Situation

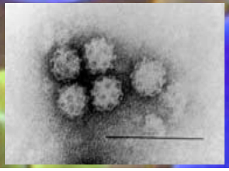
William Heath, 1828

Microbial Pathogens

Cryptosporidium oocysts – 3 um



Escherichia coli O157H7 – 1 um cells



Viruses – bar =0.1 um

Robert Koch about his observations in India (1884):

cholera was endemic in certain regions in Bengal, and localized around ponds and swamps with multiple uses by the inhabitants

Today still 1.1 billion with not clean drinking water

Today still 2.4 billion with no sanitation

source of drinking water

bathing

cleaning of household utensils

washing of clothes, including those of persons who had died of cholera

input of wastewater, human excreta

Outbreak of EHEC in Walkerton, Canada

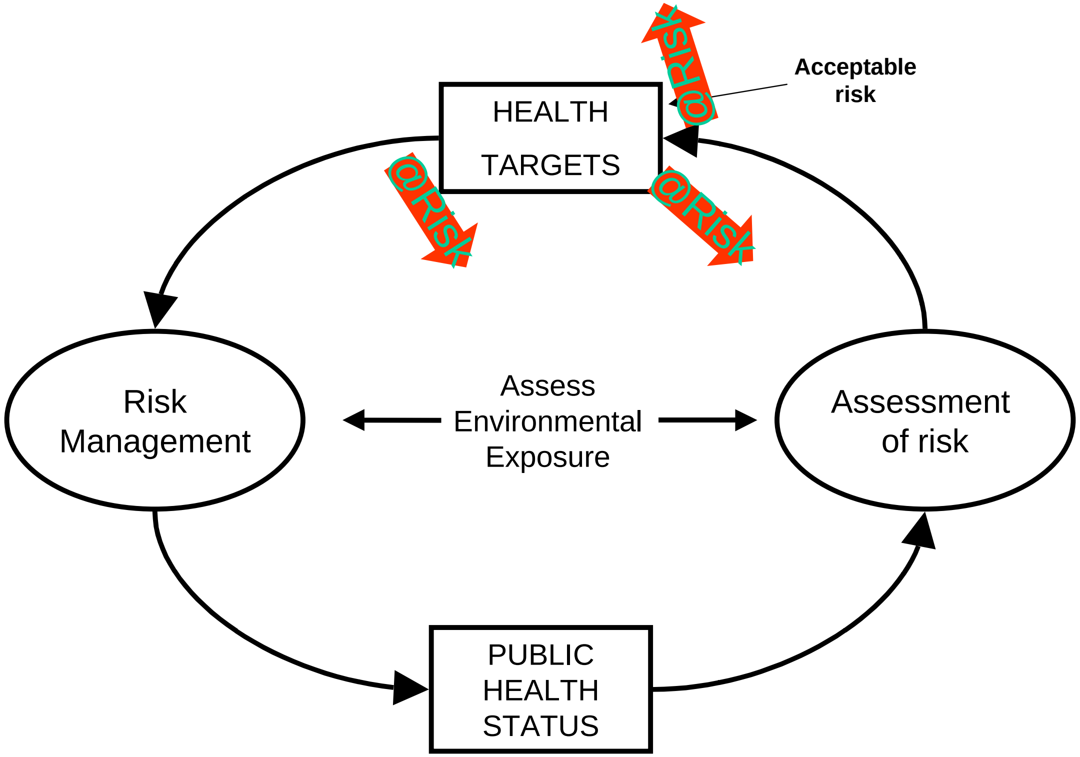
- Walkerton, Ontario (Canada) with 4,800 residents; in May 2000: more than 2,300 persons became ill, seven people died

- contamination of drinking water system with primarily *E. coli* O157:H7, but also *Campylobacter jejuni*
- primary source: manure that had been spread on a farm near a shallow well in an area of highly fractured bedrock
- outbreak 14 days after heavy rainfalls, which promoted contamination of wells
- failure of continuous chlorine and turbidity monitoring of water
- delay in reporting positive *E. coli* results in water samples

2. Why Quantitative Modelling Using @Risk

1. Guideline promotion of Risk Assessment based Management
2. Risk Principles and the Drive for Quantification
3. The Complexity problem

WHO Scheme for Water Quality Assessment and Management

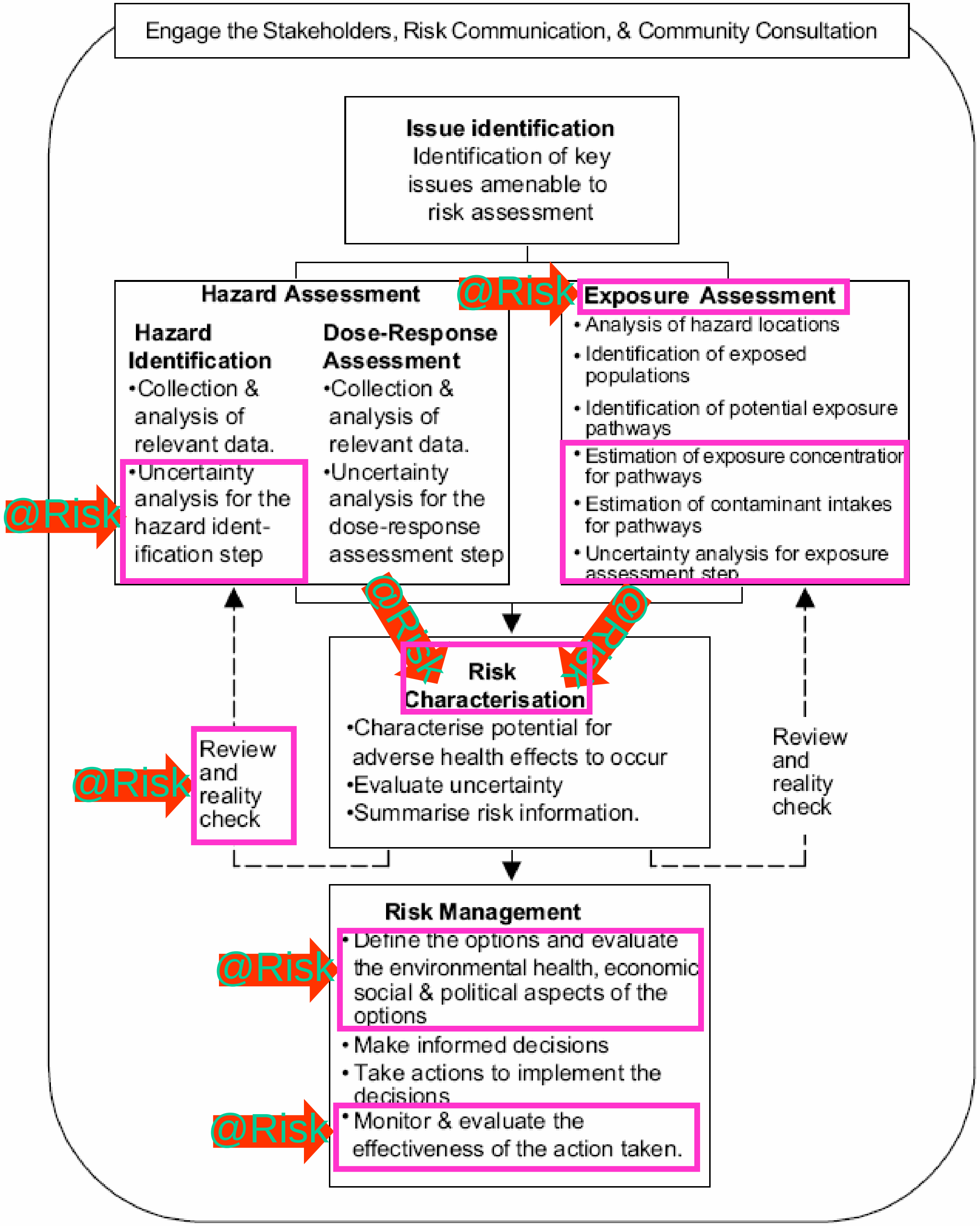


From: Fewtrell & Bartram, 2001. in Water Quality Guidelines, Standards and Health (WHO). IWA publishing.

CENTRE FOR WATER & WASTE TECHNOLOGY

Health Risk Assessment (EnHealth 2002)

- Use scheme to systematise work
- Data mining + gap filling (CWWT work)
- Requires:
  - Hazard assessment (research lit review)
  - Dose response (literature)
  - Exposure Pathway Assessment (Initial provides basis for research program)


Engage the Stakeholders, Risk Communication, & Community Consultation

Issue identification
Identification of key issues amenable to risk assessment

Hazard Assessment

Hazard Identification
- Collection & analysis of relevant data.
- Uncertainty analysis for the hazard identification step

Dose-Response Assessment
- Collection & analysis of relevant data.
- Uncertainty analysis for the dose-response assessment step

Exposure Assessment
- Analysis of hazard locations
- Identification of exposed populations
- Identification of potential exposure pathways
- Estimation of exposure concentration for pathways
- Estimation of contaminant intakes for pathways
- Uncertainty analysis for exposure assessment step

Risk Characterisation
- Characterise potential for adverse health effects to occur
- Evaluate uncertainty
- Summarise risk information.

Review and reality check

Review and reality check

Risk Management
- Define the options and evaluate the environmental health, economic social & political aspects of the options
- Make informed decisions
- Take actions to implement the decisions
- Monitor & evaluate the effectiveness of the action taken.

Example > Australian Drinking Water Guidelines

http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm

The Six Fundamental Principles (strategic)

Twelve elements (operations)

Framework Includes:

@Risk • HACCP - Hazard Analysis Critical Control Point

@Risk • AS/NZS 4360 - Risk Management

CENTRE FOR WATER & WASTE TECHNOLOGY

Principles 1 & 2

@Risk

- ***The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised.***

- ***The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.***

@Risk

CENTRE FOR WATER & WASTE TECHNOLOGY

Principles 3, 4 & 6

@Risk

- ***Any sudden or extreme change in water quality, flow or environmental conditions (eg extreme rainfall or flooding) should arouse suspicion that drinking water might become contaminated.***

- ***System operators must be able to respond quickly and effectively to adverse monitoring signals***

@Risk

- ***Ensuring drinking water safety and quality requires the application of a considered risk management approach***

@Risk

CENTRE FOR WATER & WASTE TECHNOLOGY

The 12 Elements of The Framework

1. Commitment to Drinking Water Quality Management

@Risk 2. Assessment of the Drinking Water Supply System

@Risk 3. Preventive Measures for DWQ Management

@Risk 4. Operational Procedures and Process Control

@Risk 5. Verification of Drinking Water Quality

@Risk 6. Management of Incidents and Emergencies

7. Employee Awareness and Training

8. Community Involvement and Awareness

@Risk 9. Research and Development

10. Documentation and Reporting

@Risk 11. Evaluation and Audit

@Risk 12. Review and Continual Improvement

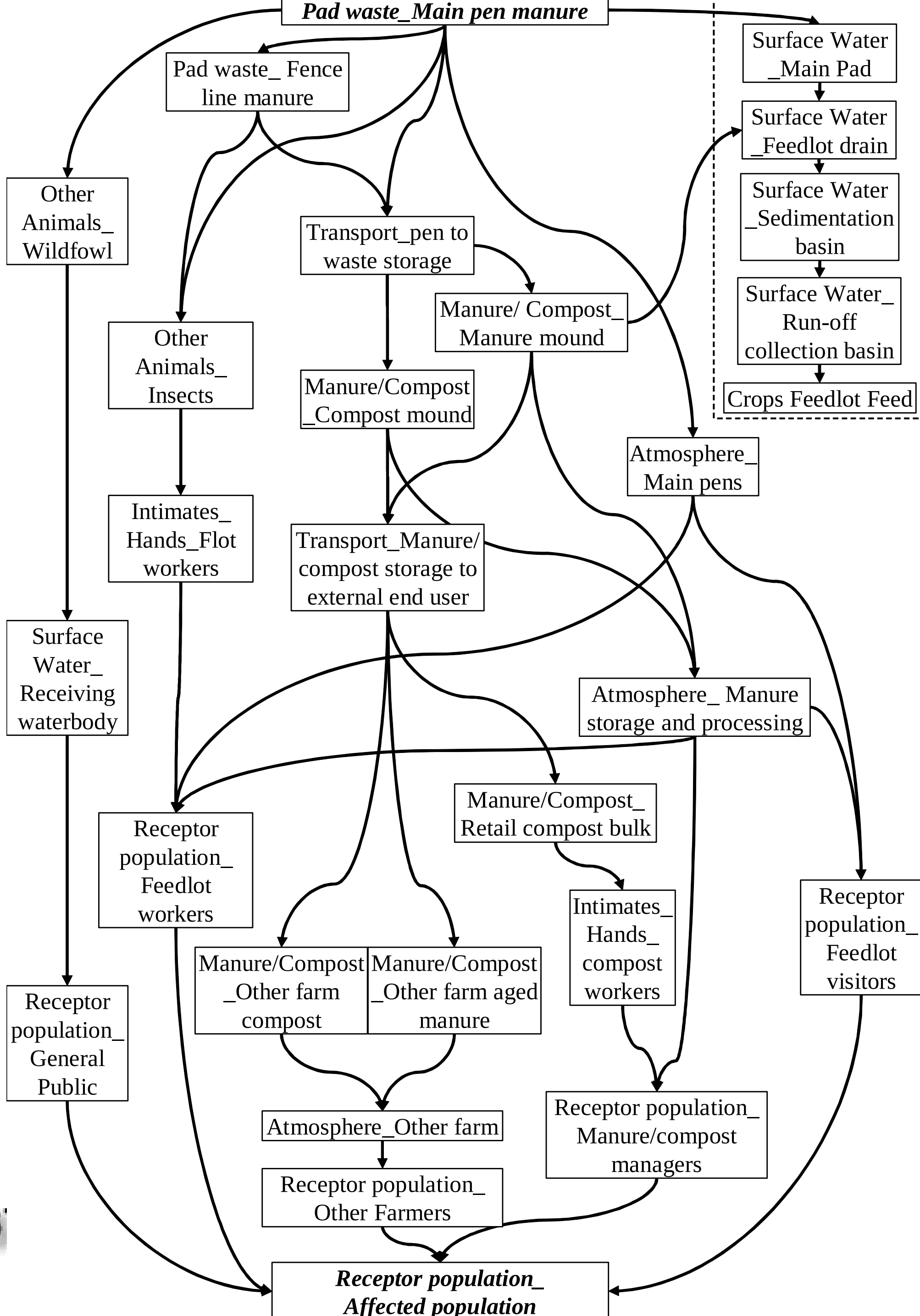
Definition of Risk

Risk = likelihood x consequence

Qualitative risk analysis matrix: level of risk for each hazardous event

Likelihood	**Consequences**				
	1 Insignificant	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
A (almost certain)	Moderate	High	Very high	Very high	Very high
B (likely)	Moderate	High	High	Very high	Very high
C (moderate)	Low	Moderate	High	Very high	Very high
D (unlikely)	Low	Low	Moderate	High	Very high
E (rare)	Low	Low	Moderate	High	High

Exposure Pathway Complexity (feedlot example)



Pad waste_Main pen manure

Pad waste_ Fence line manure

Other Animals_ Wildfowl

Transport_pen to waste storage

Manure/ Compost_ Manure mound

Other Animals_ Insects

Manure/Compost _Compost mound

Intimates_ Hands_Flot workers

Transport_Manure/ compost storage to external end user

Surface Water _Main Pad

Surface Water _Feedlot drain

Surface Water _Sedimentation basin

Surface Water_ Run-off collection basin

Crops Feedlot Feed

Atmosphere_ Main pens

Surface Water_ Receiving waterbody

Atmosphere_ Manure storage and processing

Manure/Compost_ Retail compost bulk

Receptor population_ Feedlot workers

Intimates_ Hands_ compost workers

Receptor population_ Feedlot visitors

Manure/Compost _Other farm compost

Manure/Compost _Other farm aged manure

Receptor population_ General Public

Atmosphere_Other farm

Receptor population_ Manure/compost managers

Receptor population_ Other Farmers

Receptor population_ Affected population

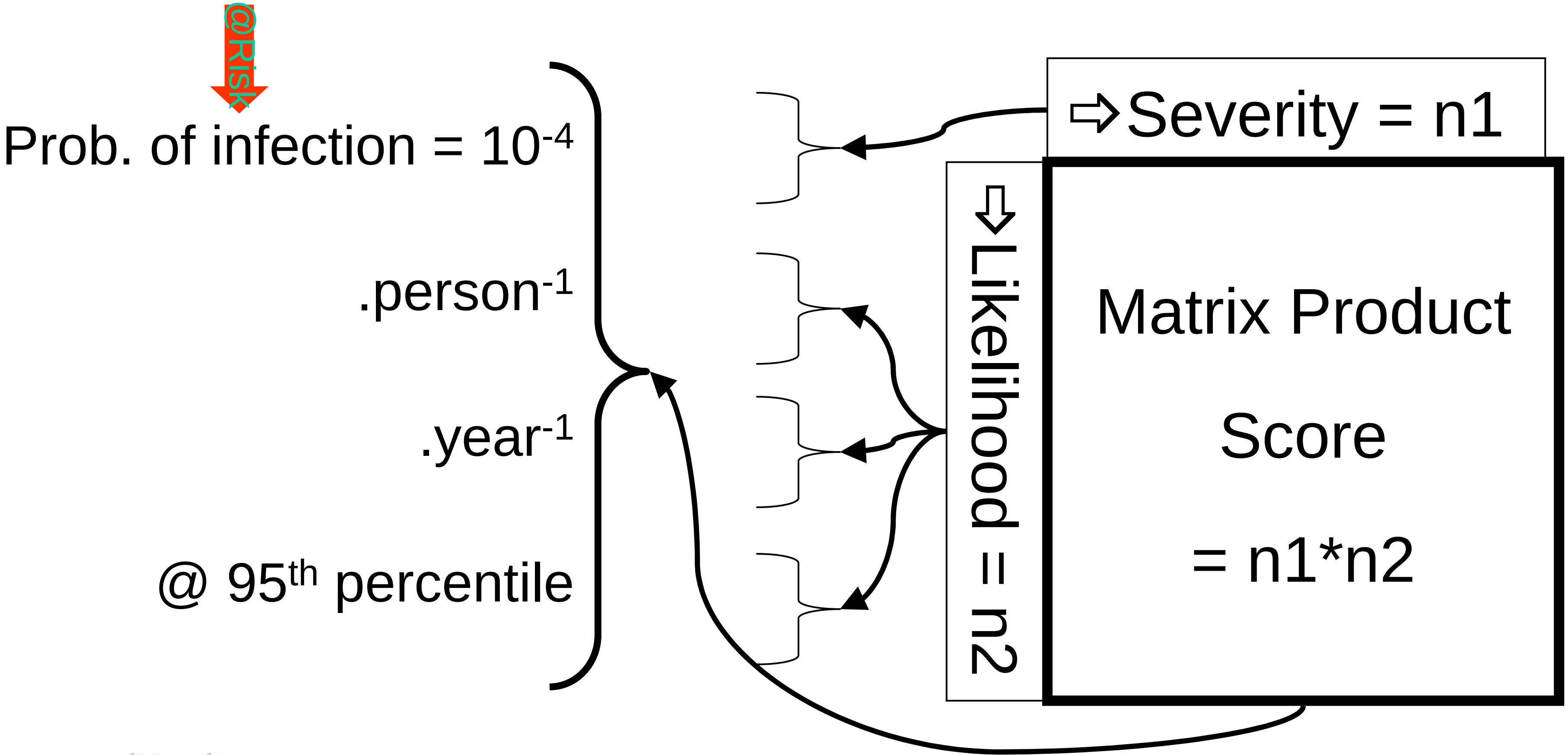
CENTRE FOR WATER & WAS

QMRA

(Decision Analysis)

Qualitative Risk Assessment

(Decision Intuition)



@Risk

Prob. of infection = 10^{-4}

.person^{-1}

.year^{-1}

@ 95th percentile

⇨Severity = n1

⇩Likelihood = n2

Matrix Product

Score

= n1*n2

@Risk

Other drivers for going ‘Quantitative’

- Can’t maintain zero risk fiction– need more objectivity & precision.
- More knowledge (pathogens, impacts, environment) and need to better utilise expensive data/study outcomes
- Need to define/quantify ‘safe’ in auditable fashion
- Ecological Sustainability Philosophy
  - Base natural resource use limits and ‘sustainability’ of exploitation on mathematics + science (e.g. Malthus, Ehrlich, Diamond)

CENTRE FOR WATER & WASTE TECHNOLOGY

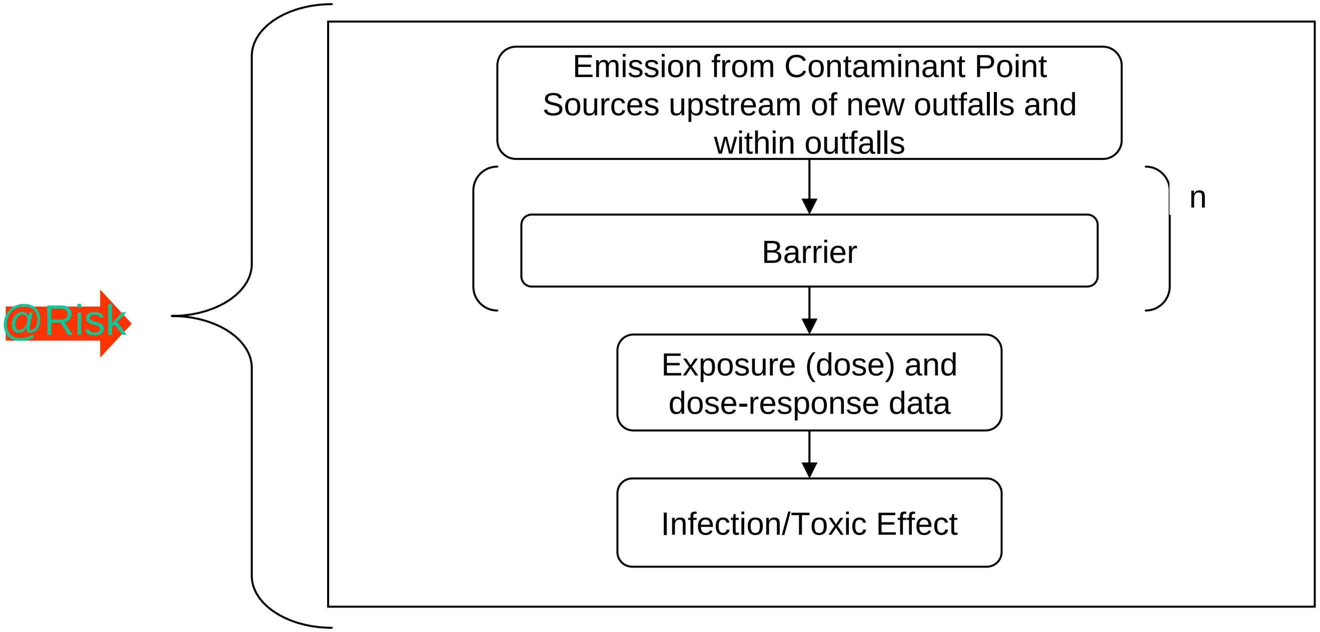
3. Application of Quantitative Risk Technology in the Water Industry

- Examples of Use
- The Barrier Concept
- Modelling challenges posed when attempted

Examples of Use

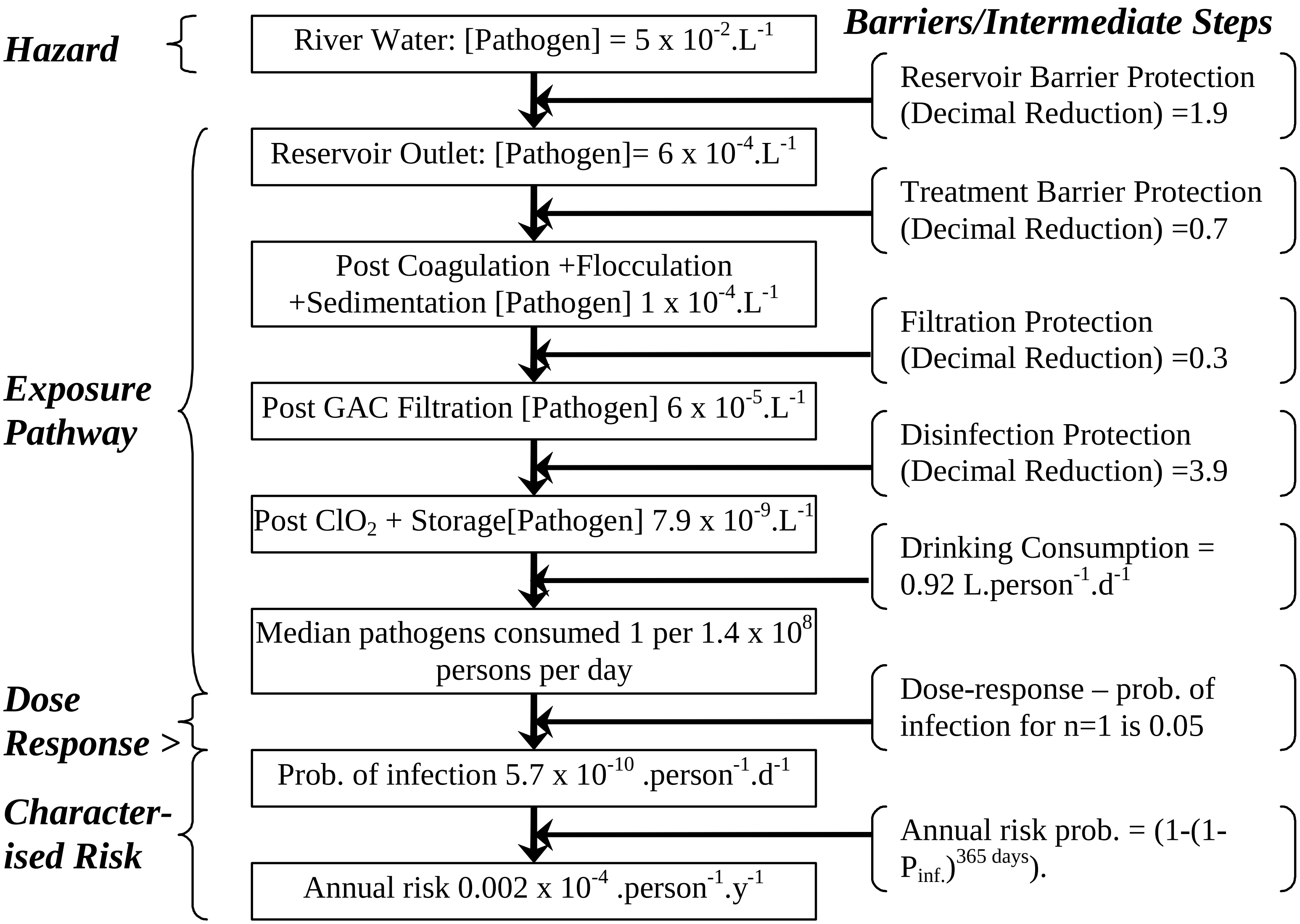
- Water Supplies supplies - EU MicroRisk (www.microrisk.com) - 14– *So many – need to ‘Industrialise’ QMRA?*
- Water Reuse - Flow Replacement *=Flow Augmentation*
- Recreational risk exposure - Lake Parramatta = *Bathing in stormwater/run-off*

The Barrier/Exposure Pathway Concept



@Risk

Integrated (“Holistic”) Exposure Pathway



Hazard

River Water: [Pathogen] = 5 x 10^{-2}.L^{-1}

Barriers/Intermediate Steps

Reservoir Barrier Protection (Decimal Reduction) =1.9

Exposure Pathway

Reservoir Outlet: [Pathogen]= 6 x 10^{-4}.L^{-1}

Treatment Barrier Protection (Decimal Reduction) =0.7

Post Coagulation +Flocculation +Sedimentation [Pathogen] 1 x 10^{-4}.L^{-1}

Filtration Protection (Decimal Reduction) =0.3

Post GAC Filtration [Pathogen] 6 x 10^{-5}.L^{-1}

Disinfection Protection (Decimal Reduction) =3.9

Post ClO_2 + Storage[Pathogen] 7.9 x 10^{-9}.L^{-1}

Drinking Consumption = 0.92 L.$person^{-1}$.d^{-1}

Median pathogens consumed 1 per 1.4 x 10^{8} persons per day

Dose Response >

Dose-response – prob. of infection for n=1 is 0.05

Prob. of infection 5.7 x 10^{-10} .$person^{-1}$.d^{-1}

Character-ised Risk

Annual risk prob. = $(1-(1-P_{inf.})^{365\ days})$.

Annual risk 0.002 x 10^{-4} .$person^{-1}$.y^{-1}

CENTRE FOR WATER & WASTE TECHNOLOGY

@Risk

Quantitative Risk Modelling Challenges

- Logistics (next slide)

- Specialisation
  - Institutional environmental assessors cant be experts in all software

- ‘Risk Assessment not Industrialized (MicroRisk)
  - Documentation of assumptions
  - Coping with multiple scenarios
  - Large numbers of similar but unique projects

- The allergy of senior managers to numbers
  - Detail distracting and often not informative
  - Opacity of high level models

CENTRE FOR WATER & WASTE TECHNOLOGY

@Risk

Logistics

~Infinite Permutations and Combinations

- Pathogens
- Exposure Scenarios
- Hazardous Events (multiple?)
- Barrier functions
- Environment (season, load)
- Populations
- Hydrology
- Multiple Exposure Pathways

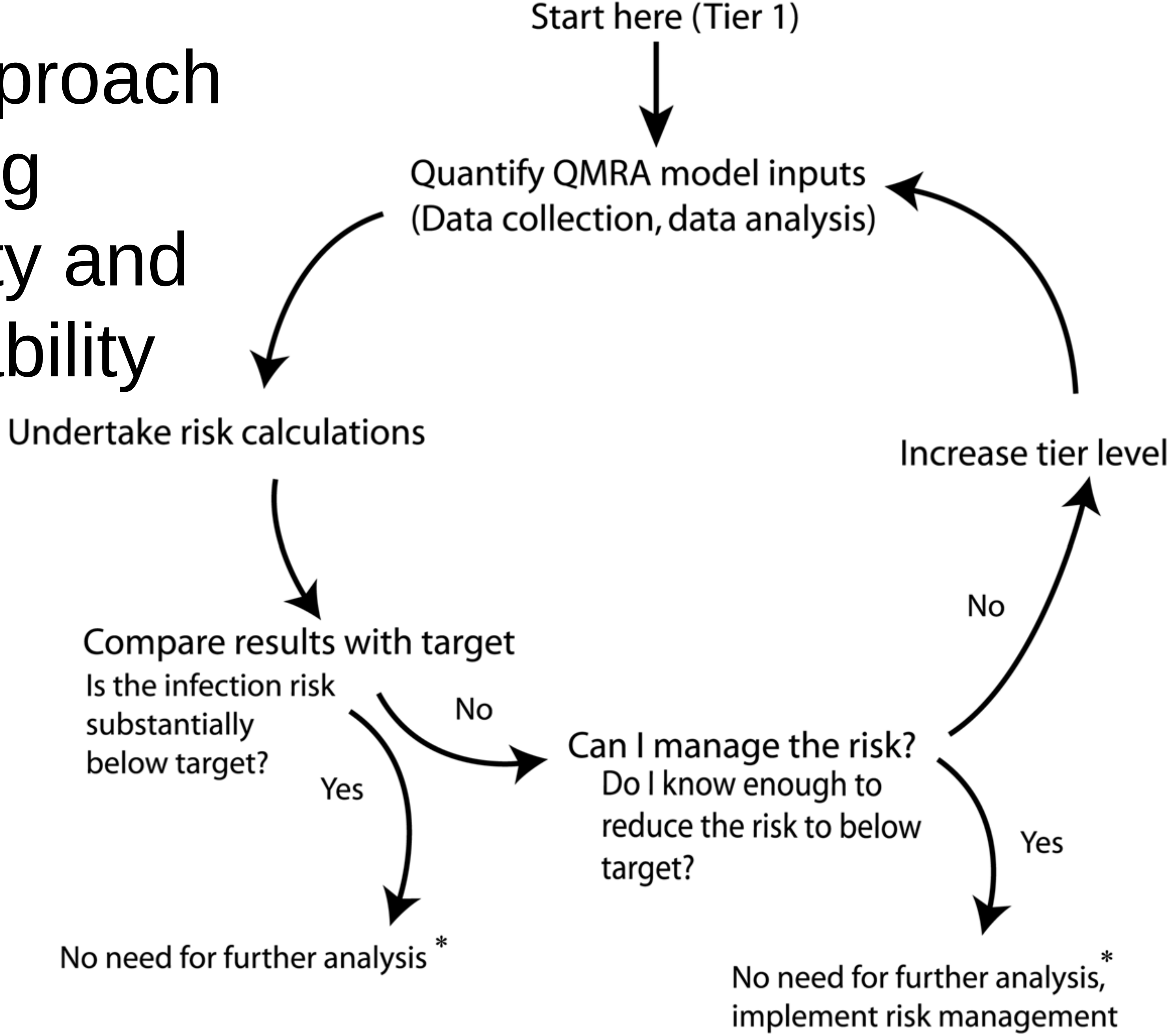
4. Strategies for making @Risk a Useful Day to Day Tool

- Programming strategy
- Tiered Approach
- Linking Risk Characterisation to Risk Management Information Needs (HRA scheme)

Programming strategies

- Use of Metamodel Approach (central calculation engine + library of @Risk submodels – accessed like lookup tables)
- Construction of Informative (easily revised) Scenarios
- Separation of Baseline and ‘Hazardous Events’ (deal with one bit at a time)
- Scenarios based on Exposure Pathway/Barrier Assessment > drives input parameter data mining

Tiered approach in reducing uncertainty and data variability



Start here (Tier 1)

Quantify QMRA model inputs (Data collection, data analysis)

Undertake risk calculations

Compare results with target

Is the infection risk substantially below target?

Yes

No need for further analysis *

No

Can I manage the risk?

Do I know enough to reduce the risk to below target?

Yes

No need for further analysis, * implement risk management

No

Increase tier level

CENTR

---

* The risk level of the system should be reviewed at a regular interval according to the relevant risk management protocol

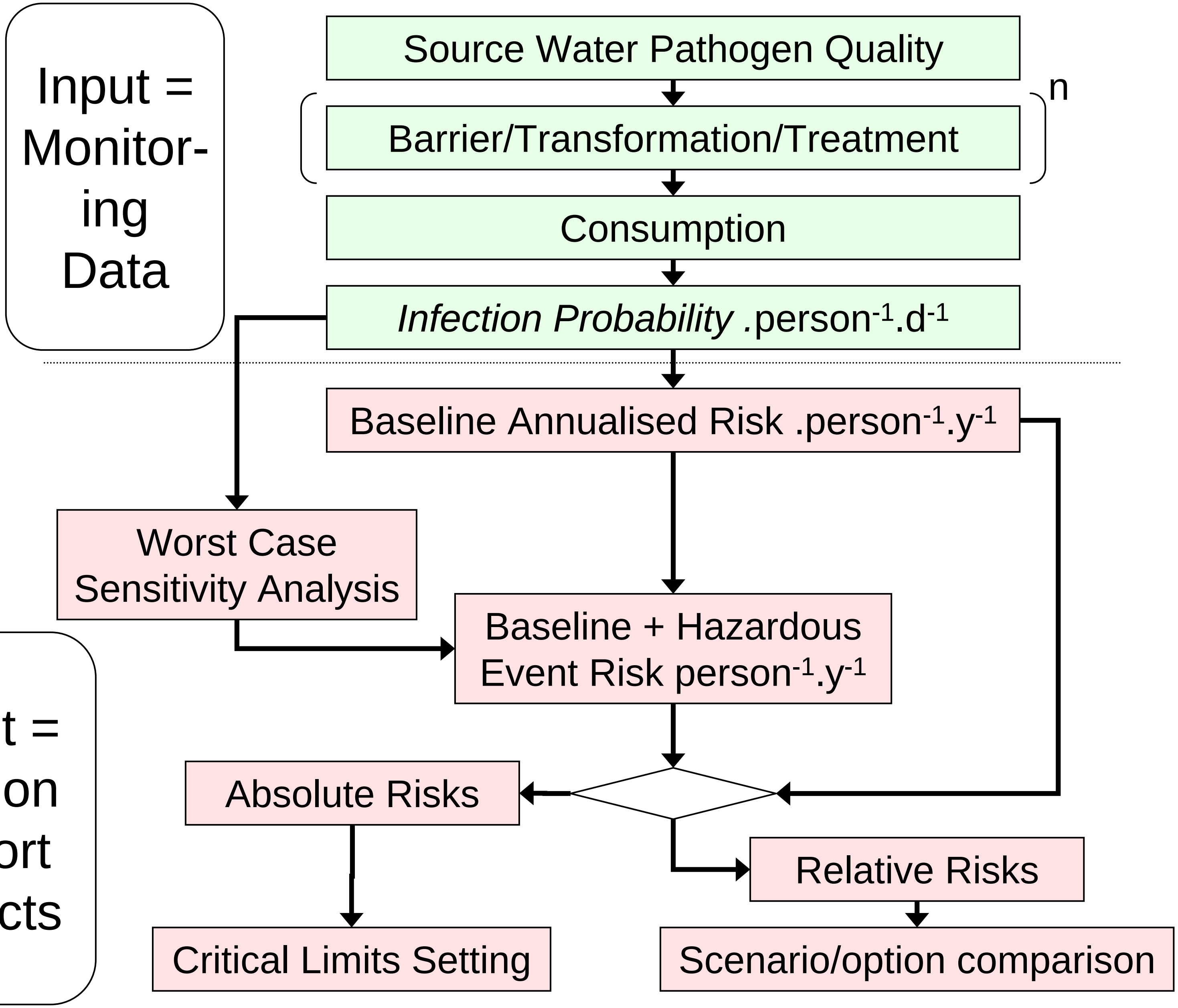
Managing the Risk Assessment

- Use style
  - ***For Decision Support***
  - ***Address questions/hypotheses/what if?***
  - ***Critical limit development (from HACCP)***
- Use of reference/baseline scenarios
  - ***High ('event') Risk/Concurrent Failure Modelling***
- High Priority Foci
  - ***large population, worst environment, major exposure points, priority pathways***
- 'Industrialise' Risk Assessment
  - ***hydrology example - what is possible / what not to do***
- Develop Operational Assessment System

5. @Risk Programming – the Nuts and Bolts

- Inputs and Outputs Scheme
- Baseline > Sensitivity > Events > Critical Limits
- Programming with Excel and @ Risk
- Program illustration
- Cautionary notes

Linking Data and Decisions



Input = Monitoring Data

Source Water Pathogen Quality

Barrier/Transformation/Treatment

n

Consumption

Infection Probability .person^{-1}.d^{-1}

Baseline Annualised Risk .person^{-1}.y^{-1}

Worst Case Sensitivity Analysis

Baseline + Hazardous Event Risk person^{-1}.y^{-1}

Absolute Risks

Relative Risks

Critical Limits Setting

Scenario/option comparison

Output = Decision Support Products

CENTRE FOR WATER & WASTE TECHNOLOGY

Campylobacter Risk Sweden 2

Critical Stage	Stage Transformation Units and Modal Value	Output after Transformation	
Source Water	-	Pathogen. L^{-1}	4.7×10^{-2}
Reservoir	Decimal Reduction = 1.87		6.3×10^{-4}
Coag./Floc./Sediment	Decimal Reduction = 0.73		1.2×10^{-4}
GAC Filtration	Decimal Reduction = 0.28		6.3×10^{-5}
ClO_2 + Storage	Decimal Reduction = 3.9		7.9×10^{-9}
Consumption	$L.d^{-1}$ consumed = 0.92		7.4×10^{-9}
Dose Response	(infectious dose *ca* 10 organisms)	Infection prob.	5.7×10^{-10} $.person^{-1}.d^{-1}$
Annualized Rate (@Risk simulated values)	Annualization $(1-(1-Pinf.)^{365\ days})$		2×10^{-7} $.person^{-1}.y^{-1}$

CENTRE FOR WATER & WASTE TECHNOLOGY

Baseline Infection Rates

Measure	**Water Supply system**	**Pathogen**					
		Crypto-sporidium	*Giardia*	*Campylo-bacter*	*E. coli* O157	*Norovirus*	Enterovirus
95th %ile Annualized Probability (10^{-4}.person^{-1}.y^{-1})	Australia 1	***0.68***	6.7E-06	***0.29***		-	-
	UK 1	***0.16***	1.7E-06	1.21E-07	1.9E-08	-	1.51E-06
	Sweden 1	**2200**	***0.44***	***0.84***	**-**	***(19)***	(3.0)
	Sweden 2	**334**	***1.40***	0.012	-	(0.66)	(0.082)

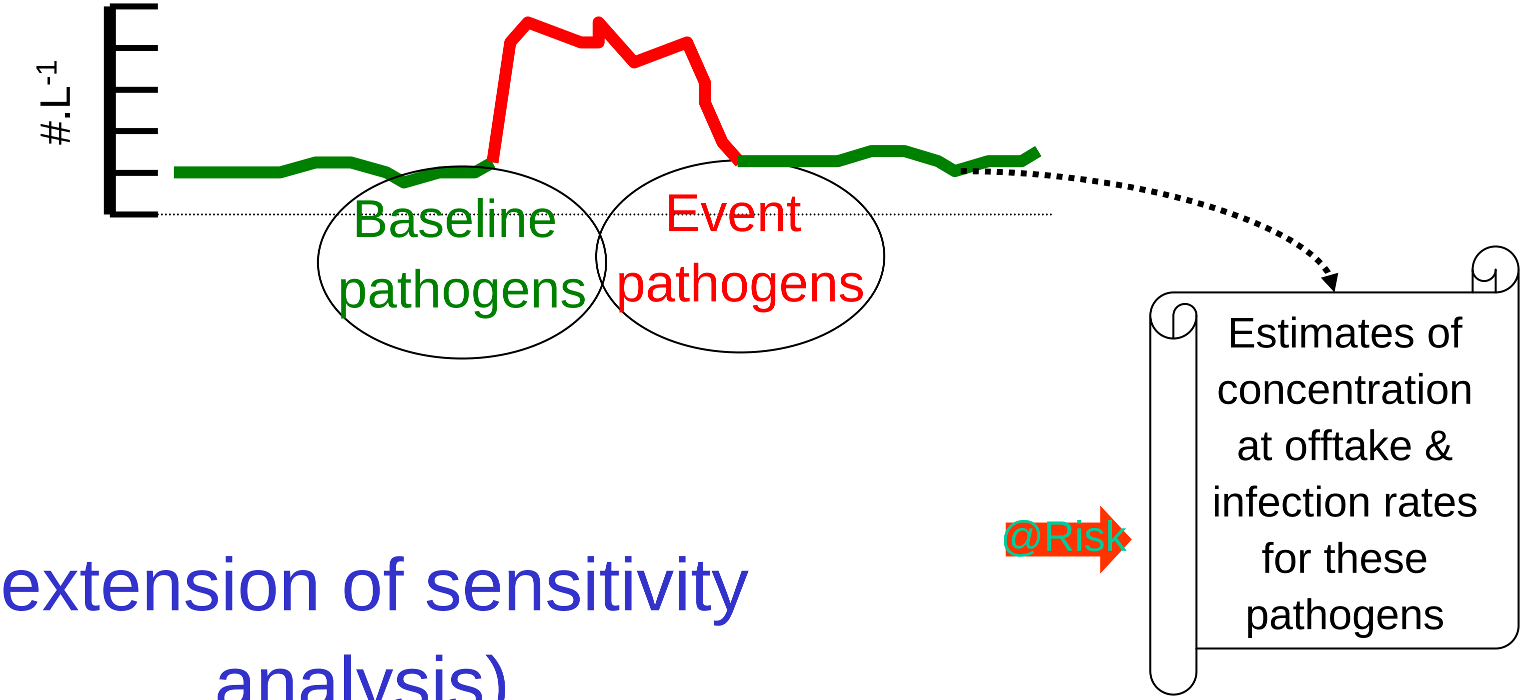
Notes: 1. Infection rates in brackets are based on 95th percentile source water concentration data

2. Bold + underlined = of high concern, Bold + Italics marginal concern

CENTRE FOR WATER & WASTE TECHNOLOGY

Assigning the origin of Pathogens to Baseline v. Event Conditions

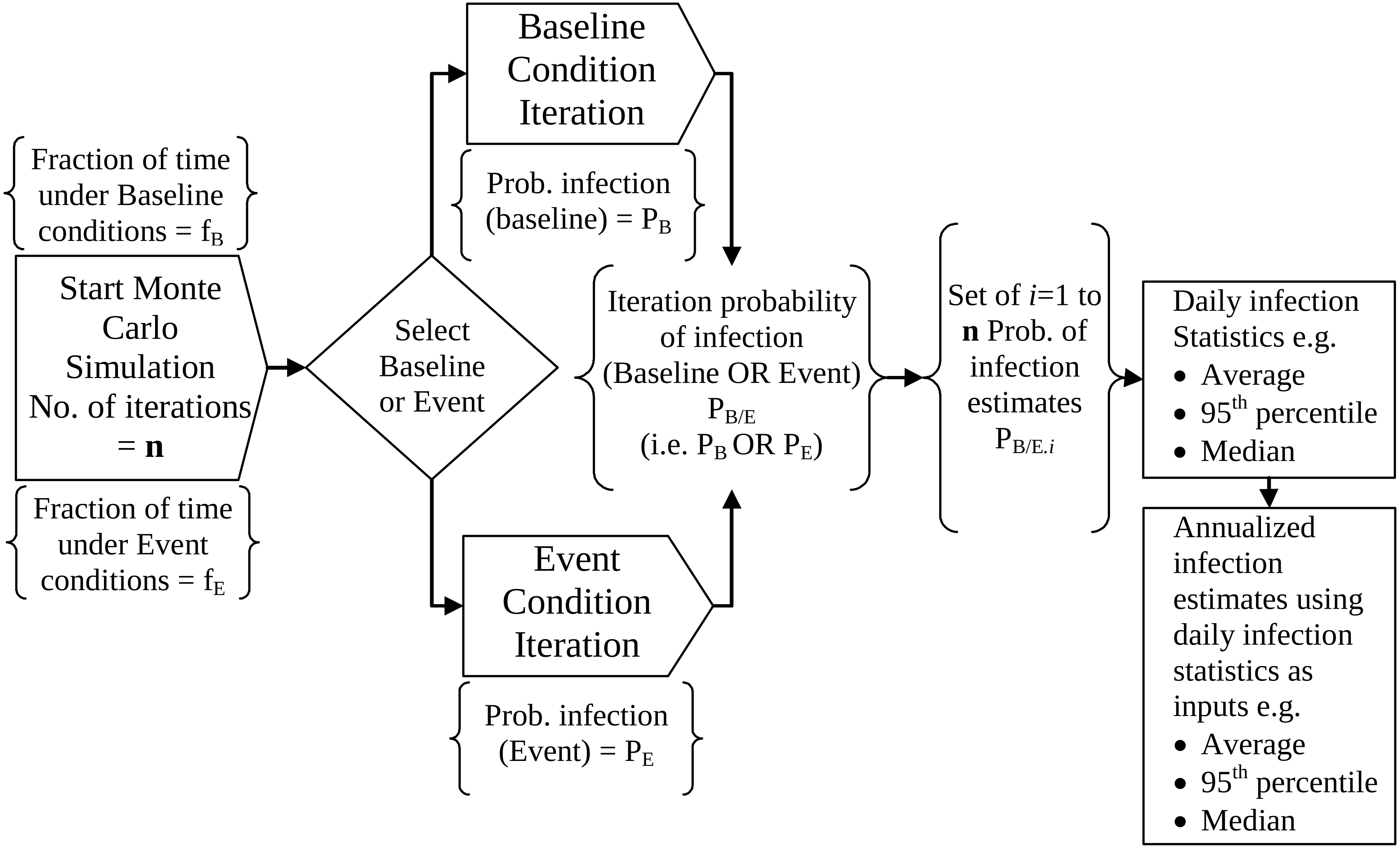
Small River



Estimates of concentration at offtake & infection rates for these pathogens

(extension of sensitivity analysis)

Concurrent Baseline and Event Simulation with @Risk



Fraction of time under Baseline conditions = f_B

Start Monte Carlo Simulation No. of iterations = **n**

Fraction of time under Event conditions = f_E

Select Baseline or Event

Baseline Condition Iteration

Prob. infection (baseline) = P_B

Event Condition Iteration

Prob. infection (Event) = P_E

Iteration probability of infection (Baseline OR Event) $P_{B/E}$ (i.e. P_B OR P_E)

Set of i=1 to **n** Prob. of infection estimates $P_{B/E.i}$

Daily infection Statistics e.g.

- Average
- 95th percentile
- Median

Annualized infection estimates using daily infection statistics as inputs e.g.

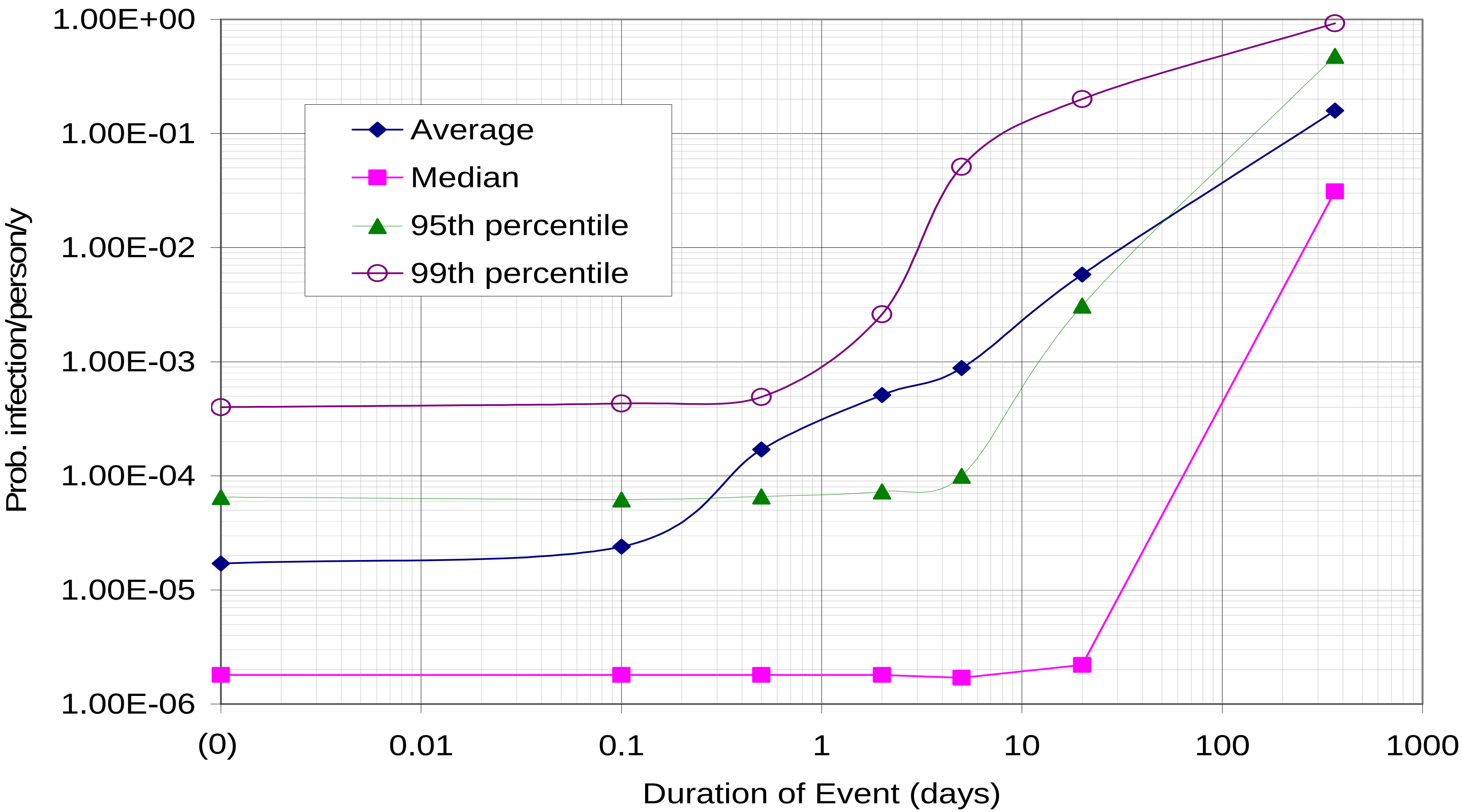
- Average
- 95th percentile
- Median

CENTRE FOR WATER & WASTE TECHNOLOGY

Average Annualised Risk person^{-1}.y^{-1} for swimming (illustrates hazardous events issue)

Scenario Summary Description	**High Flow Penrith Recreation (26 days)**	**Low Flow Penrith Recreation (26 days)**	**Low Flow Penrith Recreation (26 days) +MF/RO failure**
Cryptosporidium	2.94E-13	6.31E-12	-
Campylobacter	2.41E-09	5.29E-08	**7.49E-02**
Rotavirus	2.46E-08	5.30E-07	**9.05E-02**

Infection risk in response to simulated chlorination failure (illustrates critical limit issue)



CENTRE FOR WATER & WASTE TECHNOLOGY

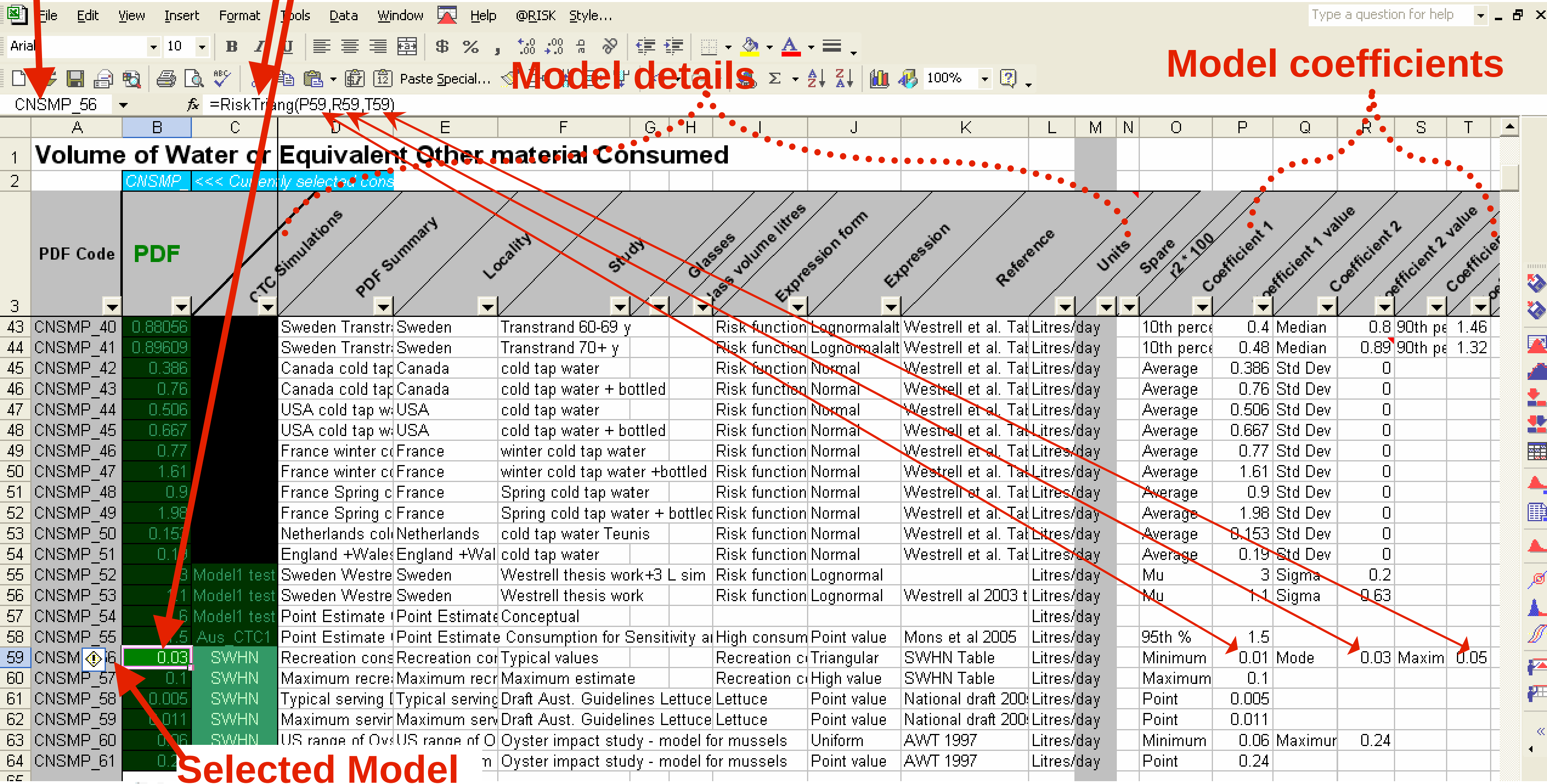
Model Code

The Metamodel Library

@Risk Probability Density function

Model details

Model coefficients



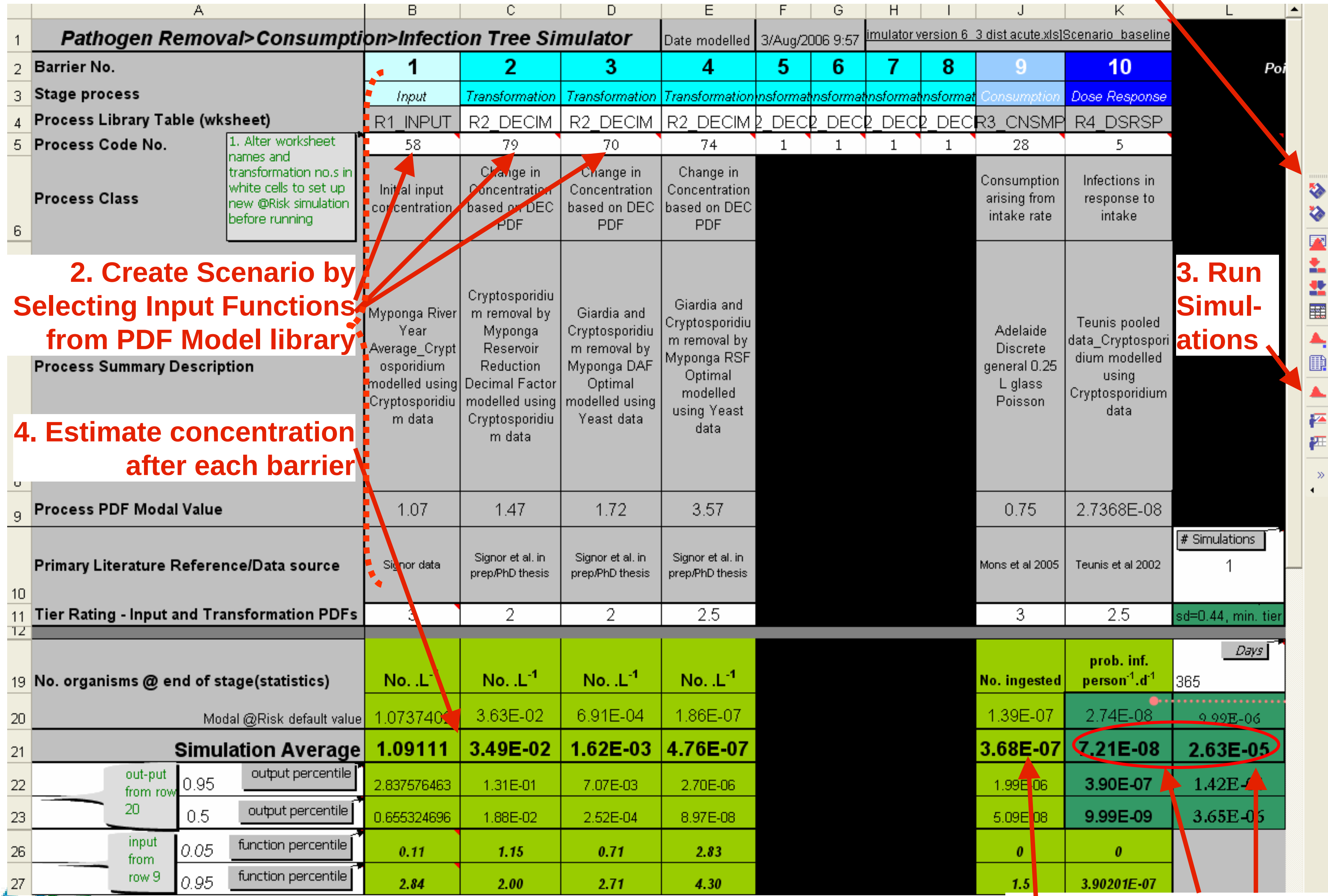
CNSMP_56 =RiskTriang(P59,R59,T59)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	**Volume of Water or Equivalent Other material Consumed**																			
2		CNSMP_	<<< Currently selected cons																	
3	**PDF Code**	**PDF**	CTC Simulations	PDF Summary	Locality	Study	Glasses	lass volume litres	Expression form	Expression	Reference	Units	Spare	r2 * 100	Coefficient 1	oefficient 1 value	Coefficient 2	oefficient 2 value	Coefficie	oe
43	CNSMP_40	0.88056		Sweden Transtr	Sweden	Transtrand 60-69 y			Risk function	Lognormalalt	Westrell et al. Ta	Litres/day			10th perce	0.4	Median	0.8	90th pe	1.46
44	CNSMP_41	0.89609		Sweden Transtr	Sweden	Transtrand 70+ y			Risk function	Lognormalalt	Westrell et al. Ta	Litres/day			10th perce	0.48	Median	0.89	90th pe	1.32
45	CNSMP_42	0.386		Canada cold tap	Canada	cold tap water			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.386	Std Dev	0		
46	CNSMP_43	0.76		Canada cold tap	Canada	cold tap water + bottled			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.76	Std Dev	0		
47	CNSMP_44	0.506		USA cold tap w	USA	cold tap water			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.506	Std Dev	0		
48	CNSMP_45	0.667		USA cold tap w	USA	cold tap water + bottled			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.667	Std Dev	0		
49	CNSMP_46	0.77		France winter c	France	winter cold tap water			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.77	Std Dev	0		
50	CNSMP_47	1.61		France winter c	France	winter cold tap water +bottled			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	1.61	Std Dev	0		
51	CNSMP_48	0.9		France Spring c	France	Spring cold tap water			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.9	Std Dev	0		
52	CNSMP_49	1.98		France Spring c	France	Spring cold tap water + bottle			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	1.98	Std Dev	0		
53	CNSMP_50	0.153		Netherlands col	Netherlands	cold tap water Teunis			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.153	Std Dev	0		
54	CNSMP_51	0.19		England +Wales	England +Wal	cold tap water			Risk function	Normal	Westrell et al. Ta	Litres/day			Average	0.19	Std Dev	0		
55	CNSMP_52	3	Model1 test	Sweden Westre	Sweden	Westrell thesis work+3 L sim			Risk function	Lognormal		Litres/day			Mu	3	Sigma	0.2		
56	CNSMP_53	1.1	Model1 test	Sweden Westre	Sweden	Westrell thesis work			Risk function	Lognormal	Westrell al 2003 t	Litres/day			Mu	1.1	Sigma	0.63		
57	CNSMP_54	6	Model1 test	Point Estimate	Point Estimate	Conceptual						Litres/day								
58	CNSMP_55	1.5	Aus_CTC1	Point Estimate	Point Estimate	Consumption for Sensitivity a			High consum	Point value	Mons et al 2005	Litres/day			95th %	1.5				
59	CNSMP_56	0.03	SWHN	Recreation cons	Recreation co	Typical values			Recreation c	Triangular	SWHN Table	Litres/day			Minimum	0.01	Mode	0.03	Maxim	0.05
60	CNSMP_57	0.1	SWHN	Maximum recre	Maximum recr	Maximum estimate			Recreation c	High value	SWHN Table	Litres/day			Maximum	0.1				
61	CNSMP_58	0.005	SWHN	Typical serving	Typical serving	Draft Aust. Guidelines Lettuce			Lettuce	Point value	National draft 200	Litres/day			Point	0.005				
62	CNSMP_59	0.011	SWHN	Maximum servi	Maximum serv	Draft Aust. Guidelines Lettuce			Lettuce	Point value	National draft 200	Litres/day			Point	0.011				
63	CNSMP_60	0.06	SWHN	US range of Oys	US range of O	Oyster impact study - model for mussels				Uniform	AWT 1997	Litres/day			Minimum	0.06	Maximu	0.24		
64	CNSMP_61	0.2	[illegible]	[illegible]	[illegible]	Oyster impact study - model for mussels				Point value	AWT 1997	Litres/day			Point	0.24				

Selected Model

CENTRE FOR WATER & WASTE TECHNOLOGY

EXCEL Scenario MetaModel



1. @Risk Add in for Monte Carlo Simulations

2. Create Scenario by Selecting Input Functions from PDF Model library

3. Run Simul-ations

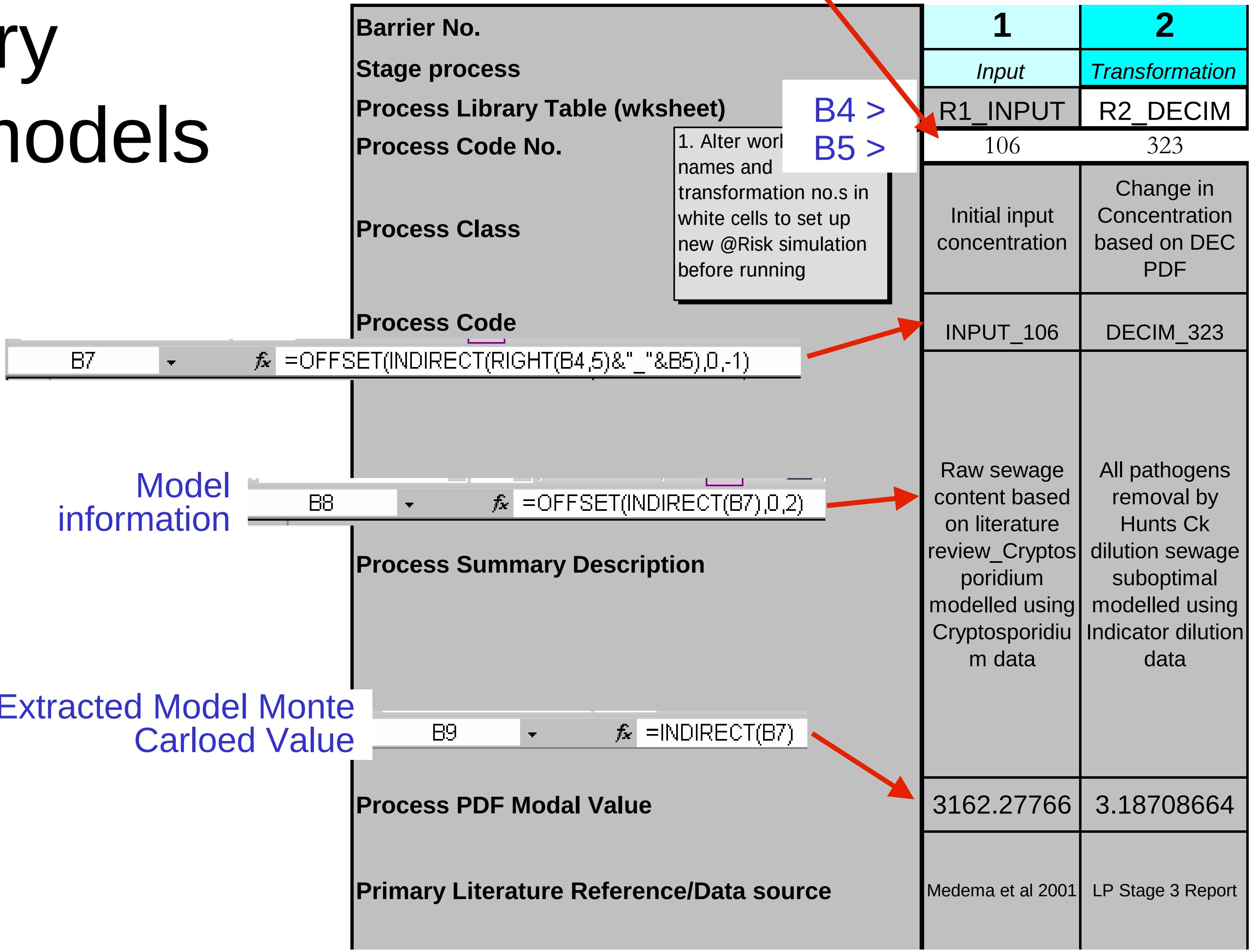
4. Estimate concentration after each barrier

5. Output risk probability statistics and pathogen numbers

	A	B	C	D	E	F	G	H	I	J	K	L
1	*Pathogen Removal>Consumption>Infection Tree Simulator*				Date modelled	3/Aug/2006 9:57		imulator version 6_3 dist acute.xls]Scenario_baseline				
2	**Barrier No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	*Poi*
3	**Stage process**	*Input*	*Transformation*	*Transformation*	*Transformation*	*nsformat*	*nsformat*	*nsformat*	*nsformat*	*Consumption*	*Dose Response*	
4	**Process Library Table (wksheet)**	R1_INPUT	R2_DECIM	R2_DECIM	R2_DECIM	2_DEC	2_DEC	2_DEC	2_DEC	R3_CNSMP	R4_DSRSP	
5	**Process Code No.** 1. Alter worksheet names and transformation no.s in white cells to set up new @Risk simulation before running	58	79	70	74	1	1	1	1	28	5	
6	**Process Class**	Initial input concentration	Change in Concentration based on DEC PDF	Change in Concentration based on DEC PDF	Change in Concentration based on DEC PDF					Consumption arising from intake rate	Infections in response to intake	
8	**Process Summary Description**	Myponga River Year Average_Cryptosporidium modelled using Cryptosporidium data	Cryptosporidium removal by Myponga Reservoir Reduction Decimal Factor modelled using Cryptosporidium data	Giardia and Cryptosporidium removal by Myponga DAF Optimal modelled using Yeast data	Giardia and Cryptosporidium removal by Myponga RSF Optimal modelled using Yeast data					Adelaide Discrete general 0.25 L glass Poisson	Teunis pooled data_Cryptosporidium modelled using Cryptosporidium data	
9	**Process PDF Modal Value**	1.07	1.47	1.72	3.57					0.75	2.7368E-08	
10	**Primary Literature Reference/Data source**	Signor data	Signor et al. in prep/PhD thesis	Signor et al. in prep/PhD thesis	Signor et al. in prep/PhD thesis					Mons et al 2005	Teunis et al 2002	# Simulations 1
11	**Tier Rating - Input and Transformation PDFs**	3	2	2	2.5					3	2.5	sd=0.44, min. tier
12												
19	**No. organisms @ end of stage(statistics)**	**No. .L**	**No. .L^{-1}**	**No. .L^{-1}**	**No. .L^{-1}**					**No. ingested**	**prob. inf. person^{-1}.d^{-1}**	*Days* 365
20	Modal @Risk default value	1.073740	3.63E-02	6.91E-04	1.86E-07					1.39E-07	2.74E-08	9.99E-06
21	**Simulation Average**	**1.09111**	**3.49E-02**	**1.62E-03**	**4.76E-07**					**3.68E-07**	**7.21E-08**	**2.63E-05**
22	out-put from row 20 · 0.95 · output percentile	2.837576463	1.31E-01	7.07E-03	2.70E-06					1.99E-06	**3.90E-07**	**1.42E-**
23	0.5 · output percentile	0.655324696	1.88E-02	2.52E-04	8.97E-08					5.09E-08	**9.99E-09**	**3.65E-05**
26	input from row 9 · 0.05 · function percentile	***0.11***	***1.15***	***0.71***	***2.83***					***0***	***0***	
27	0.95 · function percentile	***2.84***	***2.00***	***2.71***	***4.30***					***1.5***	***3.90201E-07***	

Extracting Library Submodels

Selecting the submodel



B4 >
B5 >

1. Alter worl names and transformation no.s in white cells to set up new @Risk simulation before running

Barrier No.	1	2
Stage process	*Input*	*Transformation*
Process Library Table (wksheet)	R1_INPUT	R2_DECIM
Process Code No.	106	323
Process Class	Initial input concentration	Change in Concentration based on DEC PDF
Process Code	INPUT_106	DECIM_323
Process Summary Description	Raw sewage content based on literature review_Cryptosporidium modelled using Cryptosporidium data	All pathogens removal by Hunts Ck dilution sewage suboptimal modelled using Indicator dilution data
Process PDF Modal Value	3162.27766	3.18708664
Primary Literature Reference/Data source	Medema et al 2001	LP Stage 3 Report

Model name & Reference Cell

B7 `=OFFSET(INDIRECT(RIGHT(B4,5)&"_"&B5),0,-1)`

Model information

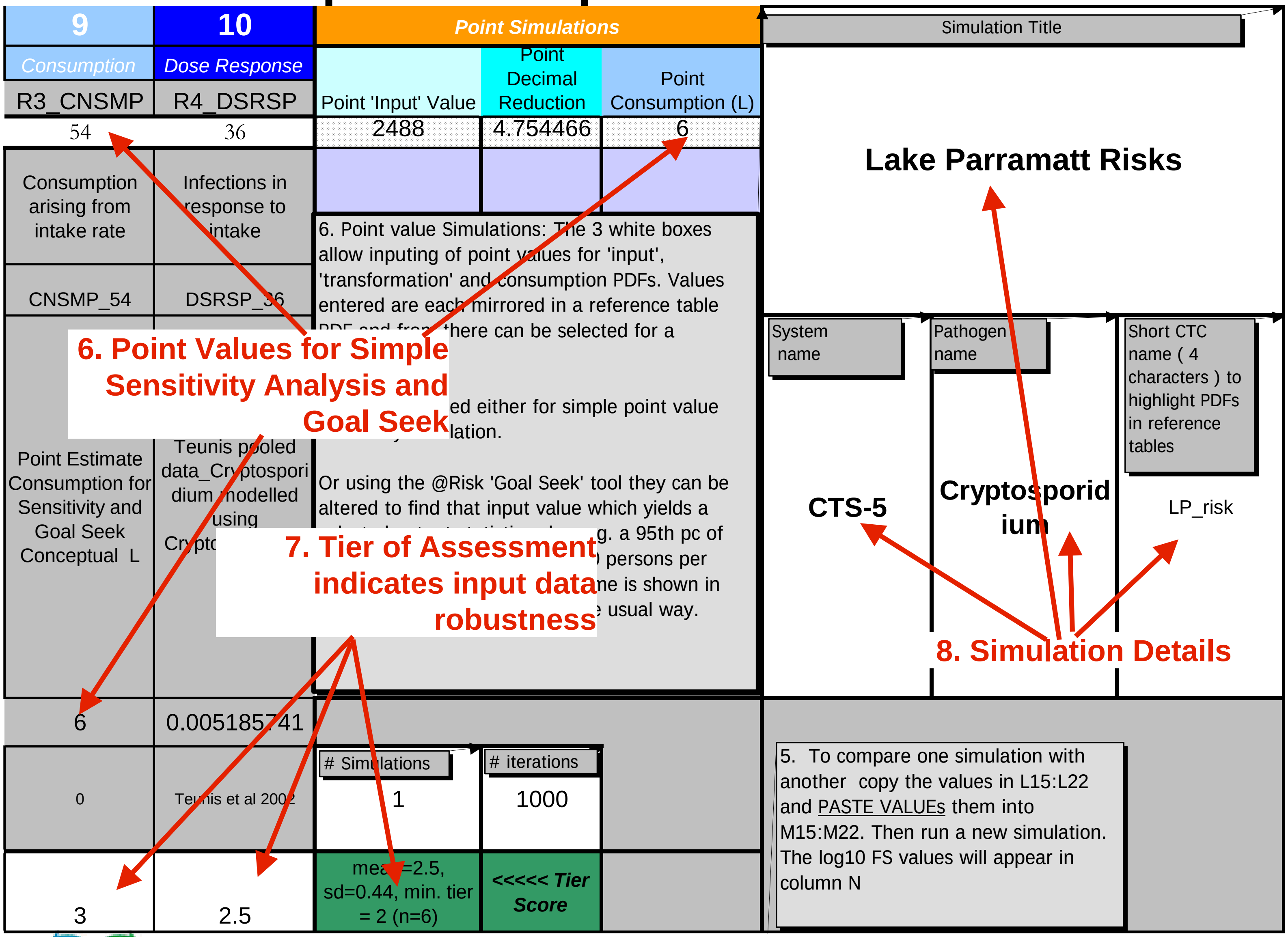
B8 `=OFFSET(INDIRECT(B7),0,2)`

Extracted Model Monte Carloed Value

B9 `=INDIRECT(B7)`

CENTRE FOR WATER & WASTE TECHNOLOGY

Other Input/Outputs



9	10
Consumption	Dose Response
R3_CNSMP	R4_DSRSP
54	36
Consumption arising from intake rate	Infections in response to intake
CNSMP_54	DSRSP_36
Point Estimate Consumption for Sensitivity and Goal Seek Conceptual L	Teunis pooled data_Cryptosporidium modelled using Crypto
6	0.005185741
0	Teunis et al 2002
3	2.5

Point Simulations

Point 'Input' Value	Point Decimal Reduction	Point Consumption (L)
2488	4.754466	6

6. Point value Simulations: The 3 white boxes allow inputing of point values for 'input', 'transformation' and consumption PDFs. Values entered are each mirrored in a reference table PDF and from there can be selected for a

ed either for simple point value lation.

Or using the @Risk 'Goal Seek' tool they can be altered to find that input value which yields a g. a 95th pc of persons per ne is shown in usual way.

# Simulations	# iterations
1	1000
mean=2.5, sd=0.44, min. tier = 2 (n=6)	**<<<<< Tier Score**

Simulation Title

Lake Parramatt Risks

System name	Pathogen name	Short CTC name (4 characters) to highlight PDFs in reference tables
CTS-5	**Cryptosporidium**	LP_risk

5. To compare one simulation with another copy the values in L15:L22 and PASTE VALUEs them into M15:M22. Then run a new simulation. The log10 FS values will appear in column N

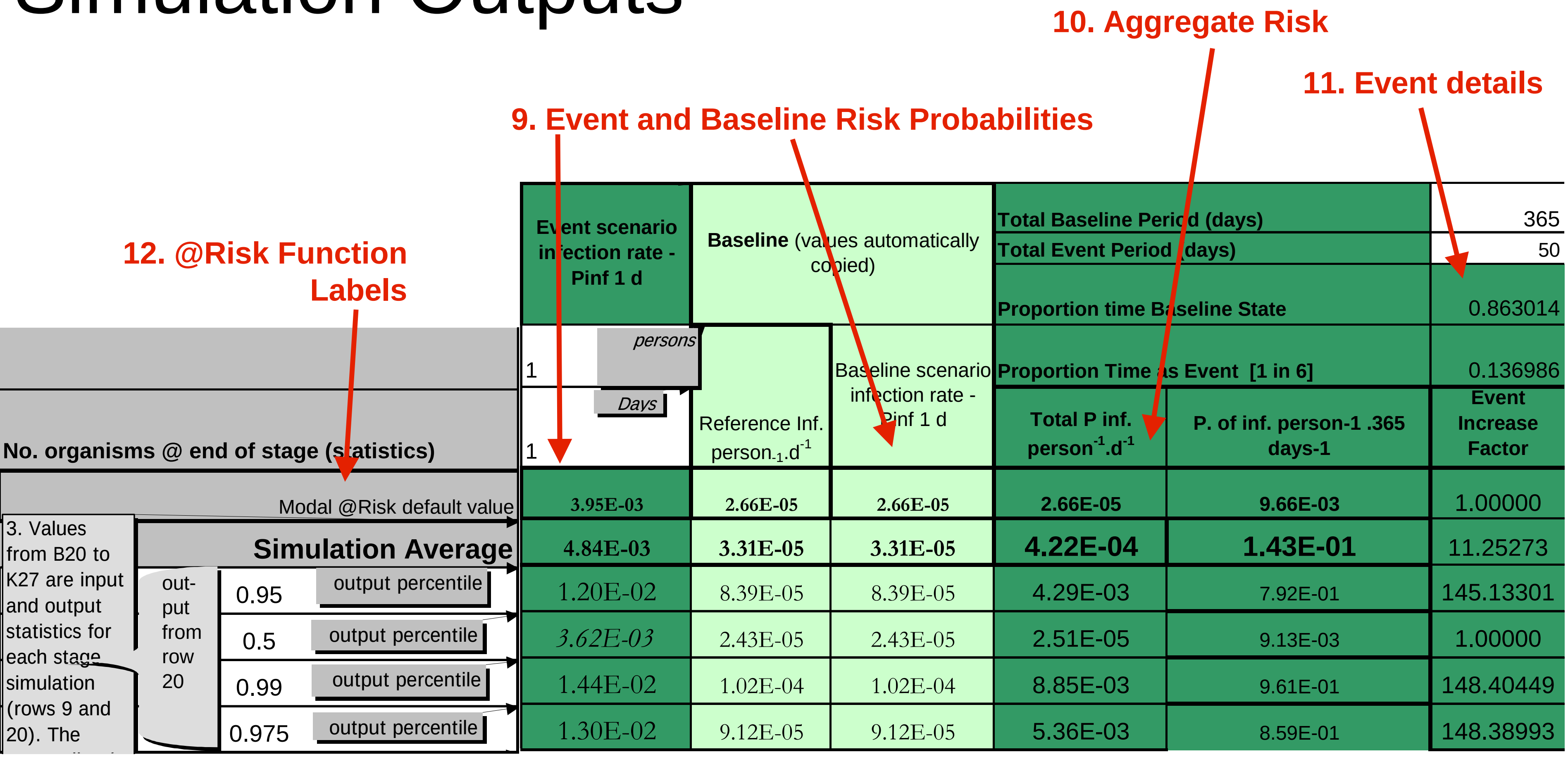
6. Point Values for Simple Sensitivity Analysis and Goal Seek

7. Tier of Assessment indicates input data robustness

8. Simulation Details

CENTRE FOR WATER & WASTE TECHNOLOGY

Baseline + Hazardous Event Simulation Outputs



10. Aggregate Risk

11. Event details

9. Event and Baseline Risk Probabilities

12. @Risk Function Labels

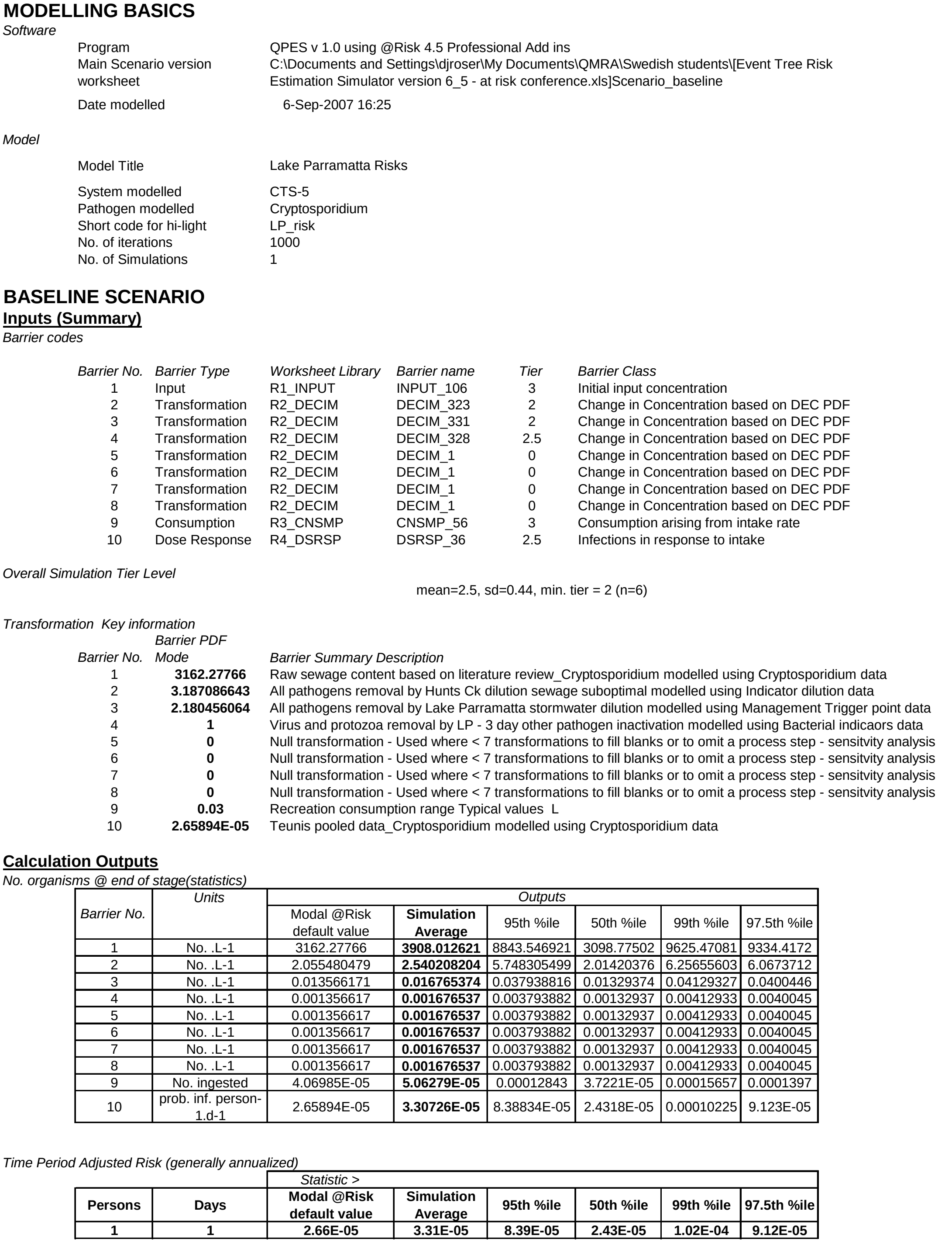
Total Baseline Period (days)		365
Total Event Period (days)		50
Proportion time Baseline State		0.863014
Proportion Time as Event [1 in 6]		0.136986

		Event scenario infection rate - Pinf 1 d	**Baseline** (values automatically copied)				
	persons	1					
No. organisms @ end of stage (statistics)	Days	1	Reference Inf. person$_{-1}$.d^{-1}	Baseline scenario infection rate - Pinf 1 d	Total P inf. person^{-1}.d^{-1}	P. of inf. person-1 .365 days-1	Event Increase Factor
Modal @Risk default value		3.95E-03	2.66E-05	2.66E-05	2.66E-05	9.66E-03	1.00000
Simulation Average		4.84E-03	3.31E-05	3.31E-05	4.22E-04	1.43E-01	11.25273
0.95	output percentile	1.20E-02	8.39E-05	8.39E-05	4.29E-03	7.92E-01	145.13301
0.5	output percentile	3.62E-03	2.43E-05	2.43E-05	2.51E-05	9.13E-03	1.00000
0.99	output percentile	1.44E-02	1.02E-04	1.02E-04	8.85E-03	9.61E-01	148.40449
0.975	output percentile	1.30E-02	9.12E-05	9.12E-05	5.36E-03	8.59E-01	148.38993

out-put from row 20

3. Values from B20 to K27 are input and output statistics for each stage simulation (rows 9 and 20). The

Reporting



MODELLING BASICS

Software

Program	QPES v 1.0 using @Risk 4.5 Professional Add ins
Main Scenario version worksheet	C:\Documents and Settings\djroser\My Documents\QMRA\Swedish students\[Event Tree Risk Estimation Simulator version 6_5 - at risk conference.xls]Scenario_baseline
Date modelled	6-Sep-2007 16:25

Model

Model Title	Lake Parramatta Risks
System modelled	CTS-5
Pathogen modelled	Cryptosporidium
Short code for hi-light	LP_risk
No. of iterations	1000
No. of Simulations	1

BASELINE SCENARIO

Inputs (Summary)

Barrier codes

Barrier No.	*Barrier Type*	*Worksheet Library*	*Barrier name*	*Tier*	*Barrier Class*
1	Input	R1_INPUT	INPUT_106	3	Initial input concentration
2	Transformation	R2_DECIM	DECIM_323	2	Change in Concentration based on DEC PDF
3	Transformation	R2_DECIM	DECIM_331	2	Change in Concentration based on DEC PDF
4	Transformation	R2_DECIM	DECIM_328	2.5	Change in Concentration based on DEC PDF
5	Transformation	R2_DECIM	DECIM_1	0	Change in Concentration based on DEC PDF
6	Transformation	R2_DECIM	DECIM_1	0	Change in Concentration based on DEC PDF
7	Transformation	R2_DECIM	DECIM_1	0	Change in Concentration based on DEC PDF
8	Transformation	R2_DECIM	DECIM_1	0	Change in Concentration based on DEC PDF
9	Consumption	R3_CNSMP	CNSMP_56	3	Consumption arising from intake rate
10	Dose Response	R4_DSRSP	DSRSP_36	2.5	Infections in response to intake

Overall Simulation Tier Level

mean=2.5, sd=0.44, min. tier = 2 (n=6)

Transformation Key information

Barrier No.	*Barrier PDF Mode*	*Barrier Summary Description*
1	**3162.27766**	Raw sewage content based on literature review_Cryptosporidium modelled using Cryptosporidium data
2	**3.187086643**	All pathogens removal by Hunts Ck dilution sewage suboptimal modelled using Indicator dilution data
3	**2.180456064**	All pathogens removal by Lake Parramatta stormwater dilution modelled using Management Trigger point data
4	**1**	Virus and protozoa removal by LP - 3 day other pathogen inactivation modelled using Bacterial indicaors data
5	**0**	Null transformation - Used where < 7 transformations to fill blanks or to omit a process step - sensitvity analysis
6	**0**	Null transformation - Used where < 7 transformations to fill blanks or to omit a process step - sensitvity analysis
7	**0**	Null transformation - Used where < 7 transformations to fill blanks or to omit a process step - sensitvity analysis
8	**0**	Null transformation - Used where < 7 transformations to fill blanks or to omit a process step - sensitvity analysis
9	**0.03**	Recreation consumption range Typical values L
10	**2.65894E-05**	Teunis pooled data_Cryptosporidium modelled using Cryptosporidium data

Calculation Outputs

No. organisms @ end of stage(statistics)

Barrier No.	*Units*	*Outputs*					
		Modal @Risk default value	**Simulation Average**	95th %ile	50th %ile	99th %ile	97.5th %ile
1	No. .L-1	3162.27766	**3908.012621**	8843.546921	3098.77502	9625.47081	9334.4172
2	No. .L-1	2.055480479	**2.540208204**	5.748305499	2.01420376	6.25655603	6.0673712
3	No. .L-1	0.013566171	**0.016765374**	0.037938816	0.01329374	0.04129327	0.0400446
4	No. .L-1	0.001356617	**0.001676537**	0.003793882	0.00132937	0.00412933	0.0040045
5	No. .L-1	0.001356617	**0.001676537**	0.003793882	0.00132937	0.00412933	0.0040045
6	No. .L-1	0.001356617	**0.001676537**	0.003793882	0.00132937	0.00412933	0.0040045
7	No. .L-1	0.001356617	**0.001676537**	0.003793882	0.00132937	0.00412933	0.0040045
8	No. .L-1	0.001356617	**0.001676537**	0.003793882	0.00132937	0.00412933	0.0040045
9	No. ingested	4.06985E-05	**5.06279E-05**	0.00012843	3.7221E-05	0.00015657	0.0001397
10	prob. inf. person-1.d-1	2.65894E-05	**3.30726E-05**	8.38834E-05	2.4318E-05	0.00010225	9.123E-05

Time Period Adjusted Risk (generally annualized)

		Statistic >					
Persons	**Days**	**Modal @Risk default value**	**Simulation Average**	**95th %ile**	**50th %ile**	**99th %ile**	**97.5th %ile**
1	**1**	**2.66E-05**	**3.31E-05**	**8.39E-05**	**2.43E-05**	**1.02E-04**	**9.12E-05**

Run Simulation Scenario (time permiting)

- Lake Parramatta Bathing
- Infection risk probability:
  - – normal
  - – & with contaminated water *ca* 20% of the time

QMRA Limitations v. Strengths

- Strengths (some of many)
  - Easily conceptualised outputs
  - Hypothesis testing possible
  - Exploration of scenarios, Events, management actions
  - Numerical Critical Limit Definition
  - Whole of system analysis possible
  - Promotes use in management of objective scientific data and systematic identification of knowledge gaps
- Limitations <u>(not limitations of @Risk but output interpretation)</u>
  - Not reality
  - PDF selection can be challenging
  - Various ‘Known unknowns’ e.g. pathogen viability and subpopulations
  - Order of magnitude precision only – may overestimate risk?

QUESTIONS