Technical Background for 2017 MfE 'Clean Water' Swimmability Proposals for Rivers

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1 Key Findings

(i) The overall concept proposed in *Clean Water* of using an approach that considers how often a water body exceeds certain *E.coli* thresholds in determining a site's relative suitability for swimming is technically sound and should be preserved in any amended version of the *Clean Water* proposals;

(ii) Whereas 97% of the 792 sites for which we have data comply with the National Bottom Line for secondary contact (boating/wading) in the current National Policy Statement for Freshwater Management (*NPS* 2014), the proportion of those sites complying with the proposed *Clean Water* primary contact categories (i.e., swimming) is 43%. The proposed categories thereby pose an incentive to improve microbiological water quality in rivers;

(iii) All proposed swimmable grades in *Clean Water* include a requirement that the median *E. coli* concentration be less than 130 per 100 mL and so, using the underlying *Campylobacter* infection risk model, the health risk is practically zero for at least half the time;

(iv) The average infection risk faced by a random swimmer on a random day in waters that just meet the *Clean Water* swimming threshold (bottom of the yellow grade) is no more than 3.1%, it is less than that for the grades above (blue and green grades).

(v) The *Clean Water* swimming threshold is more restrictive than the current secondary contact National Bottom Line in the *NPS* 2014 (median of 130/100mL versus 1000/100mL) but more permissive than the 'minimum acceptable state' for swimming in the *NPS* 2014;

(vi) Using a national dataset for rivers, applying the *Clean Water* swimming threshold was more restrictive than applying the swimming thresholds in the EU guidelines ('Sufficient' and 'Good' categories) but was more permissive than applying the threshold criteria values in the USA or the swimming threshold in the *NPS* 2014 (care needs to be taken in making such comparisons because of the differences in sampling protocols).

(vii) Criteria for sampling timing stated in the MfE/MoH guidelines of 2003 are somewhat ambiguous and the *NPS 2014* is silent on the matter, whereas the *Clean Water* proposal would require sampling 'regardless of weather conditions' and this requirement is likely to introduce a stringency to a site obtaining a swimming grade given that high *E.coli* levels in rivers are often measured during higher flow events;

(viii) The requirement of a hundred *E. coli* samples over up to a maximum of ten years could confer considerable data history when evaluating the current state of a water body;

(ix) A rounding rule is lacking to interpret the result when a percentage of samples is not an integer, as will be common.

2 Background and Issues Addressed

The Ministry for the Environment has recently produced a draft 'Clean Water' document containing proposed swimmability numeric objectives, as an amendment to the current National Policy Statement for Freshwater Management (2014), pursuant to the Resource Management Act. That draft addresses both long-term (grading, placing within attribute states)[1] and short-term (surveillance) purposes. The surveillance component is essentially unchanged from that in the 2003 MfE/MoH recreational water quality guidelines. The grading component, using a 5-colour 'traffic light' scheme (i.e., the bands A–E: blue, green, yellow, orange, red) is new. The Ministry's development of the proposed swimmability numeric objectives for site grading relies on distributions of *E. coli* in freshwaters to be used for recreation.

Given its history of involvement in these matters, NIWA has funded the preparation of this report covering the following topics[2]:

- Key components of recreational water Guidelines and Objectives, including: (i) Guidelines versus Standards versus Objectives; (ii) 'Grading' versus 'Surveillance';
- The technical basis of Guidelines and Objectives;
- Development of numeric thresholds in Guidelines and Objectives;
- Comparisons of threshold grades between the current recreational water Guidelines, the National Policy Statement for Freshwater Management 2014, the 2017 'Clean Water' proposals, and overseas approaches;
- Comparisons between these different grading approaches when applied to a national rivers water quality dataset; and
- Calculations of the risk faced by a random swimmer on a random day.

[1] 'Grading' is not used explicitly in *Clean Water*, but it is a useful term in this report.

[2] Some technical details are contained in three appendices.

3 Key Components of Recreational Water Guidelines and Objectives

Before addressing the evolution of the *Clean Water* objectives, we present some key concepts.

3.1 Guidelines, Standards and Objectives

Throughout this document we will refer to three important documents that contain explicit numerical requirements for recreational microbiological water quality:

1. *Guidelines* on microbiological water quality for recreational waters (MfE/MoH 2003)
2. National Policy Statement for Freshwater Management (NZ Government 2014)
3. Proposed amendments to the National Policy Statement ('Clean Water', MfE 2017)

To aid clarity and avoid clumsy language, throughout this document we refer to these three documents as *Guidelines*, *NPS* and *Clean Water*, respectively, in italics. It is important to understand their roles.

The term '*Guidelines*' (item 1) is self-explanatory; that is, their content is advisory only.

However the *NPS* states stronger aspects. In particular

> National bottom lines in the national policy statement are not standards that must be achieved immediately. Where freshwater management units fail the national bottom lines, they will need to be improved to at least the national bottom lines over time. It is up to communities and iwi to determine the pathway and timeframe for ensuring freshwater management units meet the national bottom lines.

So the *NPS* could be considered to contain standards to be met in the future, at each and every site.[3]

In *Clean Water*, numerical microbiological requirements do not have to be met at each and every site.[4] Rather, a certain proportion of sites should comply with those requirements sometime in the future.[5]

3.2 Faecal Bacterial Indicators

The microbial test used to assess possible pathogen presence in New Zealand freshwater systems is the detection and enumeration of *Escherichia coli (E. coli*).[6] This is consistent with many jurisdictions around the world and serves as a cost-effective indicator of the presence of animal or human faecal contamination of the water. In this way *E. coli* signals the likelihood that harmful water-borne pathogens such as *Campylobacter*, *Cryptosporidium* oocysts, *Giardia* cysts, Norovirus, other human enteric viruses and/or *Salmonellae* may also be present.

Many pathogenic bacteria and protozoa can be zoonotic, i.e., arising from animal defecation. Faecal contamination from animals can occur via runoff from farms during rainfall events, point discharges from dairy shed wastewaters, or if animals have direct access to waterways. Human faecal

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[3] Unless an exception can be claimed under the *NPS* policy CA3(b).

[4] Although the implications of the last paragraph of sec. 3.6 of *Clean Water* are not completely obvious to us.

[5] For example, '90% of rivers and lakes swimmable by 2040', as on the frontispiece of *Clean Water*.

[6] In general, *E. coli* are not infectious to humans. However, in rare situations a pathogenic strain may be present in sufficient numbers to cause infection and illness (Teunis *et al.* 2007), usually the 'O157:H7' strain, causing VTEC/STEC illness (verotoxigenic/Shigatoxigenic *E. coli*). If present, this strain will typically comprise less than 1% of the total *E. coli* in a faecal sample (pers. comm. Dr Elaine Moriarty, ESR, Christchurch). Its ID_{50} (the concentration required to cause infection and illness among 50% of the exposed, adults and children) is 100–300 (Strachan *et al*. 2005)—considerably lower than earlier estimates of nearly 4,000 for children (e.g., Teunis *et al*. 2004). Some people infected with this pathogenic strain of *E. coli* (particularly children) may go on to exhibit a severe anaemic sequela—HUS, haemolytic uremic syndrome (Giaocometti *et al*. 2012, MPI 2013).

contamination of water bodies can occur via leaky infrastructure, poorly treated sewage, septic tank systems, or via transport during heavy rain when sewerage systems cannot cope and overflow into stormwater systems. Because of the heightened health risks from sewage contamination via runoff and stormwater, people are often advised to avoid swimming for some time (e.g., 48 hours) after prolonged or heavy rain.

3.3 Grading and Surveillance

There are two distinct components to assessing the suitability of a site for swimming recognised in the *Guidelines*: Grading and Surveillance. Grading assesses the general suitability of a site for swimming on a long term basis (and uses long term monitoring to determine that) whilst surveillance assesses the suitability of a site for swimming in the short-term (is it OK to swim today?).[7]

Conceptually, it should be understood that the level of stringency associated with grading and surveillance are most often similar, but the goals are different. Because of the different goals, worldwide, different water quality metrics are used to achieve those goals (typically a geometric mean, median, or 95th percentile of many sample results determine the grade, whereas the result from a single sample may be used for short term surveillance of the recreational water). For example, a recreational site may receive an 'A' grade (excellent long term quality) but may not be suitable for swimming during specific circumstances, such as unusual contamination.

The *Guidelines* for recreational water include both grading and surveillance whilst the *NPS* 2014 contains only grading—(referred to as attribute states). The proposed changes to the *NPS* included in the 2017 *Clean Water* package include both grading (again as attribute states) and surveillance (in its Appendix 5).

In surveillance there is a problem of time lag between the collection of samples and the provision of results. When a surveillance result is reported and public health advice about water contact is given, the risk period may have passed. For that reason there is increasing reliance in the USA on the use of molecular methods which can yield same day results (see US EPA, 2012) and predictive models, particularly for popular sites. For example, such models may use a relationship between *E. coli* and flow to predict future *E. coli* levels based on forecast flows. Models of this sort have been used effectively in the Great Lakes area of the United States.

[7] As outlined in the recent report on freshwater released by Sir Peter Gluckman, the Prime Minister's Chief Science Advisor.

4 Technical Basis of the Guidelines and Numeric Objectives

Grading and surveillance of fresh waters used for human contact can guide public health intervention to minimise human illness. The value of understanding the numerical objectives is that it improves our ability to give timely, consistent and accurate advice to relevant organisations and the public—hence reducing human exposure to pathogens and illness.

The 2003 *Guidelines*, 2014 *NPS* and 2017 *Clean Water* documents all have the same technical underpinning: the Freshwater Microbiological Research Programme (FMRP).[8] This multi-agency study assessed six faecal indicators and five pathogens at 25 recreational water sites (22 rivers and three lakes) scattered throughout the country in a 15 month period of fortnightly sampling at each site in 1998–2000. It captured five major land-use types[9] and included two summers. *Campylobacter* was found to be widespread and was present at least once at all sites. Six percent of all samples contained more than 110 *Campylobacter* per 100 mL.[10] *E. coli* was always present, in varying concentrations.

The report of the results (McBride *et al*. 2002) did not recommend any particular form for the content of future Guidelines. These were subsequently developed by a Working Group who used the FMRP results, incorporated into a Monte Carlo human health risk assessment model, to inform their development. It was published in 2003. In so doing, the key decisions made by that Group (and authorized by the Ministry for the Environment and the Ministry of Health) were that:

1. The *Guidelines* should be based on the risk of *Campylobacter* infection (noting that some individuals infected with that bacterium may not become ill) and its (moderate) association with *E. coli* concentrations.
2. The *Guidelines* should adopt the WHO 'Annapolis Protocol' (WHO 1999, 2003), in which grading and surveillance are separate-yet-complementary elements.
3. The grading outcome for a recreational site takes account of both the *E. coli* data *and* a sanitary survey of the site to assess its susceptibility to faecal contamination.[11]

[8] Earlier New Zealand *Guidelines* (DoH 1992, MfE/MoH 1989, 2002) were based on the USA recreational water 'criteria' (USEPA 1986). Prior to that, standards were available for selected catchments under the Waters Pollution Regulations (1963, using total coliforms) and the Water and Soil Conservation Act 1967 as amended in 1971 (using faecal coliforms). See McBride 1990 for a detailed historical account.

[9] Catchment types were characterised by their dominant sources of faecal contribution: **B** (birds), **D** (dairy farming), **F** (forestry/undeveloped), **M** (municipal), and **S** (sheep/pastoral).

[10] *Campylobacter* concentrations were assessed by culturing in a 3x3x3 series of dilution tubes. If all of the tubes presented a positive result the concentration was unknown, but greater than 110 per 100 mL (which would be the result if all but one of the most diluted tubes to found positive).

[11] A sanitary survey involves inspecting a site and its upstream catchment for its potential to contribute faecal contaminant, even if intermittently, summarised as 'know your catchment'.

5 Development of Numeric Components of Guidelines and Objectives

5.1 Guidelines (2003)

5.1.1 Grading

The *Guidelines* adopted the Annapolis Protocol approach, which creates four grading bands called 'Microbiological Assessment Categories' (MAC), ranging from 'A' to 'D'. Their purpose is to populate the 'Annapolis Protocol' matrix, along with an assessment of local sanitary conditions, under which a site can be classified 'Very Good', 'Good', 'Fair', 'Poor', 'Very Poor' or 'Follow Up'.[12] These descriptors are called 'Suitability for Recreation Grades' (SFRG)[13] and are dictated not only by the MACs, but also by an assessment of the sites 'Sanitary Inspection Category" ('SIC') – see below.[14]

Table 1: Guidelines' Suitability for Recreational Use

Susceptibility to faecal influence		**Microbiological Assessment Category** Indicator counts (as percentiles – refer Table E1)				**Exceptional circumstances** ***
		A ≤ 130 *E. coli*/100 mL	**B** 131–260 *E. coli*/ 100 mL	**C** 261–550 *E. coli*/ 100 mL	**D** > 550 *E. coli*/ 100 mL	
Sanitary Inspection Category	Very Low	Very Good	Very Good	Follow Up**	Follow Up**	
	Low	Very Good	Good	Fair	Follow Up**	
	Moderate	Follow Up*	Good	Fair	Poor	
	High	Follow Up*	Follow Up*	Poor	Very Poor	
	Very High	Follow Up*	Follow Up*	Follow Up*	Very Poor	
Exceptional circumstances***						

Notes

* Indicates unexpected results requiring investigation (reassess SIC and MAC).

** Implies non-sewage sources of indicators, and this should be verified.

*** Exceptional circumstances: relate to known periods of higher risk for a graded beach, such as during a sewer rupture or an outbreak of a potentially waterborne pathogen in the community of the recreational area catchment. Under such circumstances a grading would not apply until the episode has abated.

The MAC *E. coli* thresholds (i.e., A/B, B/C and C/D boundaries) are based on the 95th percentiles of observed data[15] and were established using 'Tolerable' levels of predicted *Campylobacter* infection risks

[12] 'Follow-up' arises when the MAC is inconsistent with the Sanitary Inspection Category.

[13] SFRG does not feature in *NPS* nor in *Clean Water*, for unexplained reasons.

[14] This means that for a given MAC, the SFRG may not be unique. For example if MAC = 'B' and the SIC = 'Very Low' then the SFRF = 'Very Good'. But that grade drops to 'Good' for SIC = 'Low' or 'Moderate'. The non-inclusion of SIC in the *NPS* and *Clean Water*, obviates this non-unique feature.

[15] Furthermore, Table E1 makes clear that 'It is important to note there are several ways to calculate percentiles. Each uses a different formula, generating different results. The Hazen method has been chosen for these *Guidelines*, as it tends to be about the 'middle' of all the options.' (Microsoft Excel's method always gives a lower result.)

(0.1%, 1% and 5%)[16] derived from Monte Carlo risk modelling. Thus, each of the three MAC thresholds corresponds to one of the three *Campylobacter* infection risks – A/B corresponds to 0.1%, B/C corresponds to 1% and C/D corresponds to 5%. A 'percentile matching' technique was used to derive the threshold values. Based on the output of that approach, as explained in Appendix A, the following thresholds apply:

To achieve an A grade, waters would need to have a 95th percentile less than 130 *E. coli* per 100 mL.
To achieve a B grade, waters would need to have a 95th percentile less than 260 *E. coli* per 100 mL.
To achieve a C grade, waters would need to have a 95th percentile less than 550 *E. coli* per 100 mL, and
Waters with a 95th percentile greater than 550 *E. coli* per 100 mL receive a grade of D.

These thresholds invoke a precautionary approach in several ways:

1. *Campylobacter* infection does not necessarily lead to illness (i.e., campylobacteriosis). Generally, less than half of the infection cases can be expected to give rise to illness. In contrast, the marine waters component of the 2003 *Guidelines* are necessarily based on an illness health metric (because they are derived from epidemiological studies that reported illness levels).
2. The equivalent thresholds for marine waters are set at illness risks of 1%, 5% and 10% (compare the *Guidelines*' pages H25 and H26). That reduction recognises that swimmers in freshwater could be infected with pathogens other than *Campylobacter* (such as human enteric viruses) (see page I17 of the *Guidelines*), although campylobacteriosis is the most frequently reported notifiable illness and is potentially waterborne.
3. The *E. coli* assessment metric is a 95%ile, whereas risk thresholds are typically derived from median values (See US EPA, 2012). This approach minimises misclassification error risks but also inherently invokes a significant protective buffer. For example, a waterbody that just achieves the B/C threshold (a little below 260 *E. coli* per 100 mL), would be expected to exceed a 1% *Campylobacter* infection rate 5% of the time. In fact, the *median* risk would be much lower than 1%. Using a 95%ile in this way greatly reduces misclassification but does not necessarily convey the true risk of a waterbody in a transparent manner.[17] This protective buffer also caters for the possibility that some environmental strains of *Campylobacter* may be more infectious than the strain used to develop the dose-response relationship in the Monte Carlo risk model (Teunis *et al.* 2005).

Note that the underlying Monte Carlo risk assessment model captures the variability in inputs and so its results are *'on average'*. For example, if the *E. coli* concentration at a site on two different days happens to be around 550 per 100 mL, the *Campylobacter* concentration may be quite different on the two days. This means that the models address the situation in the long-term, by averaging out such variabilities. It also means that they cannot be strongly relied upon to predict illness risk on a particular day. So the modelling results were used to inform the Annapolis Protocol matrix over the long-term, (typically 5 years) – referred to as site 'grading' herein.

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[16] In international *Guidelines* (WHO 2003) the tolerable illness risk thresholds at these boundaries are 1%, 5% and 10% respectively. The New Zealand *Guidelines* for freshwater reduced these to infection levels of 0.1%, 1% and 5%, in the recognition that pathogens other than *Campylobacter* (e.g., human enteric viruses) may also cause infection and subsequent illness (Hewitt *et al*. 2013). At first sight these risk levels are high, but there is often inherent risk in being immersed in environmental waters subject to some faecal contamination from human and animal sources.

[17] Note that whereas the marine waters component of the *Guidelines* also uses a 95%ile assessment metric, it is not based on a precautionary approach in the same way.

5.1.2 Surveillance

The *Guidelines* 'Box 2' contain separate tables for day-to-day site surveillance, in a traffic light approach based on single-sample results (green if *E. coli* concentration < 260 *E. coli* per 100 mL, else amber if *E. coli* concentration < 550, else red). The thresholds for these were simply taken to be the MAC B/C and C/D thresholds.

Table 2: Guidelines' Surveillance RequirementsCAC = Catchment Assessment Checklist

Box 2:
Surveillance, alert and action levels for freshwater

Acceptable/Green Mode: No single sample greater than *260 E. coli/100 mL*.

- Continue routine (e.g. weekly) monitoring.

Alert/Amber Mode: Single sample greater than *260 E. coli/100 mL*.

- Increase sampling to daily (initial samples will be used to confirm if a problem exists).
- Consult the CAC to assist in identifying possible location of sources of faecal contamination.
- Undertake a sanitary survey, and report on sources of contamination.

Action/Red Mode: Single sample greater than *550 E. coli/100 mL*.

- Increase sampling to daily (initial samples will be used to confirm if a problem exists).
- Consult the CAC to assist in identifying possible location of sources of faecal contamination.
- Undertake a sanitary survey, and report on sources of contamination.
- Erect warning signs.
- Inform public through the media that a public health problem exists.

Notes:

- Colilert™ is the method of choice to enumerate *E. coli* or EPA Method 1103.1, 1985 Membrane Filter Method for *E. coli* (this method gives a result for *E. coli* within 24 hours): USEPA ICR Microbial Laboratory Manual.* This method and the MPN Method for *E. coli*, which is also acceptable (but gives a result in 48 hours), is described in the 20th edition of *Standard Methods for the Examination of Water and Waste Water*, American Public Health Association. These methods must be used to enumerate *E. coli* unless an alternative method is validated to give equivalent results for the waters being tested.
  * USEPA National Centre for Environmental Publications and Information (NCEPI), 11029 Kenwood Road, Cincinnati, OH 45242, USA (Document No. EPA-821-C-97-004).
- Samples to test compliance should be over the bathing season appropriate to that locality (at least 1 November to 31 March) and sampling times should be restricted to between 0800 hours and 1800 hours.

Note that the *Guidelines* are somewhat ambiguous concerning the timing of sampling. At one point they specify that sampling should '…reflect the conditions under which people are swimming'.[18] So inclusion of results from sampling at other times (e.g., during flood events) is ruled out.[19] However at another

[18] See section H(i) of the *Guidelines*, and footnote 7 of its Table H2: 'Guideline values should also be applied to waters at the time of recreational use. Availability resources may restrict the number of monitoring sites.

[19] There is also a question of which sites should be sampled. That choice is not necessarily to be made on a site's popularity. That's because the *Guidelines* moved away from a popular notion to one of an individual's risk, i.e., the four categories of site, based on a site's popularity, as used in the 'Provisional Guidelines' (DoH 1992) were not carried through to the 2003 *Guidelines*. That was based on the thought: 'Why should I face a higher risk at a site that few people use, versus a popular beach where the risk limits are lower?'

place in the *Guidelines*, the requirements can be interpreted to be at odds with such targeted sampling.[20]

5.2 NPS (2014)

5.2.1 Grading

The *NPS* sets national bottom lines for two compulsory values – ecosystem health and human health for recreation – and minimum acceptable states for other national values. Their numeric values for human health contain only the grading component; they do not include surveillance traffic lights. The grading addresses both primary water contact (regular immersion, as in swimming) and secondary contact (where ingestion of water is unlikely or minimal, such as in boating or wading). The 'National Bottom Line' is for secondary contact, often characterized as 'wading', as expressed in the following box.

Table 3: *NPS* Bottom Line

Te Hauora o te Tangata / the health and mauri of the people
Human health for recreation – As a minimum, the freshwater management unit will present no more than a moderate risk of infection to people when they are wading or boating or involved in similar activities that involve only occasional immersion in the water. Other contaminants or toxins, such as toxic algae, would not be present in such quantities that they would harm people's health. In freshwater management units where a community values more frequent immersion in the water such as swimming, white-water rafting, or water skiing, the risk of infection will be no more than moderate. In some freshwater management units, the risk of infection to people undertaking any activity would be no greater than what would exist there under natural conditions.

The grading requirements are presented below. Note that for the A and B grades, the median and the 95th percentiles have the same numerical values, e.g., for a B grade, the median and 95th percentile need to be less than 540 *E. coli* per 100 mL. At first sight this may appear to be a conflict. But this is not so. The median applies to secondary contact whilst the 95th percentile applies to waters designated for primary contact (swimming). The 'National Bottom Line' in the *NPS* requires waters to be suitable for secondary contact such as wading or boating (bottom of the C band), numerically defined as a median of 1,000 *E. coli* per 100 mL.

[20] Note H(viii): "…Data collected during or immediately following rainfall, as part of routine sampling, should be included in calculation of the MAC…"

Table 4: ***NPS* Attribute Table for *E. coli*.**

Value	Human health for recreation		
Freshwater Body Type	Lakes and rivers		
Attribute	*E. coli**		
Attribute Unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)		
Attribute State	**Numeric Attribute State**	**Sampling Statistic**	**Narrative Attribute State**
A	≤260	Annual median	People are exposed to a very low risk of infection (less than 0.1% risk) from contact with water during activities with occasional immersion and some ingestion of water (such as wading and boating)
		95th percentile	People are exposed to a low risk of infection (up to 1% risk) when undertaking activities likely to involve full immersion.
B	>260 and ≤540	Annual median	People are exposed to a low risk of infection (less than 1% risk) from contact with water during activities with occasional immersion and some ingestion of water (such as wading and boating).
		95th percentile	People are exposed to a moderate risk of infection (less than 5% risk) when undertaking activities likely to involve full immersion. 540 / 100ml is the **minimum acceptable state** for activities likely to involve full immersion.
C	>540 and ≤1000	Annual median	People are exposed to a moderate risk of infection (less than 5% risk) from contact with water during activities with occasional immersion and some ingestion of water (such as wading and boating). People are exposed to a high risk of infection (greater than 5% risk) from contact with water during activities likely to involve immersion.
National Bottom Line	1000	Annual median	
D	>1000	Annual median	People are exposed to a high risk of infection (greater than 5% risk) from contact with water during activities with occasional immersion and some ingestion of water (such as wading and boating).

*Escherichia coli

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As can be seen, the *NPS* 2014 has an A to D grading (attribute states) for *E. coli*. The *NPS* 2014 describes a minimum acceptable state for swimming as a 95th percentile of 540 *E. coli* per 100 mL (bottom of the B band). Under the *NPS*, where regional councils, in consultation with their communities choose to have waters suitable for swimming then the latter is the threshold that must be met.

To achieve an A grade for swimming under the 2014 *NPS*, waters would need to have a 95th percentile less than 260 *E. coli* per 100 mL. To achieve a B grade for swimming under the 2014 *NPS*, waters would need to have a 95th percentile less than 540 *E. coli* per 100 mL. To achieve a C grade (suitable for boating and wading) under the 2014 *NPS*, waters would need to have a median value of less than 1000 *E. coli* per 100 mL. Waters with a median value of greater than 1000 *E. coli* per 100 mL would receive a D grade.

5.3 Clean Water (2017)

A key feature of the 2017 *Clean Water* package is that the use of secondary contact is deleted and primary contact ('swimmability') is now the proposed measure for the value of 'Human health for recreation', something many interests had been advocating. The Compulsory National Values statement (in *Clean Water* 2017, Appendix 1) is thus changed to read:

> In a healthy water body, people are able to connect with the water through a range of activities such as swimming, waka ama,[21] boating, fishing, mahinga kai and water-skiing, in a range of different flows. Matters to take into account for a healthy water body for human use include pathogens, clarity, deposited sediment, plant growth (from macrophytes to periphyton to phytoplankton), cyanobacteria, and other toxicants.

5.3.1 Grading

Two grading (Attribute States) tables have been proposed.

The first is stated in the *Clean Water* discussion document.[22]

[21] Full immersion could happen during waka based activities (both traditional and contemporary), for example (but not limited to) waka ama (outrigger canoeing), waka hourua (double hulled canoe), waka tauā (traditional war canoe) or tira hoe (multiple day wānanga, where iwi retrace traditional river navigational routes, visit sites and reinvigorate cultural practices).

[22] See Appendix 2 of *Clean Water*, at page 39 (http://www.mfe.govt.nz/fresh-water/freshwater-management-reforms/water-quality-swimming-categories-attribute-states-detail)

Table 5: *Clean Water* Attribute Table for *E. coli*

Value	Human health for recreation	
Freshwater Body Type	Lakes and rivers	
Attribute	*Escherichia coli (E. coli)*	
Attribute Unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)	
Attribute State	**Numeric Attribute State** **Exceedance of the *E. coli* threshold 540 *E. coli*/100 ml**	**Narrative Attribute State**
A (Blue)	Exceeds the *E. coli* threshold less than 5 percent of the time	The river or lake is excellent for swimming. The estimated risk of *Campylobacter* infection is less than 50 cases in every 1,000 exposures.
B (Green)	Exceeds the *E. coli* threshold between 5 percent and 10 percent of the time	The river or lake is good to swim in most of the time. The estimated risk of *Campylobacter* infection is likely higher than 50 cases in every 1,000 exposures.
C (Yellow)	Exceeds the *E. coli* threshold between 10 percent and 20 percent of the time	The river or lake is fair to swim in some of the time. The estimated risk of *Campylobacter* infection is likely higher than 50 cases in every 1,000 exposures.
D (Orange)	Exceeds the *E. coli* threshold between 20 percent and 30 percent of the time	The river or lake is intermittently suitable to swim in. The estimated risk of *Campylobacter* infection is likely higher than 50 cases in every 1,000 exposures.
E (Red)	Exceeds the *E. coli* threshold more than 30 percent of the time	The river or lake is not safe to swim in.
Note: Attribute state must be determined using a minimum of 100 samples, collected on a regular basis regardless of weather conditions, over a maximum of 10 years.		

This table has only one 'Numeric Attribute State' requirement: exceedance rate of an *E. coli* threshold of 540 per 100 mL.[23] Its second version, which has four numeric measures to determine attribute states, appears on the MfE website.[24] In a letter to the Chair of the Land & Water Forum dated 28 February,

[23] For obscure technical reasons 550 *E. coli* as used in the *Guidelines* is slightly different in *Clean Water* (i.e., 540 *E. coli* per 100 mL). This has its origins in setting thresholds for the *NPS* (McBride 2012).

[24] See http://www.mfe.govt.nz/fresh-water/freshwater-management-reforms/water-quality-swimming-categories-attribute-states-detail

the Minister for the Environment has clarified that the intent of the proposal is that all four numeric measures should be used to determine attribute state (and we have assumed that herein).

Table 6: MfE Website *E. coli* Swimming Categories

CATEGORY	PERCENTAGE OF EXCEEDANCES OVER 540: E. COLI PER 100 ML	MEDIAN: E. COLI PER 100 ML	95TH PERCENTILE: E. COLI PER 100 ML	PERCENTAGE OF SAMPLES ABOVE 260: E. COLI PER 100 ML
Blue	< 5 per cent	⩽ 130	⩽ 540	< 20 per cent
Green	5-10 per cent	⩽ 130	⩽ 1000	20-30 per cent
Yellow	10-20 per cent	⩽ 130	⩽ 1200	20-34 per cent
Orange	20-30 per cent	>130	>1200	>34 per cent
Red	> 30 per cent	>260	>1200	>50 per cent

Note too that the website also contains a 'risk profile' in its Table 2, reproduced below.

Table 7: *Clean Water* Risk ProfileThis is Table 2 on MfE's Website entitled 'The risk profile of categories (attribute states).

CATEGORY	PERCENTAGE OF EXCEEDANCES OVER 540: E. COLI PER 100 ML	MEDIAN: E. COLI PER 100 ML	RISK PROFILE
Blue	< 5 per cent	⩽ 130	For at least half the time the estimated risk of Campylobacter infection is less than 1 in 1000. Less than 5 per cent of the time, the estimated risk of Campylobacter infection is ⩾50 in 1000
Green	5-10 per cent	⩽ 130	For at least half the time the estimated risk of Campylobacter infection is less than 1 in 1000. 5-10 per cent of the time the estimated risk of Campylobacter infection is ⩾50 in 1000.
Yellow	10-20 per cent	⩽ 130	For at least half the time the estimated risk of Campylobacter infection is less than 1 in 1000. 10-20 per cent of the time, the estimated risk of Campylobacter infection is ⩾50 in 1000.
Orange	20-30 per cent	>130	20-30 per cent of the time the estimated risk of Campylobacter infection is ⩾50 in 1000.
Red	> 30 per cent	>260	For more than 30 per cent of the time the estimated risk of Campylobacter infection is ⩾50 in 1000.

In the proposed *Clean Water* package, there is a move to require councils to identify 'large rivers and lakes'[25] that will be improved so they are suitable for swimming more often, and an associated target to make 90% of rivers of 4th order or larger 'swimmable' by 2040, as revealed by their grading.[26] To enable enactment of these amendments, and to overcome perceived deficiencies in the current *NPS*, the *Clean Water* package proposes a more nuanced grading system than was used previously. The grading system is composed of Blue, Green, Yellow, Orange and Red Categories. The proposed amendment would require swimmable water bodies to have a median *E. coli* concentration of no more than 130 per 100 mL (Blue, Green, and Yellow Grade waters, i.e., grades A–C), where the median risk of *Campylobacter* infection has been predicted to be extremely low (less than 0.1% or 1 in 1000 exposures). This means that at least 50% of the time, even in rivers graded as Yellow, the predicted median risk to swimmers is very low (less than 0.1%).

Additionally, MfE used our lognormal calculator with three coefficients of variation (for the blue, green and yellow bands)[27] to calculate values for their Table 1 (our Table 6). For each band, they used prescribed coefficients of variation and the median value (130) as the basis to calculate values. [28] The values in their Table define the other three tests (in addition to the median) that must be used to determine a site's attribute state (grading). (Note that as a consequence, tests 1 and 2 are not from the same distribution as tests 3 and 4.)

Clean Water also provides direction on how the grading is to be determined—using a minimum of 100 samples, collected on a regular basis regardless of weather conditions, over a maximum of 10 years.

5.3.2 Surveillance

Clean Water contains a separate table for day-to-day site surveillance. These are essentially numerically identical to the surveillance 'traffic light' system in the 2003 *Guidelines*. Note that *Clean Water* states that *E. coli* greater than 540 per 100 mL warrants an advisory that the site is unsuitable for recreation. This is stronger language than is contained in the *Guidelines*, which require that the 'public be notified that a problem exists'. *Clean Water* also specifies monthly sampling outside of the bathing season and leaves it to Regional Plans to define the season length.

[25] 'Large rivers and lakes' means rivers that are fourth order or above, and lakes larger than 1.5 kilometres in perimeter on average' (*Clean Water* 2017, page 10).

[26] 'Swimmable' appears to be in need of definition. In the Attribute Table in the *Clean Water* report Narrative States A-D all are suitable for swimming, for at least some of the time. However, under Policy A5 in the same document 'For purposes of A5(a), suitable for immersion means large rivers and lakes in Attribute State A, B or C in the *E. coli* attribute table in Appendix 2 of this national policy statement'.

[27] 1.06, 1.92 and 3.0, respectively (Dr Sheree De Malmanche, MfE, pers comm.)

[28] Recalling that the lognormal distribution is defined by only two parameters, another approach is to fix the values of the median (at 130) and the appropriate percentile at 540 (95%ile for the blue band, 90%ile for the green band and 80%ile for the yellow band). This procedure calculates the CoV, so there is no need to specify it. It also calculates the percentage of samples exceeding 260 and 540 *E. coli* per 100 mL.

Table 8: ***Clean Water*** **Surveillance Table**

APPENDIX 5: Monitoring methodologies for Policy CB1

Monitoring requirements for *E. coli*
During the bathing season (as specified in the regional plan), sampling frequency must be at least weekly. If a single sample collected during the bathing season is greater than 260 *E. coli* per 100mL: a) sampling frequency must be increased to daily until a sample less than 260 *E. coli* per 100mL is collected; and b) the regional council must notify the public. If a single sample collected during the bathing season is greater than 540 *E. coli* per 100mL: a) sampling frequency must be increased to daily until a sample less than 260 *E. coli* per 100mL is collected; and b) the regional council should inform the medical officer of health, and notify the public that the site is unsuitable for recreation. Outside of the bathing season (as specified in the regional plan), sampling frequency must be at least monthly.

6 Comparison of Grades

6.1 Elements in Common

Several important commonalities span the recommendation derivations in all three documents (*Guidelines*, *NPS*, *Clean Water*). In particular, a number of assumptions were required to derive the grades articulated within each. The most important common assumptions seem to be:

1. *E. coli* are used as an indicator of faecal contamination providing an indirect linkage to the risk of *Campylobacter* infection and illness from exposure to pathogens. *E. coli* are used as an indicator of possible faecal contamination because they are commonly found in human and animal faeces and are inexpensive to monitor. Many countries use *E. coli* as an indicator of faecal contamination for recreational (and other types of) waters.
2. Quantitative Microbial Risk Assessment (QMRA, Haas *et al*. 1999) for *Campylobacter* infection has been used in all three relevant documents as the basis for the adverse health effects endpoint. Moreover, all three documents rely on dose response relationships for *Campylobacter* based on clinical trial data (Black *et al*. 1988) analysed by international authorities (Medema *et al.* 1996, Teunis & Havelaar 2000). It is also noteworthy that additional outbreak-based dose response data and interpretations are available which could influence the overall interpretation of the level of protection associated with the recommendations (i.e., see Teunis *et al*. 2005).
3. The *E. coli* thresholds were derived through percentile matching between predicted *Campylobacter* infection rates and observed *E. coli* concentrations from results reported for the 1998-2000 Freshwater Microbiological Research Programme (FMRP, McBride *et al.* 2002). This approach is important because it allows data that are specific to New Zealand to be used to derive *E. coli* water quality thresholds. This approach captures the appropriate New Zealand-specific pathogen/indicator mixture that is based on the human/animal faecal contamination present and the relative pathogenicity of the human infectious and zoonotic microorganism mixtures present. Mixtures of human and animal contamination are predicted to vary substantially in their relative pathogenicity (Soller et al., 2014). Exclusive use of data from other locations could potentially result in inappropriate recommendations since most recreational water epidemiological investigations have been conducted in locations predominantly impacted by wastewater effluent—treated and untreated, whereas New Zealand's waters are predominantly impacted by animal contamination from farms.[29]

   The percentile matching process effectively pairs the percentiles of the predicted *Campylobacter* infection (derived via QMRA as described above) with the observed *E. coli* concentration percentiles from the same national-scale New Zealand study. Note that this same approach in a different geographic location could yield different results (since the human/animal faecal contamination present and the relative pathogenicity of the human infectious and zoonotic microorganism mixtures could vary). Appendix A provides the numeric details of this process and a health based interpretation of those results. The most important aspects from the percentile matching are the *E. coli* percentiles at which the *Campylobacter* infection risk:

[29] Consequently, the same risks of infection/illness for different countries could occur at different *E. coli* levels, i.e., one should not expect the *E. coli* levels in guidelines/standards to be the same if the same protection is being afforded.

a. rises above zero (to 0.1%); this is between the 55th percentile and 60th percentile of the infection risk profile. At this point the equivalent *E. coli* concentration is a little greater than 131 per 100 mL (but less than 154 per 100 mL);
b. reaches 1% just after the 70th percentile of the infection risk profile. At this point the *E. coli* concentration is 261 per 100 mL; and
c. reaches 5% between the 80th percentile and 85th percentile of the infection risk profile. At this point the average *E. coli* concentration is 537 *E. coli* per 100 mL.

6.2 Differences

Table 9 presents a graphical comparison of the median and 95th percentile values in the *Guidelines*, *NPS* and *Clean Water* documents followed by a discussion of the comparison.

Table 9: Graphical Interpretation of Median and 95%ile Values Apricot colour denotes the median; light blue denotes the 95%ile.

													0.1% Campy Infection		1% Campy Infection		5% Campy Infection					
Percentile of Distribution	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	97.5	>97.5
Predicted Campylobacter infection / 1000	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	18	26	72	131	329	435	>435
E. coli MPN/100mL	-	4	9	14	29	32	40	51	66	91	110	131	154	191	260	332	461	613	980	1986		>1986
2003 MfE/MoH Grade A												130										
2003 MfE/MoH Grade B															260							
2003 MfE/MoH Grade C																	550					
2003 MfE/MoH Grade D																			>550			
2014 NPS Grade A															260							
2014 NPS Grade B																	540					
2014 NPS Grade C																			1000			
2014 NPS Grade D																			>1000			
2017 NPS Clean Water Blue												130					540					
2017 NPS Clean Water Green												130							1000			
2017 NPS Clean Water Yellow												130							1200			
2017 NPS Clean Water Orange													>130 but <260								>1200	
2017 NPS Clean Water Red															>260						>1200	

6.2.1 *NPS* Compared to the 2003 *Guidelines*

The following observations may be made:

1. The 2014 *NPS* Grade (i.e., Attribute State) A is similar to the 2003 *Guidelines* Grade B; and
2. The 2014 *NPS* Grade B is similar to the 2003 *Guidelines* Grade C.

6.2.2 *Clean Water* 2017 Compared to *NPS* and *Guidelines*

Compared to the 2003 *Guidelines* and 2014 *NPS*, the following observations may be made concerning MfE's Table):[30]

1. The 2017 *Clean Water* Blue Grade is similar to the 2003 *Guidelines* Grade C and the *NPS* Grade B;
2. The 2017 *Clean Water* Orange Grade is more restrictive than the *NPS* Grade C;

[30] These direct comparisons can only be made using MfE's Table 2, not their Table 1.

3. The 2017 *Clean Water* Blue, Green, and Yellow Grades represent conditions where the predicted risk of *Campylobacter* infection is less than 0.1% for 50% of the time, whereas neither the 2003 *Guidelines* nor the 2014 *NPS* are able to quantify this condition.

As described previously, the risk profiles are based on predicted levels of *Campylobacter* infection derived via QMRA and percentile matching with observed *E. coli* levels during the 1998-2000 FMRP. Review of the summary table indicates that:

- *Clean Water* Blue Grade would be expected to have *Campylobacter* infection levels less than 0.1% (1/1000) at least 50% of the time and > 5% less than 5% of the time;
- *Clean Water* Green Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 5% less than 10% of the time;
- *Clean Water* Yellow Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 5% less than 20% of the time;

The minimum acceptable state for swimming under *Clean Water* corresponds to the bottom of the Yellow Grade. As indicated above, the *Clean Water* Yellow Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 5% less than 20% of the time.

The level of protection for swimming associated with each 2014 *NPS* grade is slightly more difficult to characterize because its categories only describe 95th percentiles and not median values. Using FMRP data and the previously described QMRA results along with the percentile matching procedure, it is possible to estimate (at a coarser level) the level of protection associated with each 2014 *NPS* grade. Those estimations reveal that:

- the 2014 *NPS* A Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 1% less than 5% of the time;
- 2014 *NPS* B Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 5% less than 5% of the time; and
- 2014 *NPS* C Grade (if used for swimming) would be expected to have *Campylobacter* infection levels less than ~13% at least 50% of the time.

The minimum acceptable state for swimming under the 2014 *NPS* corresponds to the bottom of its B Grade. As indicated above, 2014 *NPS* B Grade would be expected to have *Campylobacter* infection levels less than 0.1% at least 50% of the time and > 5% less than 5% of the time.

As noted previously, the *Clean Water* Blue Grade and the 2014 *NPS* B Grade appear similar in terms of restrictiveness. However, a direct restrictiveness comparison between the 2014 *NPS* and the proposed *Clean Water* package requires caution because not all aspects of the *Clean Water* and 2014 *NPS* attributes are in common. For example:

- *Clean Water* seeks to enhance the minimum expectation for microbial quality, from an *E. coli* median of 1000 per 100 mL in the 2014 *NPS* to 130 per 100 mL, for 90% of the freshwaters covered by the proposal;
- *Clean Water* has an inferred minimum acceptable state for swimmable waters (bottom of the yellow band) that has a less stringent requirement than the minimum acceptable state in 2014 *NPS* – *Clean Water* allows exceedance of 540 *E. coli* per 100 mL for up to 20% of the time whereas the *NPS* allows only 5% exceedance;

- *Clean Water* has, for its highest grading, requirements that appear less stringent than those in *NPS* – the *Clean Water* Blue grade allows 5% exceedance of 540 *E. coli* per 100 mL whereas the *NPS* A band allows a 5% exceedance of only 260 *E. coli* per 100 mL;
- *Clean Water* has a median requirement and three other tests for swimmable grading, which the *NPS* does not have – depending on the variability of the data at a particular site, one of these other tests may be most constraining to the site's swimmable grading under *Clean Water*; and
- *Clean Water* provides clear direction that requires grading to be determined from samples collected on a regular basis regardless of weather conditions - *i.e.*, it may include samples from high flows. Given that such samples may be expected to have high *E. coli* levels, this requirement introduces a stringency that is potentially absent from application of the *NPS* (where no direction on sampling protocols is given);

6.2.3 Other Countries versus New Zealand

The interpretation of faecal indicator bacteria with respect to risks associated with recreation in New Zealand freshwaters are likely unique compared to other locations around the globe, due to the faecal contamination sources present in New Zealand waters relative to those in other countries. Most countries base their recreational water quality guidelines on exposure to waters impacted predominantly by human sources (for example, see US EPA, 2012). Human sources are known to present high risks to humans, whereas the risks associated with animal sources can vary from relatively low to relatively high (Soller *et al*., 2010a,b). Nevertheless, a comparison of 2003 *Guidelines*, 2014 *NPS*, and 2017 *Clean Water* (the median and 95th percentile tests in Table 6) with international criteria is *illustrative* and shown in Table 10. (Note: EU Sufficient grade is excluded from this comparison because it is a 90 percentile).

Table 10: Comparisons with New Zealand and Overseas Approaches

													0.1% Campy Infection		1% Campy Infection		5% Campy Infection					
Percentile of Distribution	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	97.5	> 97.5
Predicted Campylobacter infection / 1000	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	18	26	72	131	329	435	>435
E. coli MPN/100mL	-	4	9	14	29	32	40	51	66	91	110	131	154	191	260	332	461	613	980	1986		>1986
2003 MfE/MoH Grade A												130										
2003 MfE/MoH Grade B															260							
2003 MfE/MoH Grade C																	550					
2003 MfE/MoH Grade D																			>550			
2014 NPS Grade A															260							
2014 NPS Grade B																	540					
2014 NPS Grade C																			1000			
2014 NPS Grade D																				>1000		
2017 NPS Clean Water Blue												130					540					
2017 NPS Clean Water Green												130							1000			
2017 NPS Clean Water Yellow												130							1200			
2017 NPS Clean Water Orange													>130 but <260								>1200	
2017 NPS Clean Water Red															>260						>1200	

USA RWQC - Set as 32/1000 ILLNESSES, effective CV=1.14											100						454					
USA RWQC - Set as 36/1000 ILLNESSES, effective CV=1.15												126						570				
WHO Guidelines - NOT in terms of EC, but the ENT values closely corrspond to USA ENT values which are equivalently protective to EC values via the EC derivation - estimated to be 50/1000 ILLNESS										Estimated							Estimated					
EU - Excellent Quality Bathing Water										Estimated							500					
EU - Good Quality Bathing Water													Estimated						1000			

Median value
95th %ile

***E. coli* swimmability thresholds: International comparison**

NZ	USA	EU	
AIB: 260*	126[¶] & 410*	Excellent:	500*
MAS: 540*	100[¶] & 320*	Good:	1,000*
		Sufficient:	900*

Units: #/100mL. *95%ile, ^90%ile, [¶]geometric mean
NZ max Campy infection risks are 1% (AIB) and 5% (MAS)
USA criteria are for max illness risks of 3.6% or 3.2%
EU freshwater guidelines are derived starting with WHO guidelines but are not specifically risk-based

Based on Table 10, the following observations may be made:[31]

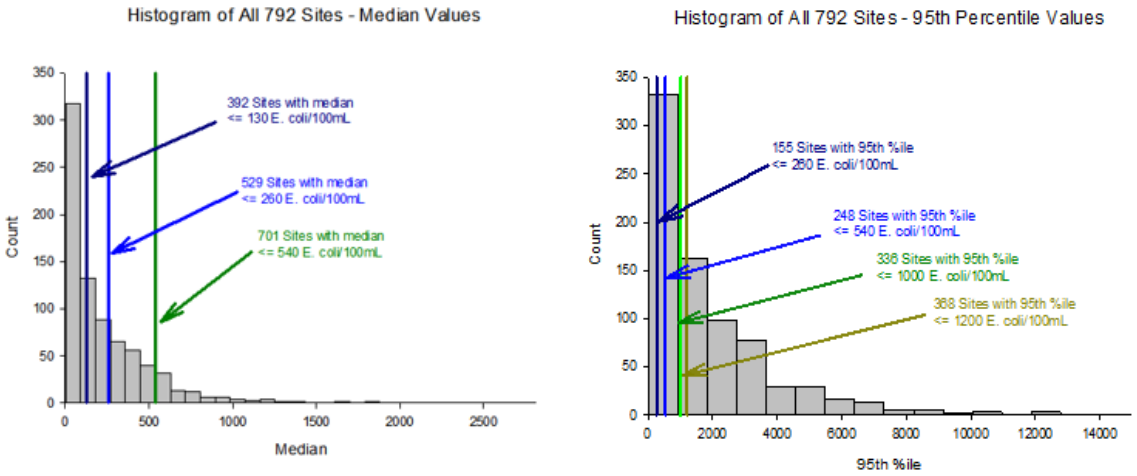
1. 2003 *Guidelines* Grades A and B and the 2014 *NPS* Grade A are more stringent than those in the USA, EU, or recommended by WHO;
2. 2003 *Guidelines* Grade C, the 2014 *NPS* Grade B, and 2017 *Clean Water* Blue are similar to those in the USA, the EU excellent Grade, and those recommended by WHO;
3. The EU Good Grade is slightly more restrictive than the 2017 *Clean Water* Yellow Grade, similar to the *Clean Water* Green Grade and more permissive than the *Clean Water* Blue Grade.
4. The USA and WHO recommendations correspond to average predicted risk levels of ~3-5% illness among recreational water users. This predicted average illness level is different than the (average or 95th percentile) *Campylobacter* infection levels predicted in NZ waters even though the faecal indicator water quality levels are similar. In fact, illness levels in NZ water at the same indicator levels may be lower than predicted in other locations impacted by human sources, but definitive data (especially for sheep faeces) are not available in this regard.
5. The *Clean Water* minimum acceptable state for swimming (bottom of the Yellow Grade) is more in line with the EU guidelines for swimming (Good) than the *NPS* which sets the minimum acceptable state for swimming at a level that is approximately consistent with the criteria values in USA, the EU excellent Grade, and those recommended by WHO.

[31] Results are indicative only because the various jurisdictions have different rules and methodologies for site grading. For example, the EU standard allows for up to 15 percent of samples to be discarded due to short term pollution; the USA approach is defined for each 30 day period and limits the geometric mean and the excursion frequency of the 'Statistical Threshold Value'; *Clean Water* requires a minimum of 100 samples. In the time and resources available we were not able to furnish such a detailed analysis.

7 Effects of Changing from *NPS* to *Clean Water* on River Grades

To set the context for the changes proposed in *Clean Water*, we present below histograms of the distribution of median and 95%ile *E. coli* concentrations for 792 river sites spread over New Zealand.[32] These data come from NIWA's National River Water Quality Network (NRWQN) data[33] and Regional Council datasets, over the period 2005-2013.[34]

Figure 7-1 Histograms of Statistics for the 792 River Sites



As shown, of the 792 sites, 392 sites had median values less than 130 /100 mL, 529 sites had median values less than 260 /100 mL, and 701 sites had median values less than 540 /100 mL. Also, 155 sites had 95th percentile values less than 260 /100 mL, 248 sites had 95th percentile values less than 540 /100 mL, 336 sites had 95th percentile values less than 1000 per 100mL, and 358 sites had 95th percentile values less than 1200 /100mL. These threshold values correspond to the *Clean Water*[35] blue, green, and yellow band median and (predicted) 95th percentile values (based on the allowable percent above 540 *E. coli* per 100mL) (with an additional median value of 130 and 95th percentile value of 260 included for comparison). These data also illustrate how the use of both a median value and 95th percentile value (as in *Clean Water*) can be useful for describing the full distribution of microbial water quality and associated risks as compared to just a single value (as in the *Guidelines*, *NPS*, and some international guidelines).

7.1 International and New Zealand comparisons

To illustrate the potential implications of changing from *NPS* to *Clean Water*, we used all of the data described above, a subset of these data that just includes those sites that meet the proposed *Clean Water* 4th order and above size criteria for inclusion, and another subset of the data (data collected in the National Rivers Water Quality Network (NRWQN), to compare the predicted number of sites that would be classified as swimmable (i.e., at least meets the minimum acceptable state) under a range of

[32] Data obtained from MfE, for the period 2005-2013 inclusive. These data include the NRWQN, for completeness.

[33] https://data.mfe.govt.nz/table/2532-river-water-quality-raw-data-by-nrwqn-site-1989-2013/

[34] Note that strictly only those sites on rivers with stream order 4 and above (and with a least 100 *E. coli* data) should be displayed, to reflect the *Clean Water* requirements. These 'qualifying' sites are considered in Table 11.

[35] That is, MfE website's Table 1.

approaches.[36,37] Note that this analysis does not take account of the possible variation between countries with respect to the potency of faecal pathogens in rivers. Nor should it do so. The comparison is based on the question 'What would be the effect were the international *E. coli* thresholds to be applied in New Zealand? The elements in this comparison[38] include the:

- European Union 'Sufficient' or 'Good' grades,[39]
- 2012 Recreational Water Quality Criteria from the USA: Recommendation 1 or Recommendation 2,[40]
- 2014 *NPS* bottom of the B Grade,
- *Clean Water* bottom of the yellow grade using tests 1–4 (see our Table 6), where all four tests must be met to qualify for an attribute state (as stated in a letter of 28 February from the Minister for the Environment to the Chair of the Land and Water Forum).

Table 11: The effect of using different methods to measure 'swimmability' attainment for NZ river sites using data for the period 2005-2013

Approach	% 'swimmable' All data	% 'swimmable' sites ≥ 4th order	% 'swimmable' NRWQN sites	Comment
EU	54%	57%	72%	Sufficient or Good
USEPA (2012)	36%	39%	49%	Recommendation 1 or recommendation 2
NPS (2014)	30%	31%	43%	Bottom of the B band
Clean Water (2017)	43%	46%	62%	Bottom of yellow band

Result are shown for: All Data = Regional/District Council data (including NRWQN data), 792 sites; Sites.4th order and above (= same data but only for all streams at least fourth order), 591 sites; NRWQN sites = data from the NRWQN run by NIWA, 76 sites; *Clean Water* 'yellow and above) is from MfE's Table 1 (our Table 6) – i.e., all 4 tests.

Unsurprisingly, from these results we can infer that the number of sites that would be classified as swimmable will vary depending on the approach taken as to how swimmability is defined. The following observations may be made from this table:

[36] https://data.mfe.govt.nz/table/2532-river-water-quality-raw-data-by-nrwqn-site-1989-2013/. The period used was 2005 – 2013 inclusive i.e., 9 years (*E. coli* sampling commenced in 2005).

[37] Again, *results are indicative only* because the various jurisdictions have different rules and methodologies for site grading. For example, the EU standard allows for up to 15 percent of samples to be discarded due to short term pollution; the USA approach is defined for each 30 day period and limits the geometric mean and the excursion frequency of the 'Statistical Threshold Value'; *Clean Water* requires a minimum of 100 samples. In the time and resources available we were not able to furnish such a detailed analysis.

[38] Comparison with the *Guidelines* 2003 is thwarted by the need to consider its sanitary survey component, as required by the 'Annapolis protocol (see section 5.1.1).

[39] It is theoretically possible to achieve 'Sufficient' and not 'Good'—because the former is based on a 90%iles (900 *E. coli* per 100 mL) while the latter is based on a 95%ile (1000 *E. coli* per 100 mL)—but that hasn't occurred in the data we have examined.

[40] https://www.epa.gov/sites/production/files/2015-10/documents/rec-factsheet-2012.pdf: "…either of which would protect the designated use of primary contact recreation…"

- The EU 'Sufficient' and 'Good' grades are more permissive than the *Clean Water* proposal in which Blue+Green+Yellow bands are considered swimmable;
- The *Clean Water* proposal is more permissive than the USA 'criteria';[41]
- *Clean Water* proposal is more permissive than *NPS* (2014).

The results shown in Table 11 do not match with the swimmable results given on page 11 of the *Clean Water* discussion document, because the latter uses results from modelling rather than a site-by-site analysis. That modelling, by its very nature, seeks to be more representative of general river conditions nation-wide whereas the dataset is biased by the focus of regional council monitoring on the most polluted waterways in lowland streams and rivers, which is understandable.

Note that these results are in strong contrast with attainment of secondary contact thresholds in *NPS* 2014: 97% of sites have a median *E. coli* less than 1,000 *E. coli* per 100 mL and therefore meet the current National Bottom Line.

[41] USA 'criteria' are in effect minimum standards, promulgated by the USEPA that States are generally required to comply with.

8 Infection Risk for a Random Person on a Random Day

The overall average infection risk to swimmers can be calculated, based on the assumption that the *E. coli* concentration at a site follows the lognormal statistical distribution and ignoring any possibility of not swimming when a surveillance advisory is in place.

Swimmers ingest water during recreational activities, thus, in effect, a swimmer is sampling from that distribution on each swimming occasion. Then, adopting the percentile-matching procedure given in Appendix A we find the *E. coli* percentile, and use that percentile to identify an estimated infection risk. This process is repeated many times in 'Monte Carlo' risk modelling. Details are given in Appendix C.

For the four-test procedure for *Clean Water* given in MfE's Table 1 (presented in this document in Table 6) we obtain the following results.

Table 12: Average Risk under *Clean Water* Proposals

Band[42]	Predicted average infection risk (%)
Blue (A)	1.0
Green (B)	2.4
Yellow (C)	3.1
Orange and Red (D and E)	>3.1

Note that our computed average risks are very similar to those predicted by Dr Jonathan Marshall.[43]

Note also that the average risks presented in Table 12 are likely higher than their actual values—because in performing the Monte Carlo modelling a site's *E. coli* concentration was assumed to be *exactly at* the test rules requirements. Some assumption is always necessary to facilitate risk calculations; in this case the particular assumption yields a precautionary result.

8.1 Effect of the precautionary approach?

In the *Guidelines*, *NPS*, and *Clean Water* the swimmability thresholds are based on a precautionary approach. That is, *E. coli* concentrations at the thresholds between grades are set as 95%iles, even though they are estimated as medians (see section 5.1.1, item 3). However the risk calculations computed here are not reliant on such re-setting to 95%iles. As the graphs in Appendix C demonstrate, the FMRP *E. coli* and *Campylobacter* data were taken at 'face value'. Therefore the risks presented are indeed *on average*, rather than being in some sense precautionary.

[42] The risk associated with the red Grade cannot be calculated (because its two *E. coli* concentrations are both minima).

[43] https://github.com/jmarshallnz/nzwater/blob/master/README.md

9 Authors' Commentary

The compilation of information presented above provides an opportunity for reflection and consideration of the relative stringency and potential effectiveness of the *Clean Water* Grades. Following are points for consideration:

- The 2017 *Clean Water* Blue, Green and Yellow Grades all restrict median risks to be less than 1 infection per 1000 exposures. A grading scheme that required a lower median value would not necessarily result in a lower median risk value since 130 *E. coli* per 100 mL is essentially a 'No Observed Adverse Effect Level' (NOAEL);
- The 2017 *Clean Water* Blue, Green and Yellow Grades differ in their treatment of variability within the *E. coli* distribution since the median values are all set at the same value. Higher risk conditions are likely to occur during time periods that correspond to the right-most portion (tail) of the water quality distributions. Grading that considers use of median, exceedance of 260 *E.coli* per 100 mL, exceedance of 540 *E.coli* per 100 mL and 95th percentile appears to provide a meaningful level of protection augmentation relative to recommendations that rely solely on the 95th percentile;
- The *Clean Water* Blue Grade (the highest grade in *Clean Water*) appears less restrictive as compared to the 2003 *Guidelines* Grades A and B, and the 2014 *NPS* Grade A. The *Clean Water* Blue Grade appears similarly restrictive to the 2003 *Guidelines* Grade C, the 2014 *NPS* Grade B, the USA Recreational Water Quality Criteria (RWQC, USEPA 21012), and the EU (EU Directive 76/160/EEC)[44] Excellent Grade.
- Compared to other Grading approaches (*Guidelines*, 2014 *NPS*, US RWQC), the 2017 *Clean Water* Grades appear to be focused within a relatively narrow range.
- The *Clean Water* grading proposal to use up to 10 years of data (compared to the *Guidelines* 5 years) could be problematical in situations where there is widespread increase in management actions (such as fencing of streams for livestock exclusion) when exceedances of 260, 540 and 95%ile values are the determinants of a site's final grading. A few high results from the early part of a monitoring period could effectively fix a site's grade long after it has improved. As noted by WHO (2003), 60 samples for percentile estimation over such a period should suffice—and see section 2.2.2 ('How many samples?') in McBride (2016). A hundred samples seems excessive; on the order of 50 should suffice.[45]
- The requirement for daily Surveillance sampling once a result greater than 260 *E. coli* per 100 mL is obtained could be onerous (but is also included in the *Guidelines,* although these guidelines are advisory rather than mandatory).

[44] https://www.epa.gov/sites/production/files/2015-10/documents/rec-factsheet-2012.pdf

[45] The *Guidelines* (at page 54) state: 'Ideally there should be 100 data points or greater collected over the previous five years, although it is feasible to consider grading with a minimum of 20 data points collected over one full bathing season'.

10 Acknowledgments

Chris McBride (University of Waikato) provided most of the analysis of the National Rivers Water Quality Network data which provided the basic machinery for the results in Table 11. Useful discussions were had with Dr Sheree De Malmanche (MfE) concerning development of the *Clean Water* proposals and provision of data.

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[46] Available from the first author.
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Appendix A Percentile Matching

The percentile matching approach is based on the observation that there was moderate correlation between *Campylobacter* concentrations and *E. coli* concentrations. The *Campylobacter* concentrations were used to derive predicted *Campylobacter* infection rates via QMRA.

Table A3.7.3 in the technical report for the 2003 *Guidelines*[48] (for all beaches and all seasons) states percentiles of predicted *Campylobacter* infection rate (per 1,000 randomly exposed people) as:

55%ile 0

60%ile 1

65%ile 3

70%ile 9

75%ile 18

80%ile 26

85%ile 72

90%ile 131

95%ile 329

Table A.3.3.2 gives percentiles of *E. coli* concentrations (per 100 mL) for all beaches and all seasons as:

55%ile 131

60%ile 154

65%ile 191

70%ile 261

75%ile 332

80%ile 461

85%ile 613

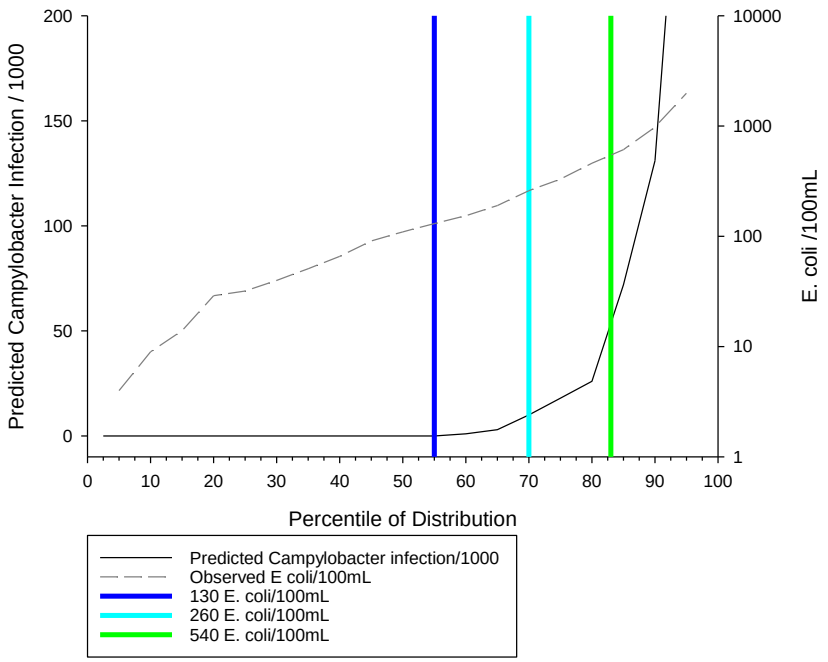
90%ile 980

95%ile 1986

An illustration of the how these data align is presented below.

[48] http://www.mfe.govt.nz/sites/default/files/freshwater-microbiology-nov02.pdf

Illustration of Percentile Matching for
Predicted Campylobacter Infection and Observed E. coli

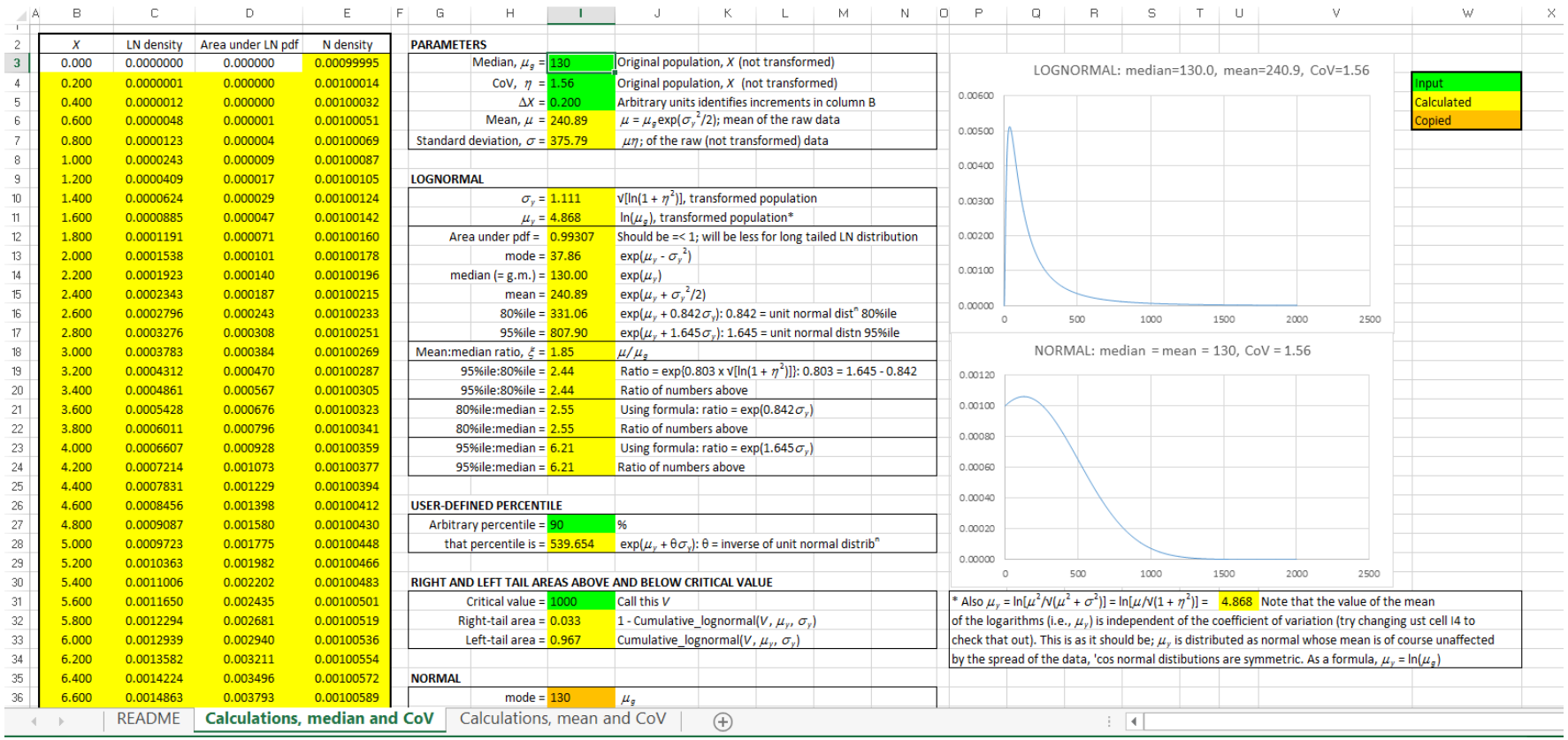


Review of these data indicate that the *E. coli* percentile at which the *Campylobacter* infection risk:

- rises above zero (to 0.1%) is between the 55%ile and 60%ile of the infection risk profile where the equivalent *E. coli* percentile is a little greater than 131 per 100 mL (but less than 154 per 100 mL)
- reaches 1% just after the 70%ile of the infection risk profile (where it is 9/1000 = 0.9%), where the *E. coli* concentration for that percentile is 261 per 100 mL.
- reaches 5% somewhere between the 80%ile and 85%ile of the infection risk profile (where it is 9/1000 = 0.9%), where the *E. coli* concentrations are 461 and 613 per 100 mL: taking a simple average this is 537 *E. coli* per 100 mL.

Appendix B Calculating Percentiles using the Lognormal Distribution

To facilitate detailed percentile calculations we developed (and tested) an Excel-based lognormal distribution calculator (it also provides normal distribution calculations). Once a median and a coefficient of variation[49] are supplied (in the green cells in the PARAMETERS box), it calculates various characteristics of these distributions. Only the green input cells can be modified, the rest are locked—to avoid any inadvertent corruption of formulae contained therein. Results for the lognormal distribution are particularly appropriate for right-skewed microbiological datasets such as are found for rivers, subject to occasional 'spikes'.



X	LN density	Area under LN pdf	N density
0.000	0.0000000	0.000000	0.00099995
0.200	0.0000001	0.000000	0.00100014
0.400	0.0000012	0.000000	0.00100032
0.600	0.0000048	0.000001	0.00100051
0.800	0.0000123	0.000004	0.00100069
1.000	0.0000243	0.000009	0.00100087
1.200	0.0000409	0.000017	0.00100105
1.400	0.0000624	0.000029	0.00100124
1.600	0.0000885	0.000047	0.00100142
1.800	0.0001191	0.000071	0.00100160
2.000	0.0001538	0.000101	0.00100178
2.200	0.0001923	0.000140	0.00100196
2.400	0.0002343	0.000187	0.00100215
2.600	0.0002796	0.000243	0.00100233
2.800	0.0003276	0.000308	0.00100251
3.000	0.0003783	0.000384	0.00100269
3.200	0.0004312	0.000470	0.00100287
3.400	0.0004861	0.000567	0.00100305
3.600	0.0005428	0.000676	0.00100323
3.800	0.0006011	0.000796	0.00100341
4.000	0.0006607	0.000928	0.00100359
4.200	0.0007214	0.001073	0.00100377
4.400	0.0007831	0.001229	0.00100394
4.600	0.0008456	0.001398	0.00100412
4.800	0.0009087	0.001580	0.00100430
5.000	0.0009723	0.001775	0.00100448
5.200	0.0010363	0.001982	0.00100466
5.400	0.0011006	0.002202	0.00100483
5.600	0.0011650	0.002435	0.00100501
5.800	0.0012294	0.002681	0.00100519
6.000	0.0012939	0.002940	0.00100536
6.200	0.0013582	0.003211	0.00100554
6.400	0.0014224	0.003496	0.00100572
6.600	0.0014863	0.003793	0.00100589

PARAMETERS

Median, μ_g =	130	Original population, X (not transformed)
CoV, η =	1.56	Original population, X (not transformed)
ΔX =	0.200	Arbitrary units identifies increments in column B
Mean, μ =	240.89	$\mu = \mu_g \exp(\sigma_y^2/2)$; mean of the raw data
Standard deviation, σ =	375.79	$\mu\eta$; of the raw (not transformed) data

LOGNORMAL

σ_y =	1.111	$\sqrt{[\ln(1+\eta^2)]}$, transformed population
μ_y =	4.868	$\ln(\mu_g)$, transformed population*
Area under pdf =	0.99307	Should be =< 1; will be less for long tailed LN distribution
mode =	37.86	$\exp(\mu_y - \sigma_y^2)$
median (= g.m.) =	130.00	$\exp(\mu_y)$
mean =	240.89	$\exp(\mu_y + \sigma_y^2/2)$
80%ile =	331.06	$\exp(\mu_y + 0.842\sigma_y)$: 0.842 = unit normal distn 80%ile
95%ile =	807.90	$\exp(\mu_y + 1.645\sigma_y)$: 1.645 = unit normal distn 95%ile
Mean:median ratio, ξ =	1.85	μ/μ_g
95%ile:80%ile =	2.44	Ratio = $\exp\{0.803 \times \sqrt{[\ln(1+\eta^2)]}\}$: 0.803 = 1.645 - 0.842
95%ile:80%ile =	2.44	Ratio of numbers above
80%ile:median =	2.55	Using formula: ratio = $\exp(0.842\sigma_y)$
80%ile:median =	2.55	Ratio of numbers above
95%ile:median =	6.21	Using formula: ratio = $\exp(1.645\sigma_y)$
95%ile:median =	6.21	Ratio of numbers above

USER-DEFINED PERCENTILE

Arbitrary percentile =	90	%
that percentile is =	539.654	$\exp(\mu_y + \theta\sigma_y)$: θ = inverse of unit normal distrib^n

RIGHT AND LEFT TAIL AREAS ABOVE AND BELOW CRITICAL VALUE

Critical value =	1000	Call this V
Right-tail area =	0.033	1 - Cumulative_lognormal(V, μ_y, σ_y)
Left-tail area =	0.967	Cumulative_lognormal(V, μ_y, σ_y)

NORMAL

mode =	130	μ_g

[49] The Coefficient of Variation ('CoV', or '⍰' in the PARAMETERS box) is defined as the standard deviation of the raw data divided by their mean.

Appendix C Calculating Infection Risks

The overall infection risk to swimmers can be calculated, based on the assumption that the *E. coli* concentration at a site follows the lognormal distribution. This distribution is uniquely defined by only two parameters.[50] Because there are four tests we fitted two lognormal distributions to tests 1&2 and tests 3&4, respectively, based in each case of percentiles and associated numbers of exceedances of thresholds.

Adopting the percentile-matching procedure given in Appendix A, we use the lognormal calculator (Appendix B) to calculate the following iterative Monte Carlo sequence:[51,](i) select a random value of *E. coli* concentration from that lognormal distribution; (ii) find the corresponding *E. coli* percentile; (iii) calculate the value of the *Campylobacter* infection risk at that percentile. This requires some curve fitting to percentiles of FMRP *E. coli* data and that study's predictions of *Campylobacter* percentiles. These are shown graphically In Figures C1–C3 below.

Calculating the FMRP percentile of the selected *E. coli* concentration and associated risk

A functional form was fitted to the FMRP data (McBride *et al.* 2002).[52]

- predicted *E. coli*: $E_{pred} = d[\exp(kp)]^g$ with parameter values $k = 6$, $d = 0.07$, $g = 1.8$ and p is the percentile abscissa (i.e., p runs in increments from 0 to 100), as shown in Figure C1 below.[53]
- This relationship was then inverted to get a predictive equation for the percentile ($100p$) corresponding to E_{pred}, i.e, $p = (\ell n(E_{pred}) - \ell n(d))/(kg)$, with $k = 8.6$, $d = 0.001$ and $g = 2$, as shown in Figure C2 below.
- Finally, this proportion (p) was inserted into the infection–percentile relationship to obtain $n_{prop,pred} = 0$ if $p \le 0.55$, else $d(e^{(k(p-0.5)-1)})^g$, as shown on Figure C3.

Because there are two (different) distributions (i.e., one for tests 1 and 2, and another for tests 3 and 4), we must take the *minimum* of the calculated risks for the two distributions.[54] That results in the risks shown in Table 12 which are for test 3 and 4. The average risk computed for the yellow band is 5.3% (cf. 3.1% in that table).

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[50] That is, any two from this list: mean, median, coefficient of variation, or a percentile (including the possibility that both parameters are percentiles, as will be done here). We choose one of them

[51] The Monte Carlo calculations were carried out using @RISK (Palisade Corp 2013). The lognormal function in @RISK requires specification of the mean and standard deviation (not their logarithms) whereas our lognormal calculator (Appendix B) requires specification of the median (or upper percentile) and the coefficient of variation (CoV). To get those parameters, using the calculator we adjust the CoV until the appropriate percentile (95, 90, 80) becomes very close to the appropriate *E. coli* concentration or the permissible number of exceedances (for tests 1 and 4). For the blue, green and yellow bands in the test 1&2 components the CoV values were 1.06, 1.56 and 4.06, respectively. For tests 3&4 the CoV values were 1.15, 1.80 and 1.92 respectively. The corresponding means and standard deviations for these six CoV values were: (189.4, 200.8); (240.9, 375.9); (543.6, 2207); 181.8, 209.1); (285.1, 513.2); (336.8, 645.7).

[52] The most important of these data—those at or above the 55th percentile for *E. coli* and *Campylobacter*—are given in Appendix A.

[53] The FMRP dataset contains 1.65% *E. coli* results greater than 2500 per mL. This has been handled by a random selection between 2500 and the maximum recorded (29090 *E. coli* per 100 mL) when a percentile between 98.35% and 100% is required.

[54] The minimum is taken because the threshold *E. coli* concentrations for tests 3 and 4 are generally more strict.

Figure C1: *E. coli* fitted to FMRP data

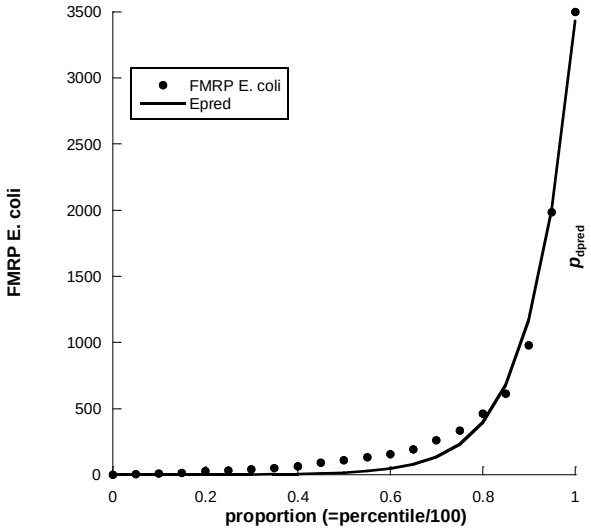


Figure C2: Predicting *E. coli* percentiles

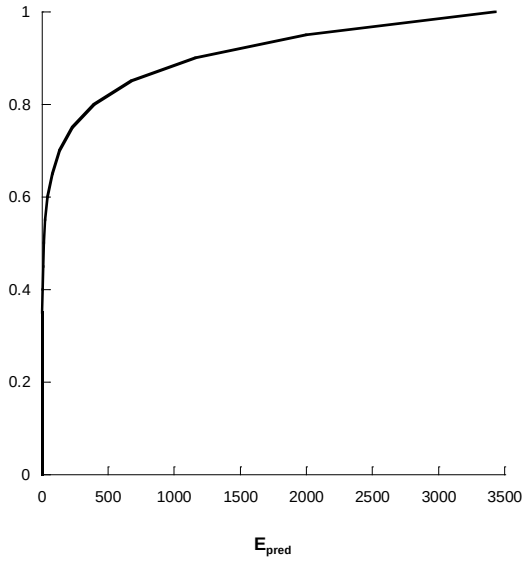
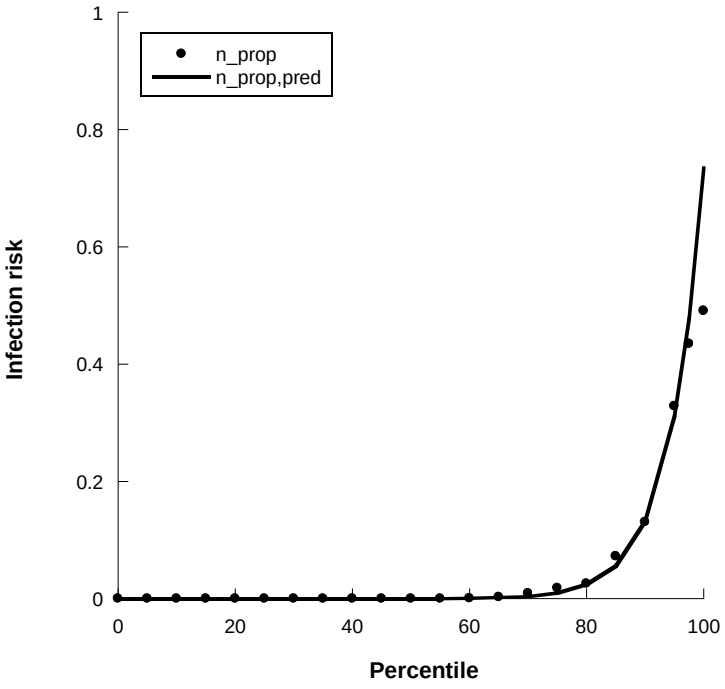


Figure C3: predicting risk from *Campylobacter* percentiles



Doing the calculations

These were obtained using @RISK for 10,000 iterations. The mean predicted proportion of infection was then used as the risk measure.