Freshwater - Fresh Thinking

Enhancing impact assessment in water management

nzaia

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Applying Quantitative Microbial Risk Assessment to Prediction of Human Health Effects in Freshwaters: State-of-Play

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NIWA
Taihoro Nukurangi

QMRA

- Focusses on pathogens
- A young science
- Attempts to quantify human health risks, allowing for
  - Variability
    - Length of swims, pathogen concentration, shellfish meal size,…
  - Uncertainty
    - Concerning dose-response
- Uses Monte Carlo statistical iterative method
- End result is a risk profile, not just a risk number
  - Explicitly accounts for possibility of rare impact events
- Choose endpoint: infection or illness?
- Use alongside faecal indicator bacteria
  - Setting context
  - Implementation

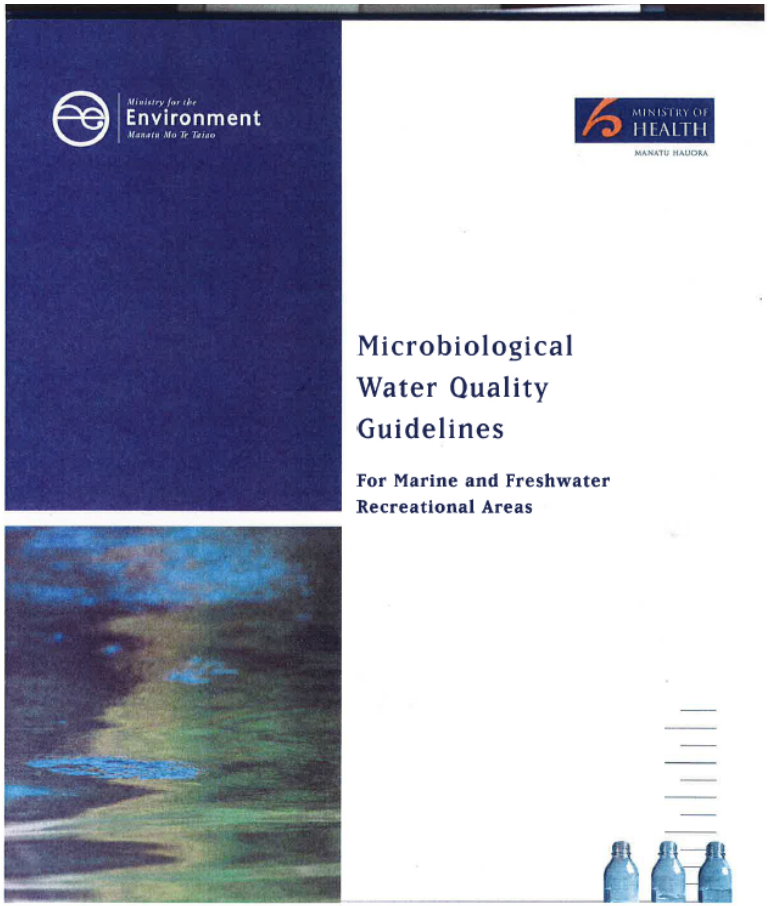
Why not stick with FIBs?

- Faecal Indicator Bacteria (FIB) breakpoints based on results of overseas epidemiological studies
  - May not be so appropriate in NZ
  - Not reliable when near to treated wastewater discharges, multiple sources—see page 4 of guidelines
  - Can't easily distinguish one source from another
- In many NZ sites pathogens are zoonotic (not anthropogenic), so transfer of FIB results confounded
- QMRA can distinguish sources and compute attributable risks
- QMRA can analyse many different environmental settings
- We end up using FIBs (for practical reasons)
  - Breakpoints informed by local QMRA, not overseas epidemiology

Key Steps

1. Select appropriate pathogen(s)
   - Esp. w.r.t. human vs. animal sources
2. Quantify exposure
   - Pathogens at source?
   - Use mixing/pollutant transport/inactivation models to convey pathogens to exposure sites
     - Simpler for rivers, harder for coasts
3. Characterise dose-response
   - Based on clinical trials and/or outbreak studies
4. Calculate risk profiles and communicate results

Primary guidelines, MfE/MoH (2003)



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Primary guidelines, MfE/MoH (2003)

- Based on QMRA for *Campylobacter* infection risk (greater than illness risk)
  - But use a FIB (*E. coli*) for implementation—for practical reasons
- Not based on viruses
  - Often detected, but relationship to FIBS unclear
  - So WHO-recommended risk breakpoints were reduced

From	<1%	1%–5%	5%–10%	>10%
To	<0.1%	0.1%–1%	1%–5%	>5%

Deriving the MfE/MoH (2003) breakpoints

Percentile (of time)	QMRA risk of *Campylobacter* infection (%)	*E. coli* (per 100 mL)
55%ile	0	131
60%ile	0.1	154
65%ile	0.3	191
70%ile	0.9	261
75%ile	1.8	332
80%ile	2.6	461
85%ile	7.2	613
90%ile	13.1	980

Example Interpretation:
If the *E coli* concentration were between 191 and 261 per 100 mL, the risk of *Campylobacter* infection would be between 0.3 and 0.9%.

- *E. coli* %ile at which infection risk rises above 1% is just after the 70%ile, where *E. coli* ≈ **260** / 100 mL
- *E. coli* %ile at which infection risk rises above 5% is 80–85%ile, where *E. coli* ≈ **550** / 100 mL

Deriving the NoF breakpoints

- Basic idea: *Rerun the primary contact model with reduced water ingestion rates*
- Primary: Min., Mode, Max. = 10, 50, 100 mL/h
- Secondary (Chicago studies; Dorevitch, Rijal):

Percentile	Ingestion rates (mL/h)		
	Boating	Fishing	Canoeing
10	1.49	2.98	5.21
25	1.65	3.30	6.02
50	1.90	3.79	7.52
75	2.23	4.47	10.15
90	2.64	5.28	14.16
95	2.95	5.89	17.84
97.5	6.26	6.51	21.99
100	7.43	22.13	34.00

Dorevitch *et al*. (2011). Water ingestion during water recreation. *Water Research 45(5)*: 2020–2028.
Rijal *et al.* (2011). Microbial risk assessment for recreational use of the Chicago area waterway system. *J. Water Health 9(1)*: 169–186.

Deriving the NoF breakpoints

Stati sti	Water contact category (infecti on cases out of 1000)						*E. coli* / 100 mL (FMRPR)
	Primary	Secondary (1/2)	Secondary (1/3)	Secondary (1/4)	Secondary (1/5)	Secondary (1/10)	
5%ile	0	0	0	0	0	0	4
10%ile	0	0	0	0	0	0	9
15%ile	0	0	0	0	0	0	14
20%ile	0	0	0	0	0	0	32
25%ile	0	0	0	0	0	0	29
30%ile	0	0	0	0	0	0	40
35%ile	0	0	0	0	0	0	51
40%ile	0	0	0	0	0	0	66
45%ile	0	0	0	0	0	0	91
50%ile	0	0	0	0	0	0	110
55%ile	0	0	0	0	0	0	131
60%ile	1	0	0	0	0	0	154
65%ile	3	0	0	0	0	0	191
70%ile	9	2	0	0	0	0	261
75%ile	18	7	2	1	0	0	332
80%ile	26	13	7	3	2	0	461
85%ile	72	40	31	23	20	8	613
90%ile	131	88	63	53	40	28	980
95%ile	329	330	277	239	207	179	1986

Deriving the NoF breakpoints

Breakpoints for tolerable infection risk	*E. coli* breakpoints (*E. coli* per 100 mL)					
	Primary	Secondary (1/2)	Secondary (1/3)	Secondary (1/4)	Secondary (1/5)	Secondary (1/10)
0.1%	130	190	260	260	395	460
0.5%	220	290	390	460	460	540
1%	260	395	535	540	540	650
5%	550	650	800	1,000	1,000	1500

NoF breakpoints based on the "1/4" case (see page 72 of MfE (2013). *Proposed amendments to the National Policy Statement for Freshwater Management 2011. A discussion document.* Wellington: Ministry for the Environment).

NoF breakpoints (page 72)

Value	Human Health (secondary contact recreation)	
Freshwater Body Type	Lakes and Rivers	
Attribute	*E. coli* (*Escherichia coli*)	
Attribute Unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)	
Attribute State	**Numeric Attribute State**	**Narrative Attribute State**
	Annual Median	
A	<260	People are exposed to a very low risk of infection (less than 0.1% risk) from exposure to water used for wading or boating (except boating where there is high likelihood of immersion).
B	260-540	People are exposed to a low risk of infection (between 0.1 and 1% risk) from exposure to water used for wading or boating (except boating where there is high likelihood of immersion).
C	540-1000	People are exposed to a moderate risk of infection (between 1 and 5% risk) from exposure to water used for wading or boating (except boating where there is high likelihood of immersion).
National Bottom Line	**1000**	
D	>1000	People are exposed to a high risk of infection (greater than 5% risk) from exposure to water used for wading or boating (except boating where there is high likelihood of immersion).

Freshwater example (Kumeu, human pathogens)

Percentile	Summer		
	Rotavirus (normal)	Cryptosporidium oocysts	Rotavirus (extreme)
Minimum	0	0	32
10%ile	1	0	69
20%ile	2	0	75
30%ile	4	0	78
40%ile	5	0	80
50%ile	7	1	81
60%ile	10	1	83
70%ile	13	2	84
80%ile	18	2	86
90%ile	25	3	88
95%ile	31	5	90
97.5%ile	36	6	91
99%ile	41	8	93
99.9%ile	54	15	96
Maximum	55	18	98
IIR(%)	10.4	1.35	79.8

Some Current Issues

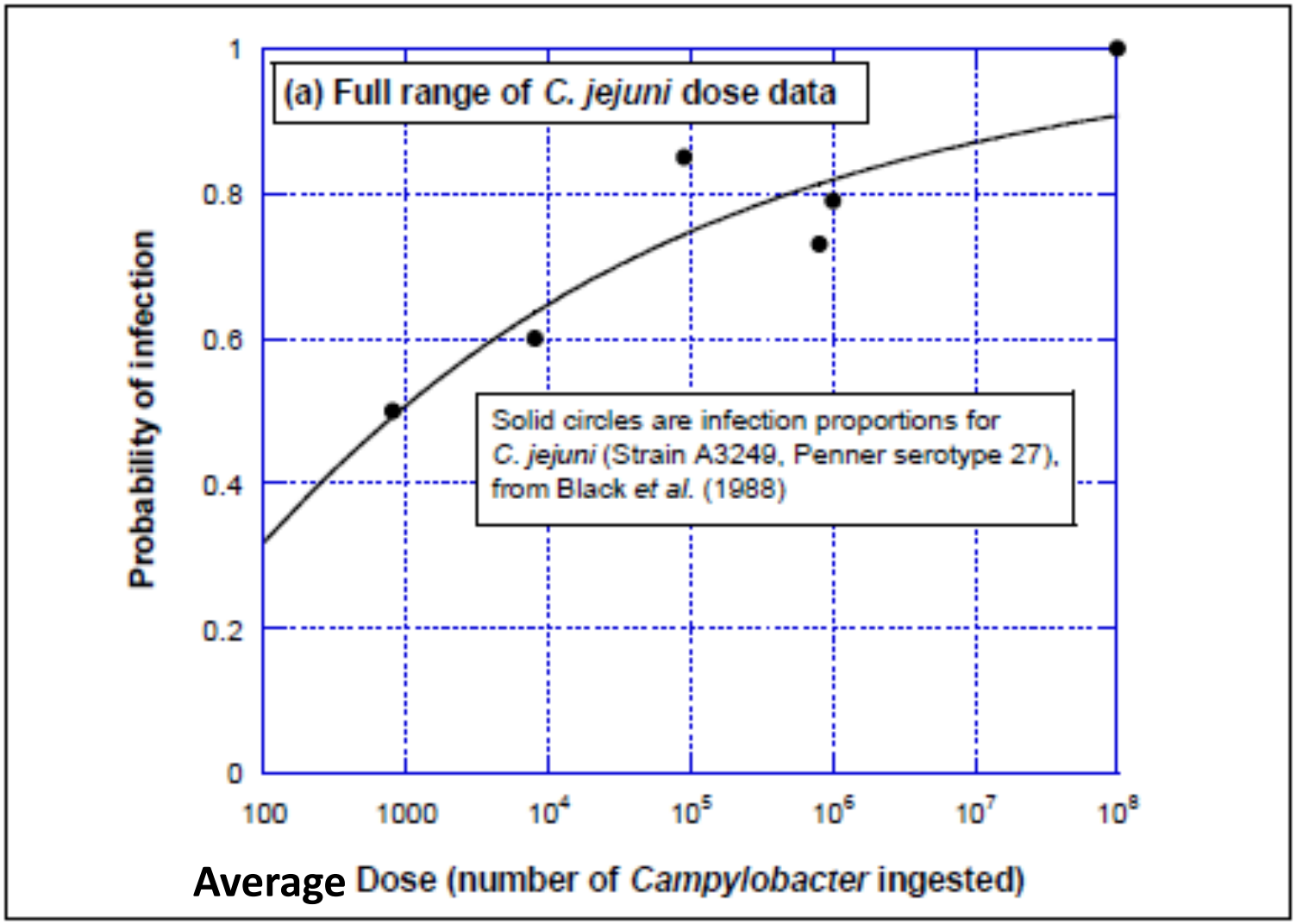
- Keep review of literature on exposure rates (ingestion and inhalation)
- Include a microbiologist in the team
  - Esp. w.r.t. pathogen(s) selection
- Include someone proficient in mathematical modelling in the team
- Lack of some dose-response information
- Harmonise “dose”
- Children?
- Increasing reliance on Norovirus
- Validation

Dose-response curves

"Lack of some dose-response information"

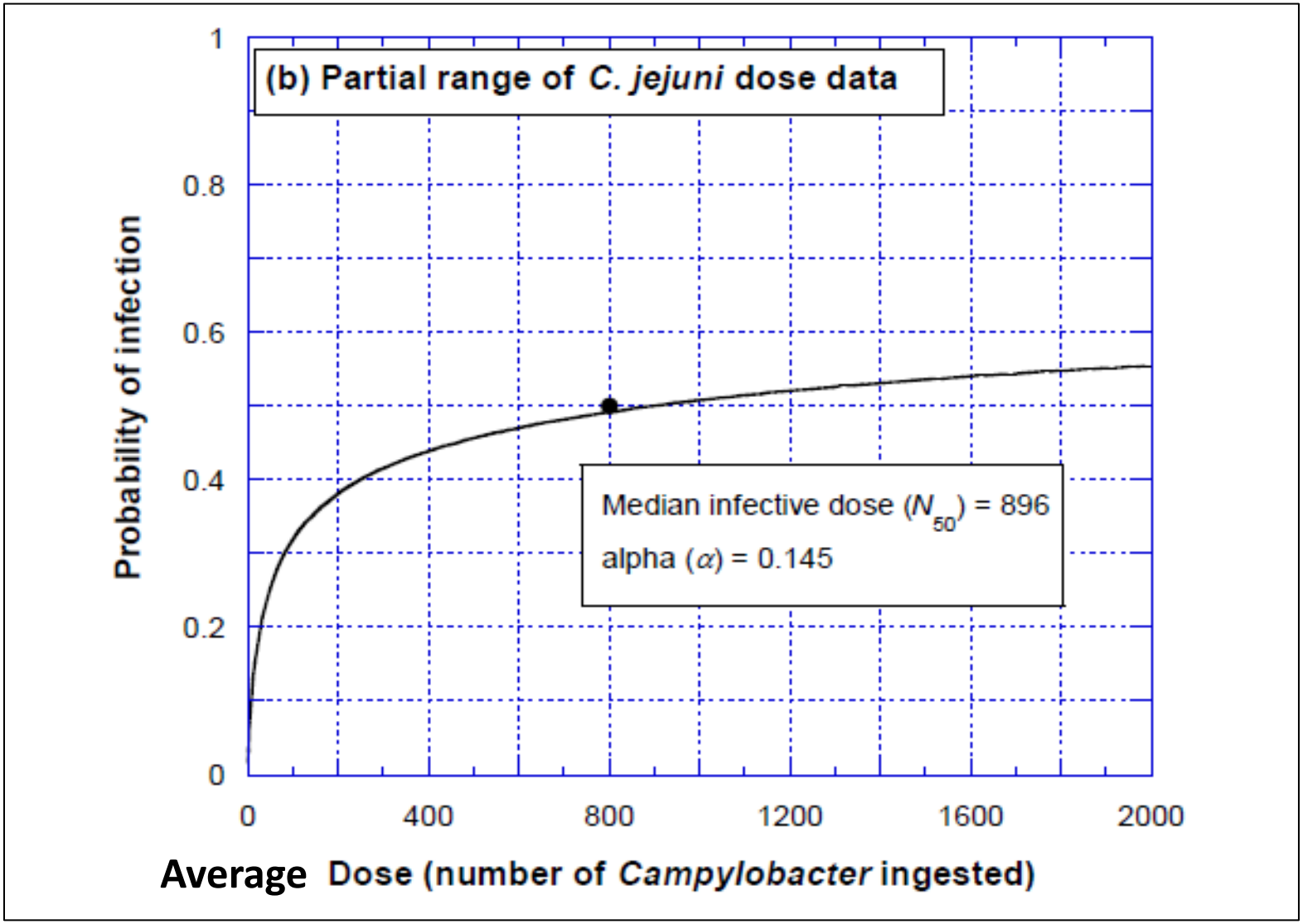
- We do have some
- Mostly based on clinical trials
  - Whose volunteers to be much-admired
  - So doesn't include children → need for precautionary approach
- Some based on outbreaks
  - Norovirus example (later)
- Most don't have "low" doses
  - So uncertainty about dose-response should be considered
  - Rotovirus an exception

Dose-response: Campylobacter (adults only)



Medema, G.J.; Teunis, P.F.M.; Havelaar, A.H.; Haas, C.N. (1996). Assessment of dose response relationship of *Campylobacter jejuni*. *International Journal of Food Microbiology 30*: 101–111.

Dose-response: Campylobacter (adults only)



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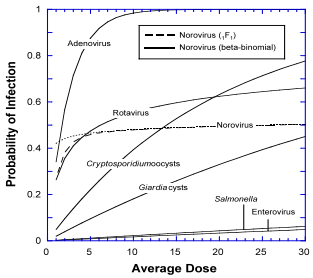
Dose-response: Campylobacter (children?)

- Can handle, to some degree, by assigning higher exposure to children (have done so)
- NZ children's reported campylobacteriosis rates rather higher than for adults
  - Lake *et al*. (2011). *Campylobacter* in food and the environment: examining the link with public health. Pathway attribution.
- Outbreak study inferred $(ID_{50})_{illness,child} >> (ID_{50})_{adult,infection}$
  - Teunis *et al*. (2005).
  - Controversial: doses were inferred, not measured
- Conversely, *Campylobacter* species in NZ freshwaters seem to be dominated by wild bird species, less infectious to humans
  - French *et al*. (2011). *Campylobacter* in food and the environment: new and emerging data on typing of *Campylobacter* strains in animals, environmental matrices and humans.

Dose-response, other pathogens



McBride *et al*. (2013). Discharge-based QMRA for estimation of public health risks from exposure to stormwater-borne pathogens in recreational waters in the United States, *Water Research 42(14)*: 5282–5297.

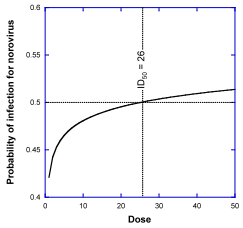
Harmonising "Dose"

- Many clinical trials rather ancient, mostly using a "culture" pathogen enumeration method
- But current methods may return much higher enumerations
  - Especially when using PCR methods
- Therefore care needed to harmonise between old and new
  - Has often been overlooked
  - Some guidance in McBride *et al*. (2013).

Norovirus!

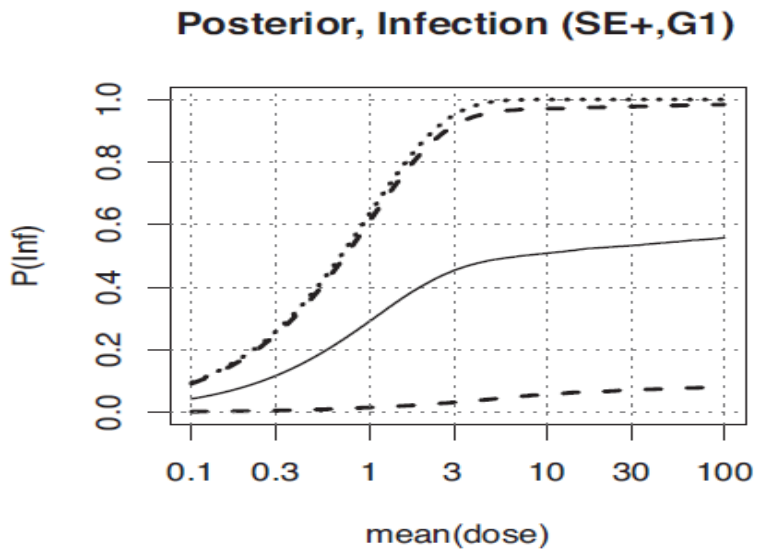
- Can't be cultured, yet seems the most common aetiological agent for swimming illness w.r.t. *human* wastes
- Clinical trial (for Norwalk virus) reported in 2008
  - Teunis *et al*. (2008). *J. Medical Virology 80*: 1468–76.
  - Enumerated using PCR
- Debate about virus aggregation resolved
  - Ignore it
- New results for outbreaks from raw oyster consumption in southern France
  - Resolves illness probability conundrum

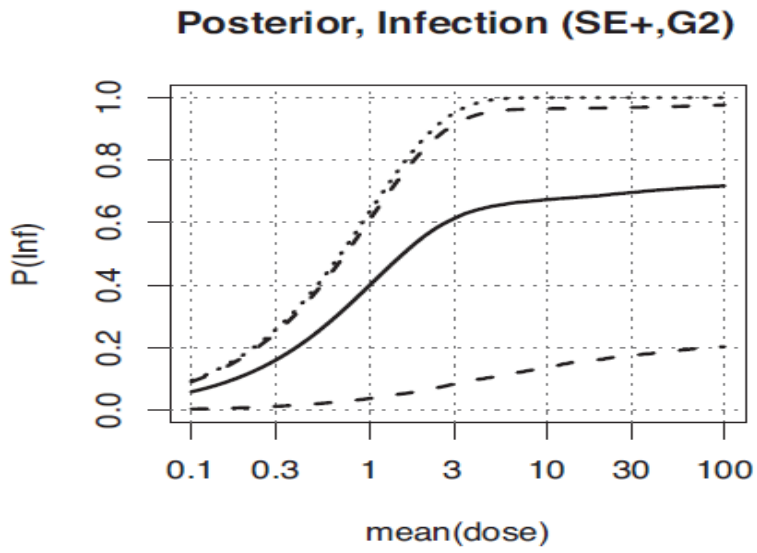
Norwalk virus: Infection probability (clin. trial)



Teunis, P.F.M., Moe, C.L., Liu, P., Miller, S.E., Lindesmith, L., Baric, R.S., Le Pendu, J., Calderon, R. (2008). Norwalk virus: How infectious is it? *Journal of Medical Virology 80*: 1468–1476.

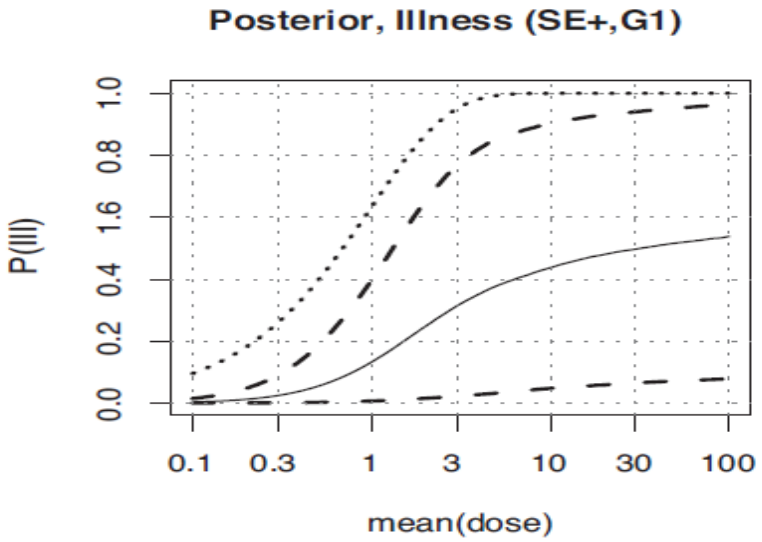
Norovirus: Infection probabilities

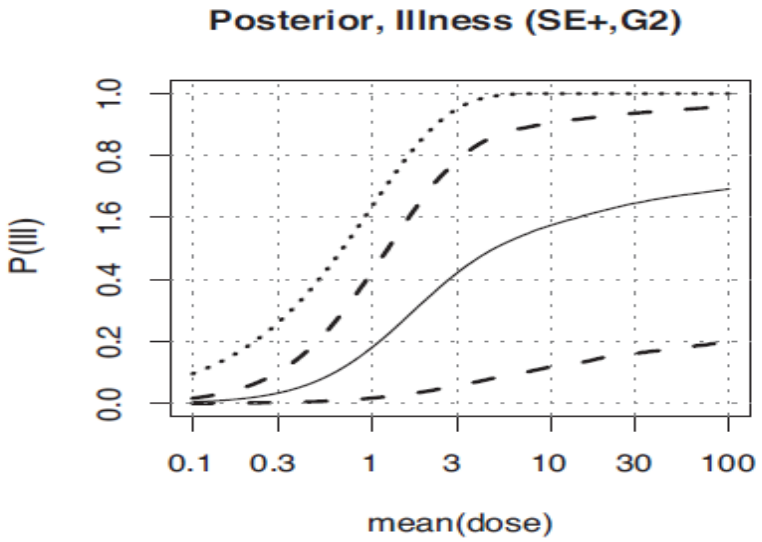




Thebault, A.; Teunis, P.F.M.; Le Pendu, J.; Le Guyader, F.S. (2013). Infectivity of GI and GII viruses established from oyster related outbreaks. *Epidemics 5*: 98–110.

Norovirus: Illness probability





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Validation

- Can apply Bradford-Hill criteria: Plausibility, exposure pathway, specificity, coherence
- Can't formally "validate"
  - To do that need to test against results of epidemiological study(ies)
  - Even then test is not strong
    - Are the particular epidemiological results in harmony with the *range* of results predicted by QMRA?
  - But those epi. studies seldom (if ever) measure pathogens (too expensive and too difficult)
  - USEPA tried to validate a QMRA (Puerto Rico epidemiological study), but data had too many holes

Conclusions: QMRA

QMRA

- Still a young discipline
- Useful for risk attribution
- Norovirus the new kid-on-the-block
- Care needed when using “dose”
- Precautionary approach is appropriate
  - Especially for children
  - And elderly and immuno-compromised

References

Papers

Dorevitch, S. *et al*. (2011). Water ingestion during water recreation. *Water Research 45(5)*: 2020–2028.

McBride *et al*. (2013). Discharge-based QMRA for estimation of public health risks from exposure to stormwater-borne pathogens in recreational waters in the United States, *Water Research 42(14)*: 5282–5297

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