Recreational Water Quality Guidelines Update

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DISCLAIMER

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EXECUTIVE SUMMARY

Water recreation is important to the wellbeing of communities and can provide economic benefits from tourism. However, the presence of pathogens from environmental faecal contamination may adversely affect public health. Recreational water quality guidelines are developed to protect public health and to support management of water quality. Recognising the importance of recreation to New Zealand, national targets have also been set to improve water quality generally to meet the acceptable microbiological criteria for recreational activity.

A review of the international guidelines highlights that while the methodology used to develop the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE 2003) differs from international approaches, health targets are similar and there is good evidence to support the choice of *Escherichia coli* (*E. coli*) as the faecal indicator bacteria (FIB) for freshwater. Despite research on indicators, other than *E. coli* or enterococci, there is insufficient evidence to include any other indicators in regulations at this time.

New Zealand monitoring and management processes for recreational areas are similar to international guidelines, except there is a specific requirement to sample daily when *E. coli* concentration is elevated above 260 MPN/100 mL. This involves a significant use of resources, whereas the approach given in international guidelines would allow councils to invest resources in identifying faecal sources and mitigations, rather than daily monitoring.

International guidelines usually include hazards such as cyanobacteria and other microbial hazards, such as wound infections and skin irritations. Another area of difference is that New Zealand has specific criteria for protection of health in the NZ Guidelines and the National Policy Statement for Freshwater Management (NPS-FM) 2020 (New Zealand Government 2020). The NPS-FM 2020 does not reflect the international guidelines as it is aimed at improving water quality overall to a standard which could be used for recreation, rather than managing recreational sites. A better explanation of these differences and reference to the NZ Guidelines would improve clarity for water quality managers.

Both Quantitative Microbial Risk Assessment (QMRA) and microbial source tracking (MST) have been shown to support investigations on faecal contamination. QMRA can model different risk and management scenarios and aligns well where epidemiological studies have been assessed. The sanitary survey for identifying faecal sources is limited to observation and documentation. MST is a new tool which is a useful part of a toolbox for identification of faecal sources. Predictive modelling is also seen as a cost-efficient tool where events that lead to contamination are well known eg rainfall. However, models are site specific and would need validation.

Future issues identified in the international literature and reviews include antimicrobial resistance, the emergence of new pathogens, sampling regimes for recreational activities outside the bathing season and environmental sources of FIB.

1 INTRODUCTION

Water recreation is important to the wellbeing of communities and can provide economic benefits from tourism. However, the presence of pathogens from environmental faecal contamination may adversely affect public health. Recreational water quality guidelines are developed to protect public health and to support management of water quality. Recognising the importance of recreation to New Zealand, national targets have also been set to improve water quality generally to meet the microbiological criteria for recreational activity.

The Ministry for the Environment and Ministry of Health are supporting a revision of the Quantitative Microbial Risk Assessment (QMRA)[1] used in the New Zealand Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (NZ Guidelines) (MfE 2003), to ensure that they reflect the current risk to human health. In the 20 years since they were developed, there have been changes in land use, waste management practices and improvements in analytical technologies. The derivation of New Zealand's guidelines differs significantly from international approaches in that it was based on a QMRA of freshwater sites across New Zealand rather than international epidemiological studies, which were based on water impacted by human wastewater discharges.

The focus of this update is on faecal contamination of recreational freshwater. An overview is given of current guidelines of New Zealand, World Health Organisation (WHO), US, Canada, Australia, European Union (EU). Key documents from WHO, US Environmental Protection Agency (US EPA) and the EU, together with recent literature are reviewed with regards to faecal contamination and management of freshwater. The NZ Guidelines and the National Policy Statements (NPS-FM) released in 2014, 2017 and 2020 (New Zealand Government 2014, 2017, 2020) are discussed as they relate to recreational water quality.

The water quality criteria, classifications, monitoring requirements and the underpinning studies that inform international criteria are compared with New Zealand criteria, protocols and practices to determine how well aligned they are, and where they differ. Key questions include:

- Is *E. coli* a suitable indicator for freshwater?
- How do New Zealand FIB criteria relate to public health risk compared with international values?
- Is QMRA a suitable approach to setting guideline values?
- Is management and monitoring in line with international practice and consistent in New Zealand documentation?
- What new tools can be used to support recreational water quality?

[1] A QMRA is a framework to combine information on the particular pathogen(s) and the potential dose or exposure (a function of the concentration of pathogens in the water and the volume of water that might be ingested during recreation), to estimate the risk of infection and illness

This review assesses evidence for the suitability of New Zealand's choice of indicator, health targets and use of QMRA to inform water quality management, to ensure that best practice and current knowledge informs any developments of the NZ Guidelines.

2 OVERVIEW OF RECREATIONAL WATER QUALITY GUIDELINES

Water quality in recreational areas will be subject to site specific factors which may be hazardous to public health. Water quality guidelines for recreation have been developed to protect human health. One of the key hazards is faecal contamination as it may contain microbial pathogens which could result in infections and/or illnesses such as gastrointestinal illness (GI), respiratory illness (RI), skin irritation or wound infections. While some pathogens such as viruses are human specific, many common pathogens often present in animal and bird faeces are zoonotic, so able to cause disease in humans. Sources of faecal contamination include discharge of treated sewage, leaking sewage pipes, combined sewage-stormwater discharges, septic tank discharges or leaks, run-off from urban and/or agricultural land, and direct deposition from farm or wild animals.

Routine monitoring for the presence of these pathogens in recreational water is impractical, as pathogens tend to be present in a population intermittently and analyses are complex and expensive. Rather, 'indicator organisms' are used to monitor microbial water quality. Indicator organisms are not usually pathogenic themselves. However, as they are typically found in the intestinal tract of warm-blooded animals, they are indicative of faecal contamination and the potential presence of pathogens. The most commonly used faecal indicator bacteria (FIB) are *Escherichia coli* (*E. coli*), faecal coliforms and enterococci. Their presence is quick, cheap and easy to test compared to pathogen analysis with robust, standard methods to provide consistency of results allowing data comparison.

Since 2003, recreational water quality guidelines use a risk management approach to identify and manage the potential risk to public health from faecal contamination of waterways. This section briefly summarises current freshwater criteria and protocols from key authorities:

- New Zealand (MfE 2003)
- World Health Organisation (WHO 2021).
- EU (Directive 2006/7/EC)
- Australia (NHMRC 2008)
- US (USEPA 2012)
- Canada (HC 2012).

An overview of the key elements of these guidelines is presented first, with more detailed summaries of each guideline in the following sections. The NPS-FM are included as they also classify recreational water into risk categories and sets criteria which councils need to meet. A comparison between New Zealand and other guidelines is provided in section 4.

2.1 OVERVIEW OF WATER QUALITY GUIDELINES

2.1.1 Faecal Indicator Bacteria and risk

With the exception of Canada and the US, guidelines for recreational water classify recreational sites. Classifications are based on differing levels of risk of illness or infection. One of the categories is usually identified as the health target eg the risk may be 0.1% of people become ill or 5%. As water quality improves, or worsens, or the public health risk is managed, the classification may change. The classification is based on FIB criteria and some assessment of the sensitivity of the water body to faecal contamination and sources, such as a sanitary survey. The guidelines of the WHO (WHO 2003), New Zealand (MfE 2003) and Australia (NHMRC 2008) use a matrix of FIB measurements and a sanitary survey to determine the classification, while in the EU it is based on FIB, with a sanitary survey informing risk. In the US and Canada, compliance FIB criteria are set. Table 1 compares the FIB criteria for the different guidelines. NZ and Canada use *E. coli* as the FIB, WHO and Australia use enterococci, and US and EU use both enterococci and *E. coli.*

Different jurisdictions set different health targets for acceptable water quality. The WHO guidelines identify both the risk of GI and AFRI (acute febrile respiratory illness) and set an acceptable risk as <10% GI and 3.9% for AFRI, while in Canada the GI risk is estimated as 1 – 2% (Table 1). The acceptable risk of *Campylobacter* infection is lower at 1 – 5%. The different tolerance for risk is reflected in the different FIB criteria. In the EU the 95th percentile for enterococci is 330cfu/100mL compared to 500cfu/100mL for WHO and Australia. Canada sets 200cfu/100mL as the criterion for *E. coli* while New Zealand sets 550cfu/100mL.

Risk is based on different sources of faecal contamination. FIB criteria for all but New Zealand are from epidemiological studies which derived a dose response between GI and FIB for sewage impacted recreational water (Table 1). From 2003-2009 the US undertook five further epidemiological studies (Wade et al 2010) known collectively as the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) studies of marine and freshwater which had 54,250 participants: 21,015 of whom visited freshwater beaches. These data are used in the revision of the US EPA criteria (USEPA 2012) in combination with data from previous studies. The NZ Guidelines are based on a QMRA using data collected on pathogens and FIB in New Zealand freshwater (McBride et al 2002) which would have been influenced less by human wastewater than the US and UK studies, with more rural influences. Viruses are considered the main etiological agent of GI (US EPA 2018) and are human specific. Therefore, the risk from faecal contamination from animal sources is likely to be lower. The exception is where there is direct bovine faecal deposition, where *Campylobacter* is the likely pathogen of concern (Soller et al 2014).

Table 1 Summary of FIB criteria and risk in New Zealand and international guidelines for freshwater recreation

Grade - sanitary survey	New Zealand 2003	WHO 2021 /Australia 2008	Grade - no sanitary survey	EU 2006	EU 2006	US		US		Canada	
FIB	***E. coli* /100mL**	**Enterococci /100mL**		**Enterococci /100mL**	***E. coli* /100mL**	**Enterococci /100mL**		***E. coli* /100mL**		***E. coli* /100mL**	
Statistic	Percentile 95th	Percentile 95th		Percentile 95th / 90th	Percentile 95th /90th	GM	STV	GM	STV	GM	Single max
A	≤130	≤40	**Excellent**	200 (95th)	500 (95th)	35 / 30	130 / 110	126 / 100	410 / 320	200	400
B	131-260	41-200	**Good**	400 (95th)	1000 (95th)						
C	261-550	201-500	**Sufficient**	330 (90th)	900 (90th)						
D	>550	>500	**Poor**	>330 (90th)	>900 (90th)						
Risk %			Not stated			3.6 (US EPA 1986) /3.2 (US EPA 2012) NGI				1-2	
A	<0.1 Campy	<1 GI, <0.3 AFRI									
B	0.1-1 Campy	1-5 GI, 0.3-1.9 AFRI									
C	1-5 Campy	5-10 GI									
D	>5 Campy	>10 GI									
Basis	McBride et al 2002	Kay et al 1994; Fleisher et al 1996; Kay et al 2001; Ashbolt et al 1997		Adapted from Kay et al 1994: EU 2002		Wade et al 2010; Cabelli et al 1982; Cabelli 1983; Dufour 1984				USEPA 1986 Dufour 1984	
Health advisory notice or beach closed	Single sample >550	Very Poor		Poor	Poor	70 / 60		235 / 190		400	

Campy is Campylobacteriosis
GM is geometric mean
STV statistical threshold value approximates the 90th percentile
GI Gastroenteritis is - any case of diarrhoea or vomiting or any case of either indigestion or nausea accompanied by fever within seven to 21 days
HCGI Gastroenteritis is- any case of diarrhoea with fever or a disabling condition, vomiting stomach-ache, or nausea accompanied by a fever: within eight to ten days
NGI Gastroenteritis – is any case of diarrhoea or vomiting, or nausea and stomach-ache, or nausea or stomach-ache plus impact on daily activity: within ten to 12 days

2.1.2 Water quality monitoring

Water quality monitoring provides FIB data for determining classifications and assessing compliance with criteria. Compliance may be described as a percentile, usually 95th, or a geometric mean. While the geometric mean is easier to calculate and requires a smaller dataset, it provides no information on elevated concentrations of FIB, which are the most important in terms of risk to human health. Miscalculation of 95th or 90th percentile occurs when the dataset is too small (WHO 2003), therefore an appropriate dataset is required for a robust calculation. Another issue is that often FIB concentrations may be at, or below, the detection limit and not normally, or log-transformed normally, distributed. In this case the Hazen method is recommended, where data is ranked to determine the percentile. All guidelines which set a percentile, except those of the EU, specify using the Hazen method for calculation of percentiles.

The sampling regimes and assessment periods used by each jurisdiction to assess compliance or for classification are presented in Table 2. Assessment periods are typically over 3 – 5 years to increase the size of the dataset. This is acceptable if there are no significant changes in the potential for faecal contamination during that period. Unlike other guidelines, the US EPA uses a geometric mean calculated from data collected every six days over a 30 day period to provide better real time understanding of water quality, rather than an assessment at the end of the season. Except for the EU, all other guidelines with a percentile as the criteria use data collected during the bathing season over a five-year period to provide sufficient samples for calculation of a robust percentile (Table 2). The EU uses just 12 or 16 samples to calculate a 95th or 90th percentile. The New Zealand NPS-FM 2020 Table 9 requires collection of data over an entire year to comply with a target attribute state for recreational water quality[2].

Water quality monitoring is also a surveillance tool, to verify that water quality matches the classification and to alert water managers to events which may present a public health risk. Actions such as closing a beach will protect public health, therefore data collected while a beach is closed is not included in the assessment of compliance. This approach is consistent across the guidelines. While any high FIB detected during routine sampling must be included in the classification, the data used for investigation of the event do not. Active management of short-term contamination, therefore, may mean that the classification is not affected, or the area can be given a higher classification than would otherwise be assigned. The NPS-FM 2020 Table 9 requires all FIB concentrations be included from routine sampling for compliance with attribute states[2]. Results which trigger actions or alerts from single sample exceedances are formalised in the guidelines of New Zealand, Australia, EU, Canada, and the US EPA. In New Zealand daily sampling is required when *E. coli* concentrations exceed 260/100mL.

[2] The targets for improvement in water quality for swimming were based on datasets which covered the entire year (New Zealand Government 2017).

Table 2 Summary of monitoring in New Zealand and international guidelines for freshwater recreation

	New Zealand 2003	NPS-FM 2020 Table 9	NPS-FM 2020 Table 22	WHO 2003	Australia 2008	EU 2006	US 2012	Canada 2012
Number of samples/year	Minimum of 20	12	Only weekly sampling is specified.	Must be 100 over up to 5 years	≤ 20 samples is unacceptable	4 (or 3) samples	5 samples	5 samples
Period	Weekly over bathing season	All conditions	Bathing season	Weekly over bathing season	Bathing season when beach is open, during times of recreational use	Bathing season min of 8 weeks	6 days in conditions when people are recreating in the bathing season	Weekly
Classification period	5 years	5 years	5 years	5 years or 100 samples	5 years	4 (or 3) years	30 days	Bathing season
Action/Alert Level	Amber level: Should undertake daily sampling if >260/100mL Should undertake investigation into sources of contamination.	Take action to halt or reverse degradation if target attribute criteria exceeded	Daily sampling >260/100mL if practicable, unless temporary or source managed Take all practicable steps to investigate source of contamination. Take action to halt or reverse degradation if 95th percentile exceeded	Advisory notice of increased risk Incident response plan implemented	Amber level: requires investigation and increased sampling	Resample within 72 hours to determine if short term event. Advisory notice of increased risk. Investigation	Beach action plan implemented at 75th percentile	Implementation of action plan Single exceedance requires resample Advisory notice of increased risk

2.1.3 Annapolis protocol

The Annapolis Protocol (WHO 1999) introduced a risk management approach that was a fundamental change in recreational water quality management. This approach been adopted in all the guidelines and an overview is provided before the individual guidelines are discussed in the following sections. A key feature of most guidelines since 2003. was the move away from compliance with a single faecal indicator to a two-component ranking of faecal contamination which relies on:

- routine monitoring data
- sanitary survey of the local conditions.

Information from each component is assessed against a risk matrix and an overall classification is determined which provides a long-term assessment of the risk to public health (usually over five years). Where the microbial data and sanitary survey data do not align, eg a high FIB concentration but no known sources of human faecal contamination, a more thorough investigation is recommended. This approach is more flexible as it takes into account site-specific considerations of faecal contamination such as animal or bird contamination, agricultural runoff or other sources of non-point source contamination in the catchment in the classification of risk.

Routine monitoring data informs short term management where exceedance of a criterion leads to immediate action eg to close the recreational area or to increase sampling to investigate the source of contamination. Where mitigations are put in place that prevent the risk to public health, such as closing a beach after rainfall events or when a high concentration is measured, samples collected for investigation or routine monitoring during that period are not included in the long-term grading for the recreational area. This is a flexible, programmatic, low-cost approach to manage risk, where eliminating faecal contamination may be financially impossible. Recreational areas can therefore potentially have a higher grading than the previous pass/fail approach based solely on FIB concentrations.

This approach is adopted directly in the WHO, New Zealand and Australian guidelines. In the EU and Canadian Guidelines, the sanitary survey (known as a Beach Profile and Environmental Health and Safety Survey, respectively) informs risk management but are not used to grade sites.

2.2 NEW ZEALAND 2003

The NZ Guidelines contain information on the health risk from freshwater and marine water for recreation and shellfish gathering. The Annapolis Protocol is used to assess, classify, and manage recreational water. There is no guidance on other hazards associated with recreation, such as cyanobacteria, other hazardous micro-organisms, drowning etc. which are given in other international guidelines.

2.2.1 Risk of infection

The epidemiological approach undertaken in the UK and US that informed the international guidelines developed in the 2000s was not used in New Zealand due to our low population basis, and the increased potential for faecal contamination to be of animal, rather than human, origin which is the basis of the international guidelines.

Instead, McBride et al (2002) undertook a survey of target pathogens and FIB in freshwater across New Zealand for 15 months (725 samples). A pilot study was undertaken first to confirm methodology. It found that sampling strategies did not have to account for variation within a day, in contrast to the recommendations of the WHO review (WHO 2018). The risk of *Campylobacter* infection was modelled using the concentrations found in the survey for four different risk levels (McBride et al 2002), as given in Table 1. Various indicators were measured including *E. coli,* enterococci and coliphage. The only association between indicators and pathogens was a moderate correlation between *E. coli* and *Campylobacter* concentrations using Spearman's rank correlation coefficient. The concentrations for the different *Campylobacter* infection risks were modelled for the 55th percentile, 70th percentile and 80 – 85th percentile. These were matched against the percentile of *E. coli* concentrations to give the criteria ≤130, 131-260 and >540 *E. coli*/100mL.

The NZ guidelines do not apply where there is a discharge of human wastewater and a site specific assessment is required to assess risk.

2.2.2 Classification and surveillance

Consistent with the Annapolis Protocol, a sanitary survey and *E. coli* data are used to determine a classification which is based on a minimum of 60 samples over five years collected during the bathing season, unless there have been changes which may increase or decrease the potential for contamination. Where the data set is less than five years, provision is made to classify a site with data from one bathing season (20 samples). The matrix consists of four Microbiological Assessment Categories, A-D, and five Sanitary Survey categories to describe susceptibility to faecal contamination. Overall, there are six classifications which range from Very Good to Very Poor. A Follow Up classification is given where there is inconsistency between the microbiological data and sanitary survey, and further investigation is required. An allowance is made for Exceptional Circumstances where there is higher risk because of certain events such as a broken sewer pipe. Prediction of poor water quality can be used to manage the public health risk eg high rainfall events. If interventions are effective eg beach closure, a higher grade may be assigned as the exceedances will not be in the database. Grading can be used to target the most important sites where resources are limited.

Once classified, routine monitoring occurs weekly over the bathing season, which is defined by the regional council, during periods where swimming would not be hazardous ie not during high rainfall events. As with the international guidelines, sampling frequency can be reduced if water quality is graded as Very Poor or Very Good and there have been no changes which would be likely to affect it. Where daily samples are taken to investigate exceedances, they are not included in the routine dataset but must be recorded.

The NZ Guidelines introduce traffic light alert levels based on single results, requiring specific responses:

- Surveillance (Green) 0– 260 *E. coli*/100mL. No response required.

- Alert (Amber) one result above 260 *E. coli*/100mL. Daily sampling is required with a catchment assessment and the Medical Officer of Health is to be informed.
- Action (Red) one result exceeds 550 *E. coli*/100mL. The Medical Officer of Health is informed, and the public should be notified of the public health risk. Daily sampling is required plus a catchment assessment to better assess the risk.

The NPS-FM 2017 assigned the role of notifying the public to the regional council, rather than the Medical Officer of Health. In the NPS-FM 2020 the public notification requirement was strengthened to 'regional council must, as soon as practicable, take all practicable steps to notify the public'. An Action Plan is required for the target attribute state the bathing season (Table 22, NPS-FM 2020).

2.3 NATIONAL POLICY STATEMENT FRESHWATER MANAGEMENT (NPS-FM)

While the NPS-FM is not New Zealand's Freshwater Recreational Water Quality Guideline, it does set criteria for grading freshwater based on the risk to public health using the Microbial Assessment Category values of *E. coli* concentrations.

The NPS-FM 2014 introduced freshwater management objectives for water quality, including a target for freshwater to meet secondary contact water quality criteria. In 2017 this was amended to primary contact with a target of 80% of lakes[3] and fourth order rivers by 2030 and 90% by 2040 based on *E. coli* profiles. Freshwater quality will vary over time, particularly if sampling is undertaken year-round and during storm events. A broader profile of water quality was set in the NPS-FM 2017 with a geometric mean, 95th percentile and range of exceedances over 260 *E. coli*/100ml (Amber Alert in the NZ Guidelines) and 540 *E. coli*[4]/100mL (Red Alert in the NZ Guidelines). Five categories were introduced to describe water quality: Blue (best), Green, Yellow, Orange, and Red (worst). The risk of *Campylobacter* infection was estimated for each attribute state[5]. Yellow is the minimum acceptable categories for recreation in Table 9 NPS-FM 2020.

Councils identify the attribute state for water bodies. Water quality for human contact (primary contact) is the only attribute that it is required to be managed such that there is an improvement in water quality, rather than just maintenance of current levels. This is reflected in the water quality targets in Appendix 3, NPS-FM 2020 which aim for an increased proportion of freshwater sites meeting the criteria for Blue, Orange and Yellow by 2030 and 2040 as well as 80% and 90% of all freshwater sites meeting the target for by 2030 and 2040, respectively. Councils must prepare an Action Plan to achieve the attribute state. In the NPS-FM 2020 water quality criteria for *E. coli* are also set for the Bathing Season with classifications Excellent to Poor. The national bottom line is set at a 95th percentile of

[3] Shoreline greater than 1.5km
[4] The guideline value of 550 has been changed to 540 for technical reasons (McBride & Soller 2017)
[5] Attribute means a measurable characteristic (numeric, narrative, or both) that can be used to assess the extent to which a particular value is provided for

540 *E. coli*/100mL: Poor (Table 22, NPS-FM 2020) and water quality during the bathing season must be improved to be above the bottom line.

2.4 WHO GUIDELINES 2021

The 2003 guidelines (WHO 2003) informed subsequent international guidelines. They have been updated in 2021 with a narrower focus on water quality related hazards to human health from faecal contamination of water or sand, chemicals, harmful algal blooms, other microbial hazards and aesthetics and nuisance, rather than the broader scope which included drowning and heat. A Recreation Water Safety Plan (RWSP) framework has been introduced, which uses the same FIB criteria and classification from the 2003 guidelines.

The framework of the 2021 guidelines is based on the following recommendations.

1. Set health targets, expressed as microbial water quality standards for sources of faecal contamination and harmful algal blooms and consider other guideline values for other water quality related hazards.
2. Develop and implement recreational water safety plans (RWSP) for priority bathing sites using a risk management approach.
3. Conduct public health surveillance of any outbreaks (animal or humans), health related incident response plans and communication of the health risks from recreational water related illness.

Recommendations 1 and 2 are discussed below in regard to the health risks from faecal pollution of water.

2.4.1 Faecal Indicator Bacteria criteria

The FIB criteria are based on a dose-response derived for FIB and GI or AFRI from the UK studies by Kay et al (1994), Fleisher et al (1996) and Kay et al (2001). Although acknowledging that the study by Wiedenmann et al (2006) identified an *E. coli* guideline value using a no-observed-adverse- effects-level (NOAEL) approach based on the risk of GI and *E. coli* concentrations, WHO still recommends enterococci as the FIB for freshwater, as it considers that there is no significant dose-response relationship for *E. coli* that can support a guideline value. It also considers that two FIB add complexity and that the study in Germany was not sufficiently representative of recreational waters. Therefore, the same enterococci criteria are used for both marine and freshwater. Although it was acknowledged in WHO 2003 guidelines that this could be more protective for freshwater recreation[6], a precautionary approach is supported in 2021 as there is less dilution of effluent and stormwater in freshwater recreational areas compared to marine waters.

The risks of GI and AFRI are calculated for four levels (A-D) based on a 95th percentile enterococci concentration. The risk of illness from recreation are based on the increased risk in the GI rate in swimmers compared to control groups. A tolerable

[6] The potentially higher rate of die-off of FIB in saline waters means the ratio between pathogens and enterococci is likely to be higher than for freshwater.

GI risk of 1-10% is proposed, which is similar to reported background rates of GI ranging from 0.9-9.7% in the studies of Cabelli et al (1982), Kay et al (1994) and van Asperen et al (1998).

QMRA is viewed as a useful management tool to compare the relative risks of different management scenarios or with different pathogens. Risk assessments using QMRA have given comparable results to epidemiology (WHO 2021) and are identified as useful in circumstances which are not suitable for an epidemiological examination. However, epidemiological data is preferred over a QMRA approach because of the uncertainties in the derivation of illness or infection. WHO advise the use of the guidelines developed from Kay et al (1994) and Fleisher et al (1996) in the absence of local, high-quality epidemiological studies.

2.4.2 Recreational Water Safety Plan (RWSP)

The development and implementation of a RWSP is a key part of the framework in the 2021 guidelines. It supports setting national health-based targets and public health surveillance using a preventative risk management approach. Once the team has been assembled there are three components: system assessment, monitoring and management and communication.

System assessment and beach classification

A description of the environment uses a sanitary survey to identify and trace entry points for faecal contamination. Supporting information may include historical water quality data, or data about the area. This information is combined with a period of intensive sampling, covering both spatial and temporal variation, where necessary, to provide an initial microbiological water quality assessment.

After hazard analysis, a risk assessment is undertaken and the control measures and limits are identified to manage the hazard and hazardous events. Control measures need to be validated to ensure they are effective. Action to reduce risk to public health could be advisory notices not to swim with evidence gathered to ensure that the notification is effective.

Classification of the recreational area is based on a matrix of the results of the sanitary survey and the FIB criteria (Table 1). The key hazard for faecal pollution is assumed to be human wastewater sources, including bather shedding in densely populated, enclosed shallow areas. Where the sanitary survey and FIB concentrations are inconsistent, a follow up assessment is required. Microbial source tracking (MST)[7] is identified as a useful tool to confirm if there is human contamination. While animal pollution can have an impact on human health, the focus of the guidelines is based on the risk from undisinfected human wastewater.

Monitoring

Once the initial intensive monitoring has been undertaken to provide a classification, monitoring is used for surveillance to give warning of exceedances beyond the

[7] MST use a range of faecal microorganisms which are host specific to identify sources of faecal contamination and include faecal source tracking markers

critical control points and to verify that the RWSP is functioning correctly. Sampling should be representative of the conditions under which the recreational area is open. Unexpectedly high results should be included if the area was open to the public at the time the sample was collected, but data from samples taken during an investigatory period are not included if the area was closed. The monitoring period is a defined bathing season. Where the sanitary survey indicates Very Low or Very High risk, sites do not need intensive monitoring unless local conditions have changed, although a five-sample minimum is required during the recording period. Where the sanitary survey indicates Moderate or High risk, 20 samples at regular intervals from four locations on five occasions is required during the bathing season with additional sampling if unusual results are obtained.

Calculation of the 95th percentile is less statistically robust with a small dataset. With 100 samples miscalculation of the 95th percentile is 1%, but with 10 or 20 samples it is >20% and >14%, respectively. Therefore it is recommended that data be pooled to give a larger dataset of 100 samples. This may include data collected over five years, if no changes have occurred that would result in lower or higher contamination. A minimum dataset is set at 60 samples. The Hazen method is proposed for calculating the percentile for data with values below the limit of detection. Methods for enterococci are specified so that there is consistency between results and between laboratories.

Management and Communication

As the focus of a RWSP is on practical preventative measures, other tools can be used in the surveillance phase such as:

- observation eg cleanliness of the beach, visual inspection for harmful algal blooms by volunteers
- easily measured parameters such as salinity/conductivity, pH, temperature
- rainfall
- advisories to avoid the beach after rainfall
- rapid monitoring using qPCR methodologies which can provide data for same day decision making.

Predictive models are proposed where weather related or short-term pollution events which result in poor water quality can be forecast. However, the model must be verified against real conditions. The forecast of the risk to public health can then be communicated to the public through advisory notices and implementation of control measures to protect public health. Other instances when advisory notices might be issued include a rare event or sewer debris which is not explained by weather patterns. Responses to adverse water quality, hazards and hazardous events are detailed in Incident Response Plans. These plans identify the procedures and actions to be taken to respond to incidents which adversely impact, or have the potential to adversely impact, the water quality. Communication plans are required for effective response to incidents and to inform the public during and after an event.

All aspects of the RWSP need to be documented with regular reviews. Annual review of the performance of the plan is proposed, with the content reviewed two yearly. Reviews should also be undertaken if there is a significant incident or an emergency.

2.4.3 Research needs

The WHO guidelines acknowledge that the epidemiological studies need updating and need to include sub-populations of vulnerable people, in a variety of locations. An epidemiological study on dose response between illness and *Clostridium perfringens* is proposed for tropical areas incorporating MST. The high level of temporal variation reported by Wade et al (2018) in UK marine waters requires further research to understand the implications for sampling and to inform predictive modelling. Another area is the environmental proliferation of faecal indicator organisms from human and animal sources and implications for monitoring and interpretation of data.

2.5 EUROPEAN BATHING WATER DIRECTIVE

This directive (EU 2006/7/EC) covers the monitoring and classification of bathing water quality, the management of bathing water quality and informing the public. Health impacts from cyanobacteria and other parameters such as macro-algae or rubbish, are to be assessed for their impact on public health, but no details are given. The water quality objective is that all states have Sufficient water quality by 2015, with a view to increasing many classifications to Excellent or Good. The directive is currently under review[8].

2.5.1 Indicators and sampling regime

The FIB employed in this directive are enterococci and *E. coli* for marine and freshwater, respectively and are based on epidemiological studies (Table 1). Routine monitoring is scheduled for four samples over the bathing season, except where the bathing season is less than eight weeks, when three samples is satisfactory, or where there are special conditions or geographical constraints. While the monitoring calendar may be suspended during abnormal events, the suspension, with reasons, must be reported annually. Any planned samples that are missed are to be taken as soon as possible after the suspension is lifted. Samples can be retaken within 72 hours to confirm the elevated concentrations are a short term event.

2.5.2 Classification

The assessment of water quality is done for each site at the end of the bathing season and incorporates the results of the previous two (12 samples) or three seasons (16 samples)[9]. Samples taken in response to short-term pollution events are not included in the classification. There are four classifications: Poor, Sufficient, Good, and Excellent, based on the 95th (Excellent, Good) and 90th percentile (Sufficient). A Poor classification may be temporary where bathing is prohibited[10], the sources have been identified and prevention measures implemented. Where there are five years of consecutive Poor classifications, a permanent bathing prohibition is

[8] June 2021
[9] The period of assessment (two or three years) must be consistent over a five-year period.
[10] The Directive details the information to be given to the public if there is a prohibition on bathing.

required[11]. A sanitary survey is not required for classification, but a Beach Profile, which would include a sanitary survey, is required to understand the sources of faecal contamination affecting the site and to inform management. There is a requirement to prepare and publish annual reports.

2.5.3 Regulatory review

The European Commission has a project to update the directive which is planned from 2021 to 2023[12]. This will include an evaluation and impact assessment. The evaluation will cover effectiveness, efficiency, relevance and coherence with other relevant EU environmental policies and objectives and added EU value. Evidence will include the yearly bathing reports from Member states, the 2018 recommendations from the WHO (WHO 2018), European Environment Agency (EEA), Joint Research Centre on cyanobacteria, European microbiology Expert Group and relevant research projects. Issues have been identified with the category Sufficient; exclusion of people who bathe outside the official bathing season; the level of health protection conferred by the criteria; emerging pollutants; the coverage of bathing sites; improving reporting and communication with the public; alignment with EU policies; and the effectiveness of implementation. The impact assessment will cover social, environmental, and administrative impacts.

2.6 AUSTRALIA 2008 GUIDELINES FOR MANAGING RISKS IN RECREATIONAL WATER

The Australian Guidelines are based on the WHO Guidelines (2003) with the same FIB criteria (Table 1). The microbial assessment and monitoring are the same as WHO 2021 and WHO 2003 Guidelines discussed above but with slight alterations to the classification matrix. The Australian Guidelines provide risk matrices for faecal contamination from bather shedding and riverine discharges which are no longer in the WHO 2021 Guidelines. They also address a broad range of physical, chemical, and potential biological hazards. The Australian Guidelines do not have regulatory status but provide recommendations to guide state and territory governments with the aim of having a similar approach.

A point of difference from WHO 2003 guidelines was the inclusion of the traffic light Alert system. Additional sampling is required when FIB concentrations are inconsistent with the overall classification of the site, or if a single sample corresponds to the microbial concentrations in the Poor, Fair or Follow Up classifications. The Action Level is triggered by a single sample above the enterococci concentration of 500 cfu/100 mL or if there is an exceptional event which may cause faecal contamination. Local government and health authorities are required to warn the public of the risk to health from recreational use. Resampling is recommended where high microbial results are obtained to determine whether it is a sporadic event or on-going contamination.

[11] This classification can be made within the five-year period if improving water quality is not feasible or too expensive.
[12] https://ec.europa.eu/environment/water/water-bathing/index_en.html

2.7 US EPA (2012)

The US EPA guidelines were reviewed in 2012 and while not regulatory, the recommendations are provided for states to set recreational water quality criteria (RWQC).

2.7.1 Epidemiological studies

The US EPA recommendations are based on the results from randomised control trials and studies using cohorts that were recruited on the day, at the beach. New data was generated by the NEEAR research programme in 2003, 2004, 2005, 2007, and 2009 (USEPA 2012). This was combined with historical epidemiological studies by Cabelli et al (1982) and Dufour (1984) which informed the 1986 guidelines. In the NEEAR studies, gastrointestinal illness (NGI)[13] was more broadly defined than the studies underpinning the 1986 guidelines. The period of symptoms was extended from 8 – 10 days after the activity to 10 – 12 days, and stomach-ache or nausea no longer needed to be accompanied by fever. These guidelines are based on the risk from human wastewater, most likely from viruses, and viral gastroenteritis is not always accompanied by fever.

The guidelines recognise that QMRA could be used to assess the risks from non-human sources. These risks may differ from those of human wastewater due to factors such as the types and numbers of pathogens, the ratio of pathogens to indicators in different sources, and their human infectivity. Site-specific criteria can be derived, with approval of the US EPA, for specific pathogens or risks where they are scientifically defensible.

2.7.2 Monitoring

There are two risk levels in the 2012 guidelines for protection from NGI during swimming (primary contact). One level uses the FIB criteria which reflect the 1986 guidelines health target of 3.6% and the new, second level has FIB criteria for a revised health target of 3.2% (Table 1). Only one health target needs to be met. The intention was to set targets for improvement in water quality. In addition to the slightly revised geometric mean for enterococci and *E. coli*, a statistical threshold value (STV) is derived which approximates the 90th percentile (Table 1). A Beach Action Plan was recommended if the 75th percentile was exceeded. The method used for enterococci was EPA Method 1600 (USEPA 2006), and for *E. coli* was EPA Method 1603 (USEPA 2014). Use of equivalent methods is acceptable.

While acknowledging that larger data sets provide a more accurate estimate of the geometric mean, the US EPA recommended that percentiles be calculated on a static or rolling 30 day duration period to provide a more immediate response than a geometric mean calculation at the end of the bathing season as is used in other guidelines. Sampling every six days is recommended, with more frequent sampling at densely populated beaches.

[13] NGI NEEAR-GI illness

2.7.3 New tools

New tools introduced in the guidelines to support management of water quality include:

- a qualitative PCR (qPCR) method EPA developed was included to provide more rapid analysis of enterococci than the traditional culture method.
- microbial source tracking (MST)
- predictive modelling to forecast water quality.

2.8 HEALTH CANADA

In Canada, most swimming occurs in freshwater, rather than the marine environment. The guidelines provide recommendations on water quality standards and protocols which need to be adopted by provincial/territorial or federal agency before they are enforceable. As well as faecal contamination, other hazards such as cyanobacteria, other biological and physical hazards, aesthetics, chemical contamination, and beach sand are also discussed.

2.8.1 Risk assessment and monitoring

The Canadian guidelines propose a multibarrier approach to managing risk with the development of a risk assessment report, which includes a sanitary survey. However, there is no accompanying classification of risk nor a grade for a recreational site. The purpose of the risk assessment report is to identify barriers, inform a water quality monitoring plan, set priorities for actions and communication with the public about health risks.

The guidelines follow the US model with FIB water quality criteria based on US EPA regression analysis of epidemiological data from Dufour (1984) between GI and *E. coli* concentrations. However, the *E. coli* concentration criterion is higher in the Canadian guidelines than the US, despite the risk of GI being estimated as 1% to 2% which contrasts with the US where the risk is 3.3% or 3.6%.

As with the US guidelines a geometric mean is recommended, but it is determined over the bathing season. A single sample limit is given to identify sporadic incidences of high faecal contamination and is set at twice the geometric mean. To comply with the guidelines, the single sample maximum must not be exceeded. The *E. coli* guidelines for primary contact recreation remains the same as in the previous guideline.

2.8.2 Secondary contact

The 2012 guidelines added new secondary contact guidelines, with a geometric mean of at least five samples of 1,000 *E. coli* /100 mL or less. This criterion was simply calculated as five times the value for primary contact.

2.8.3 Emerging issues

As the main human health risk is assumed to arise from human wastewater, indicators which behave more like viruses or protozoa would be preferred to FIB. While other potential indicators are discussed, it was considered that there was insufficient robust data for inclusion in the 2012 guidelines. The guidelines note that MST is a useful tool, but there is no consistent methodology, and they recommend multiple lines of evidence before making inferences. A robust well-defined methodology is important for regulation to ensure that the results are consistent. It was considered that significant knowledge of MST was required to use these tools in a study to trace faecal contamination, especially where there are multiple sources.

Several predictive modelling tools used in the US for forecasting water quality were identified and provided as examples. With validation models can be as accurate as FIB. However, validation is required for each specific area and the models may not work in all areas. A high level of technical expertise is required to develop these models and to analyse resulting data.

3 RECENT INTERNATIONAL LITERATURE AND REVIEWS

Recent reviews of data and re-analysis of previous data by the US EPA provides useful summary of recent literature up to 2017 (USEPA 2018). Review of the EU guidelines resulted in two publications, a review of epidemiological data commissioned by the UK Department of Environment Food and Rural Affairs (DEFRA) (King et al 2014) and recommendations from the WHO on the new EU guidelines (WHO 2018). These reviews are summarised below to highlight the key findings. In addition, the EPIBATHE 2009 studies (Wade et al 2010) collated more data from freshwater recreation epidemiological studies in Hungary and Germany. As many of the reviews assess the same studies, this section highlights additional information or different interpretations.

3.1 EPIBATHE 2009 SUMMARY

This study (European Commission 2009) was undertaken in Hungary and Spain using the randomised control trial methodology previously used in the UK (Kay et al. 1994) and Germany (Wiedenmann et al. 2006). *E. coli* was identified as a better index of GI than enterococci in freshwater, although increases in GI were not as evident with incremental increases in *E. coli* concentrations (ie not consistent with a continuous dose response). At the Expert Group Workshop in Geneva January 2009, it was agreed that a stochastic model was more appropriate, rather than the linear dose-response model between GI and concentrations of *E. coli*, used previously. Use of statistical distributions as input was seen as more realistic.

This new methodology improved the robustness of the analysis across different studies, enabling EPIBATHE and previous UK and German data to be analysed. The new dataset and stochastic modelling showed that risk levels were similar to those used to derive the WHO and EU guidelines and no changes in criteria were proposed.

Understanding the background rates of illness is important as it informs health targets. In the EPIBATHE study the background illness rate for freshwater was 4.7%, which is lower than reported in previous UK and German studies. This value is comparable with an attributable illness probability of 5%, calculated using the original WHO analysis (2003) which underpins the WHO 'Level B' and EU 'Good' criteria for this parameter.

3.2 DEPARTMENT OF ENVIRONMENT FOOD AND RURAL AFFAIRS (DEFRA) REVIEW

The 2006 EU Water Quality Directive (2006/7/EC) was based on evidence from studies up to 2003. In 2014 DEFRA commissioned a rapid evidence assessment of epidemiology studies on the incidence of gastroenteric illness at marine and freshwater beaches published since 2003, to support the revision of the EU guidelines in 2020. The aims were to:

- gather new evidence about the health risks from recreational bathing, particularly with regard to different age groups
- determine if there was evidence to support use of different classification standards (Excellent, Good, Sufficient, Poor).

The review notes that inconsistency in the study methods made comparisons difficult. Only four freshwater studies met the criteria for review: three from the US (Marion et al 2010, Wade et al 2006 and 2008) and one from Germany (Wiedenmann et al 2006). Data from the EPIBATHE studies was not included.

3.2.1 Health risk

The review concluded that only freshwater studies showed that there was an increase in GI in swimmers, compared to non-swimmers. This was significant for all age groups. Arnold et al (2016) showed that children had more exposure to the water and also had the largest attributable illness burden. Incidences of diarrhoea were greater in children 0 – 4 years old, and then 5 – 10 years old. Non swimmers had the least incidence of diarrhoea. Factors such as head immersion, swallowing water and time spent in water increased the risk.

3.2.2 Indicators

Data from the literature supported both enterococci and *E. coli* as FIB for freshwater, but not for marine water. The risk of diarrhoea/GI was associated with enterococci only where there was a known source of human faecal contamination (Arnold et al 2016). By comparison, a positive dose-response was determined between *E. coli* and GI in a watershed which was 37% agricultural, 33% light residential and 25% forestland, with no known human wastewater point source (Marion et al 2010).

While most studies related to swimming activities, Dorevitch et al (2012a and 2012b) studied limited water contact. They found the odds of GI significantly higher for water uses other than swimming, compared to other non-water related activities such as cycling or jogging in both effluent-dominant waterways and general use waters.

A wider range of indicators was used by Wiedenmann et al (2006). They determined GI risk using NOAEL, by calculating the concentration of the different indicators where the incidence of GI in bathers was significantly different between other bathers, swimming in different quality water, and non-bathers. They proposed criteria of 100 *E. coli*/100 mL and 25 enterococci/100 mL and also introduced criteria for somatic coliphages (10/100mL), and *Clostridium perfringens* (10/100 mL).

3.2.3 Classification

Most studies were undertaken in water with quality which was within the acceptable EU water quality guideline criteria of Excellent or Good. As noted by Arnold et al (2016), only 10% of swimmers in their study used beaches with poorer water quality. The swimmers at those poor water quality beaches reported higher incidences of diarrhoea where there was a known source of human wastewater contamination, compared to swimmers at beaches with enterococci concentrations within the guidelines.

While the results of the studies reviewed supported classification of recreational areas, the paucity of dose-response data from sites with poor water quality led to the recommendation for a UK epidemiological study to assess the full range of classification standards[14].

As a GI dose response was observed at concentrations as low as 21 cfu/100 mL enterococci, which is well below the guideline value of 200 cfu/100mL, the review also proposed more research, especially in Excellent water.

3.3 WHO RECOMMENDATION ON EU DIRECTIVE 2006/7/EC

This document was also prepared to inform the EU revision of the Bathing Water directive (WHO 2018). It presents a synthesis of the current literature on enterococci and *E. coli* as indictors of GI, with additional discussion of viral indicator(s), harmful algal blooms and emerging issues. The recommendations on faecal contamination are presented below.

3.3.1 Indicators

The EU uses both enterococci and *E. coli* for freshwater and marine water. However, *E. coli* was reported by the EU Member States as the key FIB for freshwater water quality, and enterococci for marine water. The review of four recent epidemiological studies on freshwater recreation (2009 – 2018) concluded that that there was insufficient data to derive a significant dose response relationship between GI and FIB. It noted that where there was non-point source pollution a significant dose response relationship was only identified between GI and enterococci, where human wastewater was present. The potential problem with sediments as a potential source of the indicator enterococci was noted. The report recommended that both *E. coli* and enterococci be retained as FIB.

3.3.2 Classification and sampling

The classification system (Excellent, Good, Sufficient, and Poor) was reported to encourage improvements in water quality by managing the public health risk to achieve higher classifications. It was recommended that the classification system be retained.

The current dataset for the assessment is based on the 95th percentile using 12 or 16 samples collected over four years. Small data sets mean the calculation of the 95th percentile is less robust than a geometric mean. A change to a minimum of 80 samples was recommended.

The grade Sufficient is the only grade based on a 90th percentile, which was found to be confusing. It was recommended that all grades should be based on 95th percentiles. Where the data is not $\log_{10}$ normally distributed, the Hazen method of

[14] Note this presents ethical issues as it would be unethical to ask people to bathe in waters classified as a health risk.

calculation of percentile is recommended. It also recommended that qPCR methods for enterococci and *E. coli* be used.

3.3.3 New approaches

There was interest in new indicators for sites where contamination is dominated by human wastewater. The die off and survival characteristics of viruses and protozoa would not be accurately reflected by FIB. While viruses have been shown to be the key etiological agent (US EPA 2018), they are usually only present intermittently and likely to be present at low concentrations, unless there was a local outbreak. Even if a suitable virus was identified, a standard methodology would need to be developed to ensure consistency of results. While viruses are the highest risk factor, there is insufficient epidemiology to support viral regulations.

The use of *Clostridium perfringens* or coliphage was discussed by expert groups, as these indicators occur consistently in human wastewater in much higher concentrations than viruses. While Wiedenmann et al (2006) found a correlation between somatic coliphage with GI above 10pfu/100 mL, overall, the results were noted as lacking consistency, with no clear dose-response relationship. No additional indicators were recommended.

There is currently no microbial indicator appropriate for skin irritations or infections, such as swimmers itch or wound infection. It was recommended that where skin irritations or wound infections occur, swimmers should be advised.

3.3.4 Future issues

Antimicrobial resistance was highlighted as a future issue, but the research is insufficiently developed for regulation. Another future issue identified was extending regulation to other recreational activities, which could be outside the bathing season.

WHO recommends MST and QMRA be used to support the development of the Bathing Water Profile. QMRA could be used to compare the effectiveness of different management options, compliment epidemiological studies and improve water quality monitoring management. QMRA has shown viruses are the key risk factor where there is human wastewater (Soller et al 2010), while in rural settings direct discharge of fresh animal faecal material could be a potential health hazard (Soller et al 2014). The use of QMRA modelling has highlighted the significant impact of rainfall events. It was proposed that the poor relationship found in epidemiological studies between GI and FIB may be an artefact of rainfall. WHO proposed a review of MST and QMRA to inform practice.

3.4 US EPA REVIEW 2018

The aim of this review (USEPA 2018) was to update knowledge since the 2012 guidelines. It also discussed new areas of research, especially on indicators which would better represent the behaviour of viruses and protozoa. Based on the review, the recommendation was that the 2012 guidelines did not need to be revised.

3.4.1 Water ingestion and children

The review highlights additional evidence that children were likely to ingest more water than adults (Dufour et al. 2017; DeFlorio-Barker et al. 2018). This was likely to increase their exposure, given their lower body weight and developing immunological and digestive systems. Children were also likely to spend longer in the water and be more vigorous in their play. This was supported by epidemiological evidence from Arnold et al (2016).

3.4.2 New indicators

E. coli was considered a good indicator for the target bacterial pathogens *Campylobacter*, *Salmonella* and STEC. However, these organisms are more sensitive to environmental stress than viruses and protozoa (Canada 2012). The reivew showed coliphages are a better indicator of viruses than bacteria and that the fate and transport of coliphages is more similar to viruses than FIB. Coliphage has been investigated as a potential indicator for these hardier pathogens, especially as most of the guidelines are based on the risk from human sewage. An association between coliphage and GI and was found where heavy rainfall led to sewage contamination of a canal in Amsterdam just days prior to a canal swim event. The Coliphage Expert Workshop[15] in 2016 concluded that it was a good potential indicator and both types should be included in future epidemiological studies.

Most of the new data presented related to marine studies. The review analysed pooled data from marine beaches in the NEEAR and University of California, Berkeley/Southern California Coastal Water Research Project (UCB/SCCWRP) California studies and concluded that where human effluent is present there was an association between GI and the presence of coliphage, both male and somatic coliphage, although the results differed between studies. Alternative indicators may be appropriate given specific circumstances. MST was identified as a useful indicator as associations with GI and *Bacteroides* at freshwater and marine beaches had been reported (Napier et al. 2017).

3.4.3 Faecal Indicator Bacteria

Enterococci, as measured by culture and qPCR, were associated with GI in marine and freshwater where there was human faecal pollution (Arnold 2016, Yau et al 2014, Colford et al 2012). It was considered that having the 1986 and 2012 guideline values and consequently the two different GI risk targets, either 3.2% (2012) or 3.6% (1986), provided flexibility for managing water quality. Use of qPCR allows rapid analysis of FIB which could be advantageous at very densely populated beaches and a draft for an improved qPCR method has been developed by the US EPA.

QMRA analysis confirmed that viruses were the most likely etiological agent in waters affected by human faecal contamination (Soller et al 2010). Disinfected effluent was likely to have lower FIB while still potentially containing significant concentrations of viruses. QMRA has indicated a risk from non-human sources, but

[15] https://www.epa.gov/wqc/2016-coliphage-experts-workshop

FIB have not been associated with GI where there are non-point sources (except for Marion et al 2010, see section 3.2).

Significant rainfall which results in contamination of waterways is associated with GI, both from discharges of human sewage (eg combined sewage stormwater overflows, leaking septic tanks or treatment plant malfunctions) and from resuspension of sediments (Abia et al 2016). The human faecal source tracking marker HF183 can be used to identify unknown sources of human sewage. MST and antimicrobial resistance were identified as developing areas of knowledge.

Swimmers not only develop GI but may also develop higher rates of respiratory and skin infections than non-swimmers, but these health impacts are not associated with human faecal contamination and occur less frequently than GI.

The review concluded that at the time of publication there was no need to revise the guidelines.

3.5 CURRENT WORK

3.5.1 EPA Victoria Port Phillip Bay QMRA

A summary of a QMRA study in Port Phillip Bay, Australia has been made available. The purpose of this study was to determine if the criteria based on overseas data was applicable, as it assumes that human wastewater is the source of enterococci entering waterways. In Port Phillip Bay animal sources are also expected to contribute to enterococci presence and therefore the risk may be over-estimated. This study occurred in the summer of 2017 – 2018 at three marine beaches and showed that 13% of the contamination was from human sources, with birds and dogs a significant source of faecal contamination. This changed the risk profile, and the risk of illness dropped from 10% to 1%. The full report is not currently publicly available.

3.5.2 National Recreational Water Quality Workshop 2021

This workshop was held in April 2021 as a virtual event organised by the US EPA and Conservation Technology Information Center. Presentations are available https://ctic.org/projects/Training/Rec_Waters/Presentations and panel discussions can be seen at https://ctic.org/2020_Rec_Workshop. A report summarising the key conclusions of this workshop is yet to be released.

Topics covered in the sessions were:

- Faecal contamination and cyanotoxins.
- New monitoring methods such as DNA-based methods, remote sensing, and other technologies.
- Communicating with the public on economic and health risks from contaminated recreational waters, with new tools such as social media and apps.
- MST, QMRA and sanitary surveys to inform remediation and the public.
- Case study of successful remediation of water quality

The final session looked at emerging concerns, which have been highlighted in previous publications, and include:

- coliphage as a viral faecal indicator
- anti-microbial resistant pathogens
- extreme weather impact on water quality

A new area of concern raised is the occurrence of vibrio in new locations.

A proceedings for the workshop is not yet available but a watching brief will be kept for its publication.

3.6 RECENT LITERATURE

The reviews above provide comprehensive coverage of the literature on epidemiology, and evidence for dose response between GI and FIB with recommendations for updating guidelines up until 2018. A search for more recent literature identified nine new publications, seven of which are reviews. Key findings from these publications are presented below.

3.6.1 Recreational activities and illness

Most research to date has focused on criteria related to swimming (head immersion, swallowing water etc). A wider range of activities was assessed in a meta-analysis of recreation and illness, which reviewed 629 studies between 1983 and 2018 (Russo et al 2020). Ninety-two freshwater and/or marine water publications met the criteria for analysis. Although the analysis did not stratify studies into marine and freshwater, 56/92 studies involved freshwater. These studies used no contact as the control and extended the analysis from direct contact to include sports contact eg surfing, white water rafting/canoeing, windsurfing, diving and snorkelling, and playing with sand (minimal contact). The review highlighted a need to consider criteria for protecting the public engaged in sports related water contact as well as swimming/head immersion/swallowing water. The risk of GI and RI from sports related activities was elevated compared to control groups and could be higher than swimming. The data was stratified into a range of direct contact and indirect contact activities. Analysis identified that direct contact had a greater risk of GI than indirect contact and that body immersion, head immersion and ingestion of water gave a greater GI risk than face splashing (direct contact) or sand contact (indirect contact). Water quality was not always quantified, with some studies describing conditions simply as Good or Poor. When the data was stratified by water quality, there was a higher risk of GI associated with swimming. No significant effect was found based on age, but this may have been due to the very broad classification of younger than 18, or 18 years and older. The risk of skin and eye infections was elevated with swimming, body or head immersion. The risk of ear, nose and throat infections was elevated for swimming and head immersion, but not significant for body immersion. A risk of cold/flu was also associated with swimming.

Outbreaks of GI following swim events where large numbers of people participated have shown heavy rainfall as a factor even where the water criteria were acceptable

(Hall et al 2017, Joosten et al 2017). The Joosten et al (2017) study on the norovirus outbreak linked to a canal swim in Amsterdam showed that existence of chronic respiratory or skin conditions was a risk factor for RI and skin irritation. The EU employs two FIB for assessing water quality. In the Amsterdam canal, enterococci concentrations were below the EU criterion of 400cfu/100 mL, but *E. coli* concentrations had increased above the criterion of 1000 cfu/100mL to 4,000 – 10,000cfu/100 mL during the event. This supports the EU Member statement that freshwater quality is driven by *E. coli* (WHO 2018).

Determining the source of GI outbreaks is complicated by the time lag before presentation of symptoms. Contamination of water may be a short-term event and sampling water quality after the event may not reflect the conditions present when people became ill. An outbreak of Norovirus GI in the Netherlands was determined to most likely be from two beaches around a freshwater lake following sand sampling (Schets et al 2018). The same Norovirus that was present in stool samples was present in the sand two weeks after the event, while water samples had concentrations which would meet EU criteria (*E. coli* 1 – 2 and 6 MPN/100 mL, and enterococci 160 and 230 MPN/100 mL). As there was no wastewater discharge into the lake, bather shedding and lack of toilet facilities were proposed as potential factors in the faecal contamination.

3.6.2 New indicators

Korajkic et al (2018) reviewed studies that reported a relationship between FIB, alternative indicators and pathogens over the last 40 years. Where statistical analysis was included it showed that more statistically significant relationships were reported in freshwater studies than brackish or marine waters for FIB and other indicators. Relationships between FIB and bacterial pathogens (STEC, *Salmonella*, *Campylobacter*) and protozoa (*Cryptosporidium* and *Giardia*) were more frequent than for FIB and viruses, but overall a correlation between FIB and pathogens was inconsistent between studies. Of five studies in freshwater with statistical analysis of pathogens and an alternative indicator, four showed statistically significant relationships. A relationship between pathogen and *Clostridium perfringens* was more common (two observations for *Campylobacter*, one each for *Salmonella, Listeria* and *STEC*) than somatic coliphage (one observation for adenovirus). A direct significant relationship between MST and pathogens was only reported in 1 of the 8 freshwater studies reviewed. Key factors were contamination by sewage, rain events or season. It was proposed that as specific contamination events are likely to result in high concentrations of pathogens dominated by a single source, associations may be easier to make.

Developing genetic and PCR technologies provide the opportunity to use new indicators and multiple MST to provide a more robust interpretation than reliance on a single MST (Holcomb and Stewart 2020). However, a relationship between MST and pathogens may differ by geographical location as it would depend on carriage rates. The importance of robust, standardised, analytical methodology was highlighted to ensure that the results are consistent across laboratories. The target indicator also needs to be present in high concentrations. Where pathogens, such as viruses, occur in low concentrations, a concentration step is required. This introduces losses from the concentration and then recovery steps. Associations are more often reported between more frequently observed organisms. In areas dominated by human wastewater contamination, the review proposed a mixture of FIB (by qPCR) and human associated MST to provide more information at little extra cost.

For non-point source contamination predictive modelling was proposed. A conclusion was that the strong relationship with rainfall may be the most reliable method of protecting human health.

3.6.3 Quantitative Microbial Risk Assessment

A review on applications of QMRA (Federigi et al 2019) supported their value as a tool to address a range of issues including:

- effects of age or gender on risk
- health risk where no epidemiological data was available
- impact of different hazard events
- health risks from high and low contact with water.

The review identified 54 relevant studies from 2003 until November 2018, with 23 studies from the US. Most of the studies were undertaken on freshwater systems and addressed risks based on age and gender. Other risks assessed were mostly from different pathogens (eg different viruses), hazardous events (eg rainfall) and recreation activities (eg amount of water ingested). Four QMRA studies were combined with epidemiological studies to aid interpretation. There was good agreement between QMRA and epidemiological studies in developed countries, but not in undeveloped countries, where there are likely to be many more sources of infection. This agreement supports their use as a tool where there is insufficient epidemiological data and human wastewater discharges.

Studies on the source of faecal contamination have confirmed the highest risk is from human contamination, but also identified potential risk from direct animal faecal contamination. Federigi et al (2019) found agreement on the level of risk in different studies using MST as the indicator of human faecal contamination. Sensitivity analysis showed that the most effective control was management of wastewater treatment plants. The uncertainty around dose-response relationships and sensitivity to input pathogen concentrations and exposure frequency were highlighted.

While FIB environmental die-off may not reflect viral die-off, where the discharge is recent, QMRA showed that the risk estimated using viral target pathogens was similar to that estimated by FIB (Sunger et al 2019). Disinfected and non-disinfected secondary treated wastewater was modelled, and ingestion based on a dilution of 1:99 and one day die-off. Viruses accounted for the main risk, followed by *Cryptosporidium*.

The application of QMRA using MST as the indicator was recommended in the review by Zhang et al (2019). MST are found more consistently and in higher concentrations than pathogens which may be seasonal, or only present during outbreaks. As well as identifying sources of contamination, it was proposed that MST thresholds be derived for human and animal faecal sources which would associate the potential pathogen load with the marker. A marker gene threshold has been established for the gull marker gene which could be developed for other animals which carry zoonotic pathogens. Rather than a universal target, they proposed site specific QMRA to support decisions to manage water quality. These would consider the differences in carriage rates and the fate of pathogens and MST in the environment. New data would be required on decay rates and viability of pathogens as qPCR does not establish whether the pathogen is viable.

3.6.4 Environmental DNA

Environmental DNA (eDNA) studies on New Zealand Department of Conservation water sources, and on faecal samples has shown similar patterns of FIB to *Camplylobacter*, but FIB were in greater abundance in the water sources (Phiri et al 2020), confirming their usefulness as indicators of faecal pollution. EDNA showed that the faecal samples from animal sources were highly similar but disparate, while water samples formed a tight cluster. Possum and rabbit were clearly differentiated from birds and domesticated mammals. However, as eDNA from water samples and faecal samples clustered differently it was not possible to use eDNA to identify sources of faecal contamination in water.

4 DISCUSSION

The NZ Guidelines were developed in 2003, based on a novel approach using a study of pathogens and FIB undertaken at rivers and lakes around NZ between 1998-2000 (McBride et al 2002). Due to this significant difference in the derivation of the guideline criteria compared to those used internationally, and the current revision of the science underpinning the guidelines, it is useful to determine how well they reflect best practice in water quality management, both in terms of the other guidelines and recent literature. The following discussion looks at key elements of the NZ Guidelines alongside international best practice and where recent literature may inform a revision of the guidelines for New Zealand.

Key questions are listed below.

- Is *E. coli* a suitable indicator for freshwater?
- How do New Zealand FIB criteria relate to public health risks compared with international values?
- Is QMRA a suitable approach for setting guideline values?
- Is management and monitoring in line with international practice and consistent in New Zealand documentation?
- What new tools can be used to support recreational water quality?

4.1 CHOICE OF INDICATOR

There is a wealth of evidence in the literature that there is a significant difference in the incidence of GI between swimmers and non-swimmers where water is contaminated by faecal material, and that young children are more susceptible (Arnold et al 2016, DeFlorio-Barker et al 2018). Factors such as head immersion and swallowing increased GI risk and there was also evidence that the risk from other contact activities such as white-water rafting could be as high, if not higher than swimming (Russo et al 2020). The is also an elevated risk of RI with other contact activities.

What is less clear is which FIB best reflects the risk of GI in freshwater. The WHO (WHO 2020) has re-confirmed enterococci as the indicator for both freshwater and marine waters, and at the same concentrations in both water types. This recommendation is based on dose response data from Kay et al (1996). The confirmation of enterococci as the FIB contrasts with WHO's earlier recommendations to EU to use both *E. coli* and enterococci. It is also in contrast to the DEFRA review (King et al 2014) which identified that studies had shown that only *E. coli* in freshwater was associated with GI. The US EPA also confirmed *E. coli* as a suitable indicator for freshwater (US EPA 2018).

The DEFRA review identified that enterococci was only associated with GI in the presence of human wastewater. The EU Member states report that water quality is driven by *E. coli* (WHO 2018). This was illustrated in the norovirus outbreak after the Amsterdam Canal swim (Joosten et al 2017). While enterococci concentrations were within the EU criterion for swimming (<330/100mL), *E. coli* concentrations were above the 90th percentile of 900cfu/100mL[16] and therefore of Poor quality and unsuitable for swimming. The swim occurred two days after heavy rainfall leading to sewage overflows. Where sewage contamination is recent, QMRA also shows that *E. coli* is a suitable indicator.

In the New Zealand context where human wastewater, and consequently virus contamination, are not the drivers of faecal contamination in many areas, *E. coli* is likely to be a better indicator. The die-off of *E. coli* in the environment reflects the behaviour of the most common bacterial pathogens associated with GI from water recreation in New Zealand, *Campylobacter* and *Salmonella,* and also shiga toxin-producing *E. coli* (US EPA 2018) which is less common. New Zealand rivers typically flow from their source to the sea in a short time compared to the inland river and lake systems of the US and Europe. Therefore, significant pathogen die-off may not occur and the differences in viruses and *E. coli* may not be as significant. Where treated human wastewater is discharged in New Zealand, the guidelines state that the water quality criteria do not apply and a site-specific risk assessment, usually a QMRA, needs to be undertaken.

Where there are diffuse and/or varied faecal inputs to freshwater it is unlikely that a simple dose response relationship would exist between GI and FIB. The EPIBATHE (2009) studies identified that the relationship between *E. coli* and GI was not linear. The expert panel agreed that application of a stochastic model was more realistic. The conclusion of their study was that *E. coli* was a better indicator of GI than enterococci. A non-linear dose response might also be impacted by rainfall which has been shown to be a key factor associated with GI.

The use of *E. coli* as an indicator for freshwater is supported by both epidemiological studies and QMRA.

4.2 ASSESSMENT OF RISK

4.2.1 Comparison of international and New Zealand FIB guideline criteria

Tolerable risk is assigned to different FIB concentrations in different jurisdictions. McBride and Soller (2017) compared the difference in risk of *Campylobacter* infection using the different FIB criteria in the NZ Guidelines, NPS-FM 2014 and NPS-FM 2017 against the risk of GI in the international guidelines from WHO (2003), EU (2006) and US EPA (2012). The comparison in Table 3 is reproduced from McBride and Soller (2017). It shows the 2017 NPS-FM Blue criteria are similar to US EPA and EU Excellent criteria. The Yellow criteria, which are the minimum acceptable criteria for recreational water in New Zealand, are slightly lower quality than the EU Good criteria.

[16] recalculated as 1789cfu/100mL 95th percentile (WHO 2018)

Table 3 Comparison of New Zealand and international 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 Attribute State A												130										
2003 MfE/MoH Attribute State B															260							
2003 MfE/MoH Attribute State C																	550					
2003 MfE/MoH Attribute State D																						>550
2014 NPS Attribute State A															260							
2014 NPSAttribute State B																	540					
2014 NPS Attribute State C																			1000			
2014 NPS Attribute State D																						>1000
2017 NPS Clean Water Blue												130					540					
2017 NPS Clean Water Green												130							800			
2017 NPS Clean Water Yellow												130								2100		
2017 NPS Clean Water Orange													>130 but <260								2580	
2017 NPS Clean Water Red																>260						>2580

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
A/B: 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% (A/B) and 5% (MAS)
USA criteria are for max illness risks of 3.6% or 3.2%
EU freshwater guidellines are derived starting with
WHO guidelines but are not specifically risk-based

Table reproduced from McBride and Soller (2017). The actual risk varies slightly to descriptions in the 2017 NPS-FM Attribute table, as it includes longer term water quality data in terms of exceedances. This is indicative only as different jurisdictions have different rules and methodologies for site grading.

While *E. coli* concentrations are similar to EU Good criteria, the risk may be lower in New Zealand as the risk assessment includes animal sources and the EU and other international guidelines are based on human wastewater which would pose a consistently higher health risk due to the potential presence of viruses.

Despite being derived from similar epidemiology studies, the setting of tolerable water health targets differs between countries. The EU water quality objective was for recreational water to be Sufficient, below an enterococci 90th percentile greater than 330 cfu/100 mL which WHO (2018) calculated as 656 cfu/100 mL as a 95th percentile. In contrast, WHO (2003) considers that above a 95th percentile enterococci concentration greater than 500 cfu/100 mL public should be advised of the risk to health.

NZ Guideline values align to similar risk profiles in international criteria, despite being derived using a different approach. Both approaches are based on healthy adults and the literature shows that young children are more susceptible to infection as they ingest more water per body weight and have higher incidences of GI (Arnold et al 2016). This has been identified in the preliminary work on the revision of the NZ Guidelines and will be taken into account in QMRA modelling (Horn et al 2018). However, the dose-response for pathogens in the model is limited to healthy adults from challenge tests in the 1990s which could not be undertaken on children.

Only Canada has criteria for non-contact recreation, although it is not evidence based, but simply five times the criterion for contact recreation.

4.2.2 Use of QMRA to determine risk

The agreement between QMRA and epidemiological studies supports its use as a basis for deriving water quality criteria (Ashbolt et 1997), although WHO (2021) recommend guideline values are based on epidemiological studies. WHO (2021) does support QMRA use for comparing mitigation strategies to manage faecal sources and better for describing the health risk from faecal sources other than human. While Soller et al (2014) has described the health risk from animals and birds when the US EPA criterion is met, there is potential to use New Zealand data to populate a model for the most common livestock, birds and pets. Soller et al (2014) showed that carriage rates in animal faecal material differs from sewage. Using animal specific carriage rates that match an enterococci concentration of 35 cfu/100 mL, QMRA showed that direct input of fresh bovine faecal material did present a risk to human health from *Campylobacter*.

As international criteria are based on the risk from pathogens in human wastewater, it could also be useful to use QMRA to provide an overview of potential risk where there is human wastewater discharge given set conditions such as dilution, disinfection method and age.

4.3 MONITORING AND MANAGEMENT

4.3.1 Classification and monitoring of recreational sites

Classification of sites and subsequent monitoring regimes in the NZ Guidelines and international guidelines align in key areas with regards to risk from faecal contamination as summarised below.

- The classification matrix described in WHO guidelines is used.
- Data from five years of routine weekly monitoring during the bathing season comprising a minimum dataset of 60 samples is used for classification. This will meet the WHO 2021 guidelines unless an area has less than a 12 week bathing season.
- Sampling occurs during the bathing season, under conditions when bathing would be likely to occur (ie not high rainfall).
- Results from samples taken to investigate an incident, eg when daily sampling is required (NZ Guidelines) do not need to be included in the seasonal calculation of the 95th percentile used for compliance in the Microbial Assessment Category (NZ Guidelines).
- Classifications can be upgraded if action is taken to protect public health during adverse events eg beach closures forecast from predictive modelling.
- Calculation of the 95th percentile is based on the Hazen method.

Areas where the NZ Guidelines do not align or there are inconsistencies include the following points.

- The number of samples to be taken in the bathing season is not defined, but is assumed to be a minimum of 12, as some areas in New Zealand will have shorter bathing seasons than others. **The minimum number of samples should be made explicit.**
- An exception is made for classification based on 20 samples. This is not consistent with the more recent advice that a minimum of 60 samples are required to avoid miscalculation of the 95th percentile.
- There is an inconsistency in the advice of when to take samples. While most of the advice is to take samples during conditions where people are using the water (Section H vii), advises to take samples routinely even when no-one is likely to be swimming ie heavy rainfall.

Better linkage and explanations between the NZ Guidelines and NPS-FM 2020 would provide clarity. Examples are given below.

- Table 9 of the NPS-FM does not align with NZ Guidelines or international guidelines as it has a different objective which is to manage water quality in general, not recreation sites specifically. The sampling period and handling of data differs. An explanation of the different objectives would be useful.
- Table 22 of the NPS-FM details categories of bathing water quality over the bathing season, but they differ from the classifications of recreational sites in the NZ Guidelines where classifications were determined from a matrix

comprising the Sanitary Inspection Categories and Microbial Assessment Categories.

- The NPS-FM 2020 uses only the Microbial Assessment Category values in the NZ Guidelines to describe the bathing season attribute states of Excellent, Good, Fair, Poor. These are similar but different to the recreational water quality classifications: Very Good; Good; Fair; Poor; Very Poor.
- There is no reference in the NPS-FM 2020 to the sanitary surveys which are required to assess risk at recreational sites and to understand potential faecal influences, although reference is made in a supporting document (MfE 2017).
- Grades A-E are also used in Table 9 of the NPS-FM as an alternative description of the colour categories. The 95th percentiles are not the same as those in the Grades A-D of the Microbiological Assessment Categories in the NZ Guidelines.

There are some small inconsistencies which if addressed would avoid confusion as New Zealand has two monitoring regimes:

1) NPS-FM 2020 programme consisting of Table 9 of the NPS-FM which is over a year and Table 22 of the NPS-FM which is over the bathing season
2) NZ Guidelines which are for the bathing season.

There are also two different classifications of recreational water quality in the bathing season:

1) Table 22 of the NPS-FM
2) NZ Guidelines.

The NPS-FM is to manage water quality in general and the NZ Guidelines are specific for recreational sites in conditions when it can be used for recreation (eg not during rainfall events with high flows).

4.3.2 Actions

Although not described as Alert Levels, daily sampling is required in response to results which exceed the same trigger value of 260 *E. coli*/100 mL in the NZ Guidelines and NPS-FM 2020. Councils are required to investigate, undertaking daily sampling, if practicable. International guidelines are not as specific in terms of actions to be taken where a single value or percentile is exceeded. In the US, a beach action plan is required to be implemented when the 75th percentile is exceeded. Canada has a single value that cannot be exceeded and WHO (2003) and EU (2006) require investigation with extra sampling as required to determine the source of short-term contamination events.

Specific advice on investigating the cause of faecal contamination is not in the NPS-FM 2020. Councils could be referred to the NZ Guidelines. Advice on determining sources of contamination using new tools such as MST would be useful. There is an inconsistency between NPS-FM 2020 and NZ Guidelines around informing the public. In the NPS-FM 2020 Council is required to “take all reasonable steps to notify, and keep the public informed, that the site is unsuitable for recreation" if individual *E. coli* results are greater than 540 MPN/100 mL and may consult with the environmental health officer or other relevant body or person. This differs from the NZ Guidelines which specifies a role for the Medical Officer of Health for public notification. However, the requirement to notify the public of a health risk is stronger under the NPS-FM.

The WHO guidelines (WHO 2021) propose a recreational water safety plan for recreational sites. This could be a mechanism to include Mātauranga Māori to help manage recreational areas (eg kaupapa Māori monitoring). A framework could be co-designed that would incorporate western science and Māori awa health indicators.

4.3.3 Investigation of the source of faecal contamination

At recreational sites where water quality is unsuitable for swimming, potential sources of faecal contamination need to be identified and managed. A sanitary survey can provide information on the more obvious potential sources of faecal contamination, but it may not be very accurate. MST has become a useful tool to support sanitary surveys and identify the sources of faecal contamination. As carriage rates and the fate of micro-organisms in the environment is likely to be affected by local conditions, application is likely to require local verification.

This approach is particularly useful in the New Zealand context where non-point source, animal and mixed sources of contamination are likely. International research is investigating the potential for determining threshold concentrations of MST that could be used as part of a toolbox that assess risk to human health, along with FIB and other indicators. While international guidelines do not support additional microbial indicators, including MST, as a regulatory tool there is evidence that they provide useful information for management steps in response to exceedances.

In addition to managing recreational water in the bathing season the NPS-FM 2020 sets attribute states for freshwater quality using data collected throughout the year. The target for water quality in the NPS-FM 2020 is to meet four criteria (Table 9), unless there is insufficient data to determine the 95th percentile[17] (Appendix 3, NPS-FM 2020). This is irrespective of recreational activity as the targets to improve water quality for swimming are determined from data collected over the whole year, which is broader than the recreational water quality guideline which manages recreational sites. The NPS-FM 2020 grading is based on 20 samples routinely collected over the year, for a maximum of five years. It will therefore include samples taken when no-one would be using the water for recreation and include high rainfall events, where contamination is likely to be high. The caveat reflects these conditions:

The predicted average infection risk is the overall average infection to swimmers based on a random exposure on a random day, ignoring any possibility of not swimming during high flows or when a surveillance advisory is in place (assuming

[17] The minimum number of samples would be 60 (MfE 2003 and WHO 2021)

that the E. coli concentration follows a lognormal distribution). Actual risk will generally be less if a person does not swim during high flows (NPS-FM 2020)

4.4 NEW TOOLS

4.4.1 Indicators

Although there has been considerable work undertaken to identify alternative microbial indicators that better reflect the fate of viruses and protozoa in the environment eg bacteriophage and *Clostridium perfringens*, there is insufficient evidence for additional indicators that could be used in a regulatory framework. Molecular-based methods for enumeration of *E. coli* may have a role in the future, but in isolation are currently more costly than culture-based methods.

MST are a useful indicator which is rapidly developing. As well as the potential use of human MST as an indicator for the presence and fate of viruses, MST from other animals would be particularly useful where there are mixed sources of faecal contamination. Current research seeks to identify a target threshold for a marker that could identify a faecal source with associated carriage rates that inform risk assessment. However different carriage rates and the range in different types means that geographical verification may be needed (Holcomb and Stewart 2020). Used alongside qPCR for FIB it could be a cost-effective method for water quality management. Currently MST have an important role as part of a toolbox for gathering evidence, rather than providing definitive information on risk. At present there is insufficient evidence to use them in regulation.

4.4.2 Predictive modelling

A number of studies have highlighted the association between rainfall and high FIB or GI. Prediction tools eg based on rainfall or associated physio-chemical parameters such as turbidity could be a very cost-effective method of managing water quality, especially between routine monitoring. Different models are available, but they need to be verified for the location in which they are used and would not be suitable for all areas.

5 SUMMARY

5.1 OVERVIEW OF NEW ZEALAND AND INTERNATIONAL PRACTICE

The NZ Guidelines generally have an approach consistent with international guidelines. While there is a key difference in the assessment of risk and derivation of FIB criteria, comparison shows that overall risk appears similar. Despite not being included in the WHO guidelines, the use of *E. coli* as the freshwater FIB for GI is supported by international studies.

5.2 CONSIDERATIONS

The requirement for daily monitoring where routine FIB concentration is above 260/100 mL in both the NZ Guidelines and NPS-FM Table 22 is very prescriptive in terms of the actions required by other guidelines. The emphasis could be on identifying and managing the source of the faecal contamination with reference to sanitary surveys supported by MST.

There needs to be clarity about managing sites for recreation (NZ Guidelines) and the NPS-FM 2020 which is managing water quality in general to a recreational standard. It is important that separate guidelines for recreational water quality are maintained, which are specific for managing recreational sites. These could be extended to incorporate developments that provide site specific understanding of the health risk and could provide a more extensive framework for identifying and managing risk from faecal contamination based on tools discussed in the literature review eg MST and predictive modelling.

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