Recreational water quality monitoring and reporting in New Zealand

A discussion paper for Regional and Unitary Councils

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Waiotaura River at Otaki Forks, Kapiti. [Juliet Milne]

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Executive summary

New Zealand's rivers, lakes and coastal waters are highly valued for a range of contact recreation activities. Monitoring of water quality at popular recreational sites is undertaken by regional and unitary councils (i.e. the regional sector) to:

- Inform the public of potential health risks posed by contact with the water;
- Assess state and trends through time in the suitability of water for contact recreation; and
- Assess the effectiveness of council policy in maintaining or improving water quality for contact recreation.

This discussion paper outlines actions the regional sector views as necessary to improve the accuracy, robustness, and meaningfulness of recreational water quality monitoring and reporting.

Current monitoring and reporting does not fully satisfy public health objectives because:

- There is public confusion between long-term grading and surveillance monitoring information;
- Microbial risk information is retrospective, with laboratory test results generally not available for at least 24 hours;
- Microbial risk is inferred from bacteriological indicators, not disease-causing organisms (pathogens);
- Information on risk is spatially and temporally limited;
- Weather conditions are inconsistently addressed between regional sampling regimes; and
- Reporting of human health risk is limited in scope, focusing mostly on indicator bacteria and overlooking risks posed by cyanobacteria (and other toxin-producers) and poor water clarity.

Current monitoring and reporting of state and trends are also inadequate due to:

- Issues around site representativeness;
- Lack of consensus around the state measure, statistic and minimum sample size to report;
- The lack of a universally applied approach to determining a meaningful improvement or decline in water quality; and
- The absence of a state measure for human health risk that combines multiple hazards in fresh waters, especially pathogens and cyanobacteria.

Other significant issues are that current monitoring is costly relative to the usefulness of the information gained, aspects of recreational water use as a value besides health should be considered (e.g., aesthetic considerations), and the roles and responsibilities of regional, local and public health authorities require further definition.

Improving current recreational water quality monitoring and reporting should involve:

1. **Providing timely information** on health risk, through developing and implementing near real-time monitoring and/or forecasts of microbial water quality and cyanobacteria blooms;
2. **Updating the scientific basis** of existing national guidance, including indicator bacteria to pathogen ratios that underpin current national microbial guidance and, longer-term, shifting to direct monitoring of pathogens rather than indicator bacteria;

3. Implementing **consistent and statistically robust methods** to measure and report on state and trends;
4. Communicating information in clear and consistent ways that are readily accessible and understandable by the public; and
5. Supporting community-based initiatives that empower the public to take personal responsibility in assessing contact recreation suitability and provide opportunities for ‘citizen science’ volunteer monitoring of recreational waters.

This paper includes a number of recommendations that address these requirements.

1 Purpose

This discussion paper has been prepared for New Zealand's 16 regional authorities (the 'regional sector'). It serves to outline the regional sector's view of current recreational water quality monitoring and reporting requirements to meet the public's expectations. The paper builds on previously documented concerns with the framework and implementation of the current national microbial guidelines for recreational waters (see Bolton-Ritchie et al. 2013). It focuses primarily on suitability of water for human contact. It is intended that this paper provide direction for both the regional sector and research providers, as well as inform central government initiatives relating to recreational water quality.

2 Background and context

New Zealand's rivers, lakes and coastal waters are highly valued for a range of recreational activities that involve partial or total immersion in the water (e.g., swimming, kayaking, waka ama, water-skiing, surfing, fishing and collection of mahinga kai). The most commonly recognised risk to human health posed by contact with recreational waters is faecal contamination which can contain a range of pathogenic organisms including bacteria, viruses and protozoa. Of increasing significance in fresh waters is risks associated with toxin-producing cyanobacteria.

The regional sector has largely undertaken the lead agency role in the collection and reporting of recreational water quality data, and have the primary responsibility of managing natural resources to achieve community outcomes (e.g., 'swimmability'). Therefore, it is appropriate that the sector outlines both the issues as well as the actions and research needed to improve the accuracy, robustness, meaningfulness, and consistency of recreational water quality monitoring and reporting.

Monitoring of recreational waters is undertaken by councils to:

- Inform the public of potential health risks posed by contact with the water – both at the time of increased risk and in general;
- Assess state and trends through time in the suitability of water for contact; and
- Determine whether the suitability of water for contact recreation is compromised due to land-based activities. This includes:
  - Assessing the current state of water for contact recreation;
  - Determining whether suitability for contact recreation is increasing or decreasing through time (trend detection); and
  - Assessing the effectiveness of council policy in improving water quality for contact recreation where appropriate.

The 2003 Ministry for the Environment (MfE) and Ministry of Health (MoH) national microbiological water quality guidelines for recreational areas ('national guidelines', MfE/MoH 2003) are the principal guidance used by councils to manage health risk posed by faecal pollution. However, as documented in the Bolton-Ritchie et al. (2013) discussion paper, these guidelines are in need of review because some aspects are unclear and/or outdated.

Health risks posed by planktonic (floating) or benthic (bottom covering) cyanobacteria blooms in freshwaters are currently managed through separate national guidance that remains in draft form (MfE/MoH 2009). Separate guidelines also exist for other factors relevant to recreational use, including visual water clarity (MfE 1994) and nuisance periphyton growth in rivers (Biggs & Kilroy

2000). Guidelines for the former relate specifically to poor water clarity as a potential hazard to swimmers.

In 2011 the National Policy Statement for Freshwater Management (NPS-FM, New Zealand Government 2011) was introduced, with an amendment that added the National Objectives Framework (NOF) in August 2014 (New Zealand Government 2014). Appendix 1 of the NPS-FM identified human health for recreation as a compulsory national value that all lakes and rivers must be managed for. The NOF *E. coli* attribute table in Appendix 2 included a 'national bottom line' at a median of 1,000 *E. coli*/100mL. This was an annual median to protect, at a minimum, safe secondary contact described as *"occasional immersion and some ingestion of water"*. A 95th percentile of 540 *E. coli*/100mL was also included as a 'minimum acceptable state' for primary contact recreation *or "full immersion"* but it was not mandatory to manage lakes and rivers above this minimum state. This meant councils had discretion to set freshwater objectives for *E. coli* anywhere above the national bottom line, provided it gave effect to the NPS-FM as a whole, including the objective that the *"overall quality of fresh water is maintained or improved within a region…".*

In March 2017, the Government released *Clean Water,* a discussion document (MfE 2017a) that proposed to remove all references to secondary contact from the NPS-FM and replace the existing *E. coli* attribute table in Appendix 2 with one based around the amount of time a freshwater management unit (FMU) was "swimmable". The proposed amendments were gazetted (with minor modifications) in August (MfE 2017b) and mean that the regional sector must now consider swimming during all phases of the objective and limit-setting process under the NPS-FM. The amendments:

- Establish national targets to increase proportions of specified rivers and lakes that are suitable for primary contact over time[1];
- Require a regional plan to specify primary contact sites on rivers and lakes – as well as targets to improve water quality at these sites (and across FMUs) that will contribute to achieving the national targets;
- Introduce four different numeric attribute states for *E. coli* across five bands (A (blue) to E (red)) that vary according to the amount of time microbial water quality meets the swimming thresholds of 260 and 540 *E. coli* per 100 mL;
- Require the *E. coli* attribute state to be determined based on a minimum of 60 samples collected over a maximum of five years, regardless of weather or (river) flow conditions; and
- Introduce weekly surveillance monitoring requirements for *E. coli* (as already set out in the MfE/MoH 2003 guidelines) that apply to every primary contact recreation site identified in a regional plan.

With so many different iterations and variations of *E. coli* 'measures' proposed and/or reported in recent years, there is now wide scale public confusion about what swimmable means and the actual risk to human health that contact with different waters poses. The predominantly narrow focus on microbial water quality and planktonic cyanobacteria has added to the confusion since – as outlined in Section 3.3 – swimming is an activity that encompasses more than human health attributes. The regional sector therefore seeks to clearly identify the purpose and 'customers' of its recreational water quality monitoring, and the most effective mechanisms to deliver clear, usable, robust and timely information to them.

[1] The targets of at least 80% by 2030, and 90% no later than 2040, apply to rivers that are 4th order or larger and lakes with a perimeter of 1.5 km or more.

3 The current situation – why it isn't working

3.1 Protection of public health

As outlined in a recent audit of Auckland Council's SwimSafe programme (Neale & Schollum 2016), current recreational water quality monitoring and reporting in New Zealand is not delivering on one of its primary objectives of protecting public health. The likely reasons for this are outlined below.

There is public confusion between grading and surveillance information

Under the national guidelines, there are two distinct components to assessing the *microbial* suitability of a site for swimming – grading and surveillance. A Suitability for Recreation Grade (SFRG) assesses the general suitability of a site for swimming over the long term, making use of both a semi-qualitative catchment assessment and the 95th percentile from historical summer microbial water quality data. In contrast, surveillance refers to ongoing (usually weekly) sampling which is used to assess the suitability of a site for swimming in the 'here and now'. Surveillance sampling reduces the risk of selective grading assessments and provides the data needed for long-term trend assessment (Gluckman 2017). However, because it is feasible to have a long-term grade of 'good' (or 'low risk')[2] and a red/action level (i.e., 'unacceptable' risk) microbial test result from the latest round of surveillance sampling, the public (and media) are often confused by the dual reporting presented on LAWA (Figure 1) and council websites.

Figure 1: Example of current recreational water quality reporting on LAWA's "Can I swim here?" module.

The general public also has limited understanding of the highly changeable nature of microbial contamination in natural waters. People seem to perceive that, based on the latest weekly test result, water quality for swimming either remains safe or unsafe. In reality, the risk of microbial infection and potential illness associated with recreational activities can range from very low to very high, and this risk can change continuously.

One significant concern with long-term grades is that, more often not, the 95th percentile indicator bacteria value that underpins the grade reflects an elevated test result(s) for a water sample taken during or following rainfall. This is particularly the case in fresh waters where council monitoring data indicate that *E. coli* counts are generally highest during or after rainfall. As a result, the grade for the site is not considered to reflect the human health risk in dry weather which, for swimming at least, is when most contact recreation occurs (Bolton-Ritchie et al. 2013).

Microbial risk information is retrospective

As required by the national guidelines, most council surveillance programmes rely on laboratory testing of weekly (or less frequent) water samples for indicator bacteria (*E. coli* for fresh waters and enterococci for coastal waters). This testing does not yield results for at least 18 to 24 hours, and

[2] On LAWA, only the microbial component of the SFRG is reported at present. See Section 3.2. The reader is referred to McBride and Soller (2017) for detailed technical background on the derivation of grading and surveillance criteria in the MfE/MoH (2003) guidelines.

sometimes longer. Because of this delay in receipt of results, the public cannot be informed of potential health risks in a timely manner.

A recent example in Wellington highlights the issue and likely applies to many regions. After a short burst of rain just before midnight on Sunday 19 February 2017, a warm (24°C) and sunny Monday attracted significant numbers of people to some of the inner harbour swimming spots, including the very popular Taranaki Street dive platform.[3] Results from routine water samples collected that day became available late on the Tuesday and highlighted that six sites, including the Taranaki Street site and Oriental Bay at Freyberg Beach, had enterococci counts above the red/action mode of the national guidelines (280 enterococci/100mL).

Microbial risk is inferred from bacteriological indicators

While it is still commonplace across the world to use bacteriological indicators to infer risk of infection or illness from pathogens, Quantitative Microbial Risk Assessment (QMRA) studies have demonstrated that the potential health risks from human and some non-human faecal sources are different. This is due to the nature of the faecal source, the type, number and virulence of pathogens from any given source, as well as variations in the co-occurrence of pathogens and faecal indicators associated with different sources (e.g., Soller et al. 2010a; Till & McBride 2004).

Research in the U.S. also demonstrates that swimming-associated illnesses are caused by different pathogens, which depend on the source of faecal contamination (U.S. EPA 2015). For example, in human-waste impacted recreational waters, human enteric viruses appear to cause a large proportion of illnesses (Soller et al. 2010b). In contrast, in recreational waters impacted by gulls and agricultural animals, such as cattle and chickens, bacteria and protozoa are the main concern (e.g., Soller et al. 2010a). The relative level of predicted human illness in recreational waters impacted by non-human sources can also vary depending on whether the contamination is direct or via runoff due to a storm event (U.S. EPA 2010g) and how recently the faecal matter was deposited (Stott et al. 2011).

Another important consideration is natural environmental reservoirs of faecal indicator bacteria, such as sediments and aquatic plants. These reservoirs take up and store faecal microbes on declining flows where they can survive (out of sunlight) for extended periods (e.g., Drummond et al. 2015). The faecal microbes in these reservoirs may than be entrained back into the water column on the fronts of hydrograph events. *E. coli* can survive for many months in stream sediments and other in-channel reservoirs, but a priority pathogen, Campylobacter, does not survive well in the environment, including in-channel reservoirs, and is mobilised by hydrograph events mainly by wash-in of recent faecal matter (e.g., Stott et al. 2011).

In nutrient-rich reservoirs such as organic sediments in wetlands, faecal microbes, including indicator *E. coli*, may actually grow rather than simply survive (out of sunlight). Understanding of 'naturalised' (actively growing) faecal indicators has improved over the last decade, raising questions about their contributing to apparent microbial indicator load through sediment re-suspension, decaying vegetation and soil run-off. The presence of naturalised indicator bacteria is likely to confound the correlation between indicator bacteria and pathogens, making it difficult to determine the health risk represented by elevated indicator bacteria counts (Devane 2015).

[3] http://www.stuff.co.nz/national/89597747/After-the-worst-summer-in-30-years-Wellingtonians-are-facing-up-to-10-days-sun Accessed 24 May 2017

Overall, the research literature suggests that the risk of microbial infection in fresh waters or illness in coastal waters[4] may be currently under-stated or, more likely, over-stated. Therefore, the science behind the microbial thresholds of the national guidelines needs to be revisited or pathogens should be monitored directly.

Information is spatially and temporally limited

Microbial water quality is highly variable in space and time as a result of the influence of multiple factors, including rainfall, discharge and tributary inputs, the presence of livestock or wildlife, sediment resuspension and – in coastal waters – tides. Often only one or two spot locations are sampled, particularly along coastal beaches and embayments, meaning risk for an entire beach is inferred from 'point'-based information. Many children, for example, will likely play in shallower and warmer water near stream and drain outflows.

Taking a single spot sample once per week (or less frequently) is unlikely to provide a good estimation of microbial risk across this time scale, as the Wellington example above illustrates. Furthermore, faecal contamination can increase by 100-fold or more over a few minutes near flood wave fronts in rivers due to mobilisation from riverbed stores (e.g., Stott et al. 2011).

Regional sampling regimes are also limited to where and when *most* people swim, which is often closer to city and town centres and the warmer months of the year. This is appropriate for public health monitoring but the general public may interpret the statistics as being representative of a whole region and year-round. A further complication, particularly where resources are limited, is that sampling may be biased towards the 'mid-quality' sites. This is at least in part because the current guidelines (MfE/MoH 2003) state that sites graded 'very good' or 'very poor' do not require sampling on an ongoing routine basis. As a result, many councils either no longer monitor these sites, or do so infrequently (e.g., monthly sampling, or weekly sampling for one season once every five years) (Bolton-Ritchie et al. 2013). For fresh waters, this will change once councils have given effect to the NPS-FM amendments which direct them to identify primary contact sites in their regional plans and sample those sites weekly over their defined period(s) of use (MfE 2017b).

Weather conditions are inconsistently addressed between regional sampling regimes

In most regions, water samples are collected on a regular weekly schedule which, by and large, results in samples representative of a range of environmental conditions. However, in a few regions due to either logistics (e.g., Auckland where beaches are sampled by helicopter at high tide), or overlaps with other monitoring programmes (e.g., Taranaki where most sites are sampled under all flow and weather conditions, but for SoE State of the Environment (SoE) reporting purposes, subsets of 'bathing conditions' and 'all conditions' are generated), sampling is restricted to fine weather and/or high tide conditions. Limiting sampling to fine weather and high tide will likely underestimate the risk recreational water users are exposed to (Neale & Schollum 2016), particularly kayakers and surfers who commonly recreate in a range of weather conditions. For fresh waters at least, the Government appears to have addressed this issue with its recent amendments to the NPS-FM (MfE 2017b). Appendix 5 of the updated NPS-FM requires primary contact sites in rivers and lakes to be sampled weekly and although it is not stated explicitly, this is intended to mean consistent weekly intervals, regardless of weather or river flow conditions (K Forsyth[5], pers. comm. 2017).

[4] This is an important distinction between microbial guidance for fresh waters and coastal waters – the former is more conservative, being based on risk of infection which doesn't necessarily translate to illness (McBride & Soller 2016).
[5] Kirsten Forsyth, Senior Analyst – Ministry for the Environment.

Current reporting of human health risk is limited in scope

In most regions, monitoring and reporting focuses on indicator bacteria to infer human health risk. However, for lakes and an increasing number of rivers, toxic cyanobacteria also pose a potentially significant health risk.[6] There is currently no integrated reporting for fresh waters that addresses both microbial and cyanotoxin risk, let alone other aquatic hazards. This can make it difficult for users of LAWA and council websites to determine the current health risk at a particular fresh water site. Some councils (e.g., Greater Wellington Regional Council in relation to the Hutt River and Environment Canterbury in relation to the Temuka River) have been publicly criticised for reporting water sample test results and/or SFRGs that indicate a low risk for swimming when *Phormidium* bloom warnings have been in place for a period of the summer.

There are also toxins that can affect recreational users in the coastal domain (e.g., tetrodotoxin from the grey side-gilled sea slug (*Pleurobranchaea maculata)* that caused the deaths of dogs on some Auckland beaches in 2009 – McNabb et al. 2009), as well as other issues that pose a high health risk (e.g., jellyfish stings) when microbial water quality may be good or excellent.

In addition to biological hazards, safety of recreational users can be affected by poor visual clarity of water and some categories of trash – which can interact (e.g., Lopes et al. 2016).

3.2 Tracking and reporting state and trends

The spatial and temporal issues raised in Section 3.1 relate to environmental 'representativeness', a fundamental requirement of state and trend reporting (Larned & Unwin 2012). Additionally, there are varying approaches to reporting microbial water quality state, such as the minimum number of sample results, the length of season, and which sample statistic(s) to use (e.g., median, 95th percentile). This is particularly problematic for recreational shellfish gathering waters because the current guidelines do not define a shellfish gathering season and lack clear advice on the duration and frequency of monitoring (Bolton-Ritchie et al. 2013).

In addition to statistical measures of state, the MfE/MoH (2003) national guidelines also include Suitability for Recreation Grades (SFRGs) which have two subcomponents: the semi-qualitative Sanitary Inspection Category (SIC) and the quantitative Microbial Assessment Category (MAC). The SIC reflects catchment microbial risk and the MAC represents a 5-year 95th percentile from actual monitoring data. Many councils report SFRGs and they have been applied in the form of water quality targets in some regional plans (e.g., the Canterbury Land and Water Regional Plan, ECan 2015) and non-regulatory catchment strategies (e.g., the Canterbury Water Management Strategy (ECan 2010) and Te Awarua-o-Porirua Harbour Catchment and Action Plan, PCC 2015). However, due to serious concerns about the robustness of the SIC determination process (see Bolton-Ritchie et al. 2013), the recreational water quality module launched on LAWA in December 2014 simplified reporting to provision of weekly (surveillance) water sample test results and a 95th percentile statistic based on sampling results from the last three summer seasons. This is at odds with the national guidelines which recommend five years' data be used to derive a MAC value[7] but is consistent with draft NPS-FM monitoring guidance (MfE 2015) which suggests a 95th percentile based on 30 data points is sufficiently robust. More recent advice (McBride & Soller 2017) suggests in the order of 60 samples is preferable. This advice has been incorporated in the latest amendments to the NPS-FM (MfE 2017b).

[6] The health risk is particularly pertinent to animals, including dogs and livestock, which is of great public concern.
[7] Less data can be used but means the SFRG must be classified as "interim" (MfE/MoH 2003).

The updates to the NPS-FM (MfE 2017b) include other changes that address recreation-related monitoring and reporting requirements for lakes and rivers. While recent monitoring guidance (MfE 2017c) states that these changes are not intended to replace the national guidelines in any way, there is now some duplication and inconsistencies between the NPS-FM and the national guidelines. For example:

- As outlined above, the national guidelines already provide a dual reporting framework based on both regular (typically weekly) surveillance monitoring and long term risk grading (using both sanitary survey information and longer-term historical water quality data);
- The national guidelines use a surveillance threshold of 550 *E. coli* per 100 mL as the threshold for public health notification whereas the NPS-FM uses 540 *E. coli* per 100 mL;
- The national guidelines utilise a SFRG as an indicator of general 'swimmability' that incorporates a MAC based on the 95th percentile *E. coli* value calculated from 100 sample results[8] over the last five swimming seasons – whereas the NPS-FM has four different numeric states to represent an *E. coli* 'grading' and accepts a minimum of 60 sample results over five years[9]; and
- The national guidelines (Section B.2) recommend that territorial authorities and the Medical Officer of Health notify the public of potential health risks arising from elevated indicator bacteria counts but – in the case of fresh waters – Appendix 5 of the NPS-FM directs regional councils to notify the public (and to continue daily sampling where required).

The different reporting statistics and frameworks available create confusion and do not aid effective communication with the public on the suitability of waters for swimming. For fresh waters, this confusion is exacerbated by the lack of a single state index of human health risk that incorporates both microbial water quality and cyanobacteria.

Challenges for consistent inter-regional and national reporting of surveillance monitoring include:

- As noted in Section 3.1, existing sampling regimes for many regions are biased towards the 'mid-quality' sites and, for some regions, reporting of state statistics is potentially more negatively skewed because resources have been invested in monitoring 'very poor' sites as part of targeted remedial investigations.
- There is no one universally applied approach to determining a meaningful improvement or decline in microbial water quality for consistent trend reporting.
- Differences in sampling regimes – season length is a good example, with the summer monitoring period in Southland being shorter than that used across most of the North Island (Bolton-Ritchie et al. 2013).

3.3 Further challenges

Microbial monitoring is costly relative to the information gained

For many regions, recreational water quality monitoring programmes are a significant resourcing burden, requiring multiple staff and days to carry out weekly surveillance sampling alone. Daily re-

[8] If less than 100 data points are used, it is an *interim* SFRG (MfE/MoH 2003).

[9] The *E. coli* attribute table is what regional councils must use to set their freshwater objectives for each FMU and represents long term grades (MfE 2017d) while Appendix 5 addresses weekly surveillance monitoring. Under the national guidelines, a MAC and SFRG are based on surveillance monitoring data. In contrast, the NPS-FM does not specify that *E. coli* attribute state needs to be based on surveillance data – recent guidance (MfE 2017d) indicates that attribute state should be based on *monthly* sample results from SoE monitoring.

sampling when alert or action microbial guidelines are breached adds an additional resource burden. This re-sampling can assist with identification of contamination issues but, particularly when rainfall related, often yields little new information and may direct already limited resources away from more targeted efforts to identify and remedy contamination issues. The latest amendments to the NPS-FM (MfE 2017b) will further stretch council resources through requiring all river and lake primary contact sites listed in a regional plan to be monitored weekly for *E. coli* during the period(s) specified in the plan, even if the risk of microbial contamination is very low. A perverse potential outcome could be that 'low risk' sites are not identified in regional plans.

Human health is not the only consideration for recreational water use as a value

While microbial water quality and toxins are fundamental attributes to monitor in recreational waters, they are seldom the factors that influence people's decision to enter a water body. Research by West et al. (2016) has shown that both colour and clarity of water are among the strongest influences of people's perception of water quality. Various council initiated surveys (e.g., James 2011, Greenfield & Martin 2016) and overseas research support this and further identify rubbish, scums/foams, odour and 'slimes' as being key factors most likely to deter water-based recreation. Such survey findings suggest it is difficult to convince someone that a river with conspicuous periphyton growth or its banks littered with rubbish is safe to swim in, regardless of the latest *E. coli* count.

The current human health focus of monitoring and reporting, versus a more holistic 'experience'-based approach (i.e., one that takes into account indicators such as rubbish and visual water clarity), may potentially contribute to the perceived public 'scepticism' of current information on swimming water quality. The focus on pathogens aligns with general abhorrence of direct human waste input to water by Maori, but misses other aspects of cultural suitability for swimming use that typically combine swimming with practices such as gathering kai and other resources (Tipa et al. 2017).

The roles and responsibilities of regional, local and public health authorities are unclear

The national guidelines provide a recommended framework for establishing the roles and responsibilities of different agencies in recreational water quality monitoring and reporting. However, the two major pieces of legislation the guidelines cite – the RMA and the Health Act – do not explicitly define these responsibilities (MfE/MoH 2003). Key issues exist around:

- Which agency should monitor when water quality at a site repeatedly breaches alert or action level microbial thresholds,
- Improving consistency in who communicates health risk and the messages communicated, and
- Regional variation in notification practices and health warning signage.

New surveillance monitoring requirements provided as Appendix 5 to the updated NPS-FM (MfE 2017b) indicate that regional councils are now the primary agency responsible for both follow up sampling and public notification of elevated test results. This is at odds with the framework outlined in the national guidelines and the process for coastal waters remains unclear.

4 What needs to change?

Current monitoring and reporting of recreational water quality must improve. The New Zealand public expect meaningful monitoring and reporting and the current suitability of waters for recreational activities in fresh and near shore coastal waters needs to be improved over time.

Emphasis should be placed on:

- Providing **timely information** on health risk, through developing and implementing near real-time monitoring and/or forecasting of microbial water quality and cyanobacteria blooms;
- **Updating the scientific basis** of existing national guidance, including indicator bacteria to pathogen ratios that underpin the current guidelines and, longer-term, shifting to direct monitoring of pathogens rather than indicator bacteria;
- **Implementing cost-effective, consistent and statistically robust methods** to measure and report on state and trends;
- **Communicating information in clear and consistent ways** that are readily accessible and understandable by the public (including iwi); and
- **Supporting community-based initiatives** that empower the public to take personal responsibility in assessing contact recreation suitability and provide opportunities for 'citizen science' volunteer monitoring of recreational waters.

4.1 Providing timely information

Near real-time monitoring or forecasting approaches are needed to adequately inform the public of water quality-related health risks.

4.1.1 Real-time monitoring

Real-time, or near real-time, monitoring of microbial water quality would provide the public with more up-to-date and useful information on health risks associated with swimming. In recent years there have been developments in quicker microbial testing, including the MicroSnap™ *E. coli* test kit that can return indicator bacteria results in 8 hours. Massey University has been using the U.S. EPA-approved TECTA™ B16 automated microbiology detection system to enumerate *E. coli* in both drinking and general fresh waters[10]. Specifications indicate *E. coli* results are available in 2 to 18 hours, depending on the level of contamination in the water sample – concentrations expected in recreational waters are likely to take 10-12 hours (Veolia 2015). The TECTA™ B16 has been approved by the Ministry of Health for testing drinking water samples but research is needed into the efficacy and reliability of such technology in recreational waters.

Reliable technology needs to be not only fast but sensitive, portable and well correlated with current laboratory methods (Lebaron et al. 2005). The Austrian-developed ColiMinder® is one such portable machine now available. The ColiMinder® is a small, automated bankside laboratory that measures specific enzyme activities of targeted indicator bacteria such as *E. coli* using fluorescence detection and provides a result in 15 to 30 minutes. It can detect metabolically active cells, including viable but non-culturable *E. coli* (VWM GmbH 2015). In contrast, traditional culture-based assays rely on growth of target organisms on agar media over a period of 18 to 72 hours (Figure 2).

[10] https://www.massey.ac.nz/massey/about-massey/news/article.cfm?mnarticle_uuid=E807C798-958D-D2BF-3D85-61B350A3DAAD Accessed 29 March 2017.

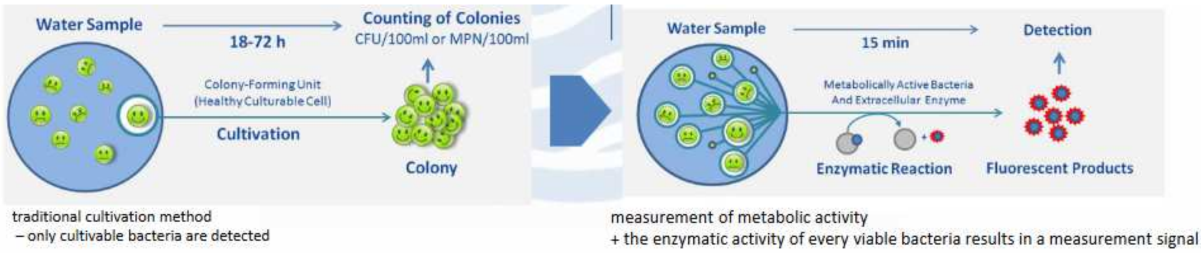


Figure 2: Current culture-based assays (left) vs ColiMinder. (Source: VWM GmbH 2015, p4)

ColiMinder® reports *E. coli* results as Modified Fishman Units or MFU and so needs to be calibrated against traditional culture-based laboratory methods. NIWA is currently performing such testing in New Zealand (Stott et al. 2016), alongside collection of high frequency monitoring data for proxies of microbial contamination (e.g., turbidity, flow and potentially tryptophan), with the view to developing predictive microbial water quality models based on these proxies.

4.1.2 Predictive forecasting

Microbial water quality

Microbial forecasting is essentially the ability to predict near-future expected microbial water quality conditions at a given site or sites. While, like weather forecasts, predictions inherently carry a degree of uncertainty, their strongest value is that they provide recreational water users with *advance warning* of the likely risk associated with recreation. The degree of warning can be broken down into: a) what is the expected *current* risk, and b) what is the *future* risk (e.g., tomorrow), which affects decisions about immediate and future recreational activity. Depending on their set-up, predictive tools can also provide information that has greater spatial and temporal application.

Predictive models are in use in parts of the U.S (e.g., the Great Lakes) and Europe (e.g., Scotland – SEPA 2016) and are recognised in the U.S. EPA (2015) recreational water quality guidelines as an approach that may supplement water quality monitoring results to allow for timely beach notification decisions.[11] Predictive modelling tools include statistical regression models, rainfall-based notifications, decision trees or notification protocols, deterministic models, and combinations of these. There are also 'artificial intelligence' methods like neural networks which have been trialled in New Zealand for assessing risk of contamination of shellfish aquaculture product (Coco et al. 2009). There are various considerations for developing and selecting such models which, to be effective, should reflect site-specific conditions such as inter-seasonal variations (U.S. EPA 2015). Development of predictive models typically requires monitoring data for establishing and maintaining statistical relevance. Statistical models can require large datasets.

In New Zealand, Auckland Council has invested in a microbial forecast for popular recreation sites in Waitematā Harbour, making use of a hydrodynamic model developed by DHI. A similar DHI-generated forecast is under development in the Wellington Region in Te Awarua-o-Porirua Harbour. These forecasting systems are underpinned by hydrodynamic modelling that simulates tidal and wind-driven currents to predict how faecal contamination will enter and disperse throughout each harbour. Simulations are carried out every 12 hours using the latest three-day forecasts of rain and wind. Accuracy has been variable to date but is improved with collection of high resolution data,

[11] The EPA has conducted research and published a two-volume report to advance the use of predictive models (U.S. EPA 2010a, 2010b). Volume I summarises the basic concepts for developing predictive tools for coastal and non-coastal waters. Volume II provides the results of the EPA's research on the development of statistical models at research sites. It also presents Virtual Beach, a software package designed to build statistical multivariate linear regression predictive models. The EPA is expanding the Virtual Beach tool to include other statistical approaches and is pursuing improved predictive modelling efforts, such as linking catchment and statistical models and developing approaches to incorporate time lags (U.S. EPA 2015).

both spatially and temporarily, particularly in rain events when stormwater (and at times wastewater) enters the harbours (B Tuckey, DHI, pers. comm. 2015). Greater Wellington Regional Council is intending to extend their forecasting to Wellington Harbour (Conwell[12] pers. comm. 2017).

In terms of riverine environments, some councils, such as Horizons Regional Council, have established river flow and *E. coli* relationships for the purposes of using real-time flow to indicate likely *E. coli* counts and therefore risk of infection from swimming. This approach has proven promising at 12 sites (Matthews & Roygard 2016) but is undergoing further calibration at others where relationships are weak (Patterson, pers. comm. 2016)[13]. As well as flow, water clarity and turbidity are also being trialled as proxies for *E. coli* contamination, with relationships between these variables currently an active area of research at NIWA under the Freshwater and Estuaries Centre's Causes and Effects of Water Quality Degradation programme. Preliminary analysis of NIWA's national river water quality network data by Davies-Colley et al. (in prep) indicates that *E. coli* counts correlate moderately well with visual clarity (better than flow) and supports practical advice offered by many councils, such as Horizon's *"Swim here, when the water's clear"* message that appears on information signs at selected recreational sites. In Southland, a range of statistical-based approaches have recently been applied to predict *E. coli* counts in the Oreti River in Southland, with a Bayesian network approach looking promising (Avila et al. in prep).

E. coli predictive models have also been developed for lake environments. For example, Dada and Hamilton (2016) developed predictions for five Lake Rotorua 'beach' sites, utilising meteorological and bacteriological data covering 14 swimming seasons, as well as data of inflowing streams. The models include predictor variables such as wind speed and antecedent rainfall. Bay of Plenty Regional Council are now looking at a forecasting project for the lake (Scholes[14] pers. comm. 2017).

The Auckland and Wellington coastal examples represent a significant resource investment into a mechanistic 'white box' model (Figure 3). While other regions also have hydrodynamic models or river dilution-type studies that may assist with microbial forecasting (e.g., Northland – Kaipara Harbour, Bay of Plenty – Tauranga Harbour), such models are likely unaffordable for some regions. Investigations should be made into developing regression-based 'black box' models based on indicator bacteria relationships with observed or predicted river flows, rainfall, tides, currents, wind and water clarity or turbidity. Such models could range from sophisticated regression or machine-learning models to simpler rule-based systems. Considerable data, including extensive microbial data sets under a range of weather and flow or tidal conditions, is held within most councils that could be used to statistically explore how predictor factors influence water quality at local swimming sites. Effort should be put into interrogating these data sets to develop predictions that could be categorised as 'low', 'moderate' or 'high' likelihood to give users an indication of how much confidence to place in relying on them. These simple predictive approaches, whilst inexpensive to use and informative for rapid water quality management decisions, do require good catchment knowledge which forms a fundamental component of managing microbial water quality in recreational waters (MfE/MoH 2003; Soller[15] pers. comm. 2016).

[12] Dr Claire Conwell, Environmental Scientist – Coast, Greater Wellington Regional Council.
[13] Maree Patterson, Senior Water Quality Scientist, Horizons Regional Council.
[14] Paul Scholes, Science Team Leader – Water Quality, Bay of Plenty Regional Council.
[15] Jeff Soller, Principal Scientist, Soller Environmental, Berkeley, California.

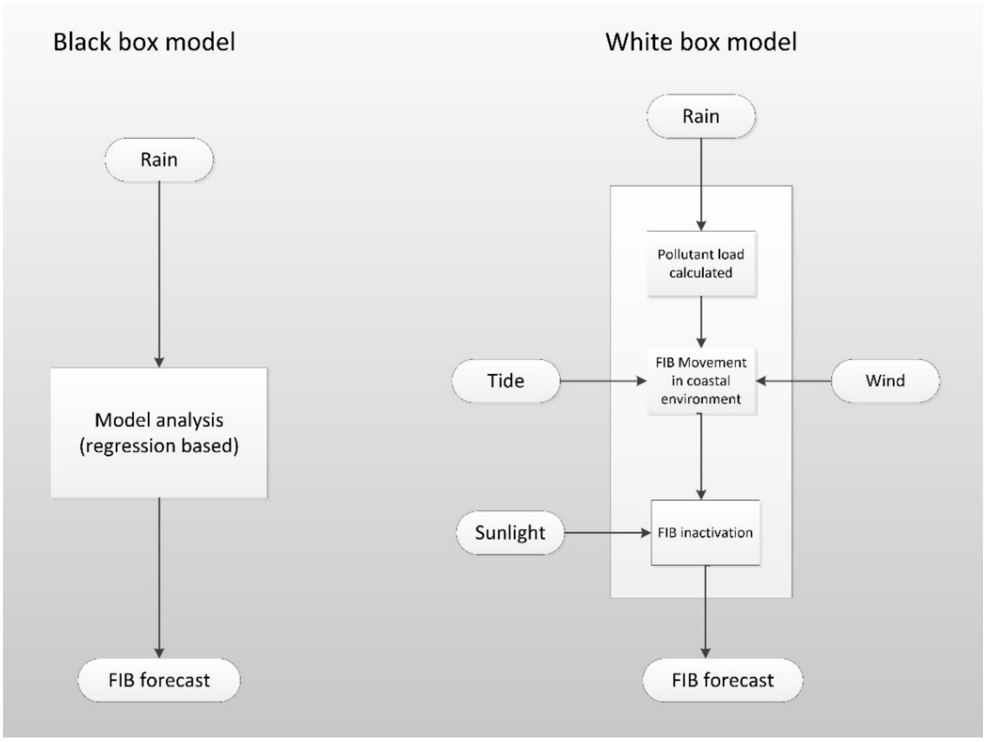


Figure 3: **Schematic of predictive-based models. 'Grey' box models also exist (e.g., neural networks).** (Source: Martin & Schollum 2016, p16)

If councils progressively move to predictive models, guidance will be needed on validation requirements so that the costs associated with current spot water sampling can eventually be scaled down to periodic revalidation exercises. Attention should also be given to timely, accessible, and meaningful reporting of the results of predictions (e.g. statement of risk rather than indicator bacteria concentrations), including uncertainty aspects. Lastly, a discussion will also be required with central government to determine the implications for predictive assessments of microbial water quality in terms of the existing national guidelines, national reporting and, for freshwaters, the *E. coli* attribute in the NOF. The recent amendments to the NPS-FM (MfE 2017b) focus on spot sampling rather than predictions.

Cyanobacteria and marine biotoxins

Predictions of cyanobacteria blooms and marine biotoxins is currently reliant mostly on regular surveillance monitoring over summer to provide an early warning indication of biovolume or cell counts (planktonic cyanobacteria) or density or bed cover of riverbed *Phormidium* growths that might lead to unacceptable health risks to recreational users. However, blooms frequently occur outside of monitored locations and sometimes the regular summer monitoring period. This has been the case with riverbed cyanobacterial mats in the Wellington Region which led GWRC to develop automated early warning system for popular recreational rivers based on the frequency of 'flushing flows' (Milne & Watts 2007) that reduce/prevent *Phormidium* blooms. While such systems provide useful general 'forecast' guidance, further work is needed to identify flushing flow requirements (e.g., magnitude and frequency) which are river-specific and complex (Heath & Greenfield 2016, MfE/MoH 2009). A national river susceptibility model has been developed for *Phormidium* blooms (Wood et al. 2017) for MfE and Environment Southland are also looking to develop a model with Cawthron that can predict *Phormidium* abundance at six high use recreational sites on a real-time basis (Wilson[16] pers. comm. 2017).

[16] Karen Wilson, Senior Science Coordinator, Environment Southland.

4.2 Updating the science

Human health assessment need to be underpinned by robust science. The current national microbial water quality guidelines were based on the best available information at the time but are in need of review to update their underlying scientific basis. The 2009 national guidelines for cyanobacteria in lakes and rivers remain in "interim" status and are also in need of review, to reflect research carried out in the intervening period, particularly in terms of benthic cyanobacteria (S Wood[17] pers. comm. 2017). Updates required to these respective guidelines are outlined in this section.

4.2.1 Indicator bacteria to pathogen ratio assessments

There is strong evidence that the indicator bacteria to pathogen ratios that underpin the 2003 national guidelines are in need of review (e.g. Moriarty et al. 2008). Despite an initial commitment to investigating a review following release of the regional sector's discussion paper in 2013 (Bolton-Ritchie et al.), central government has to date not formally commenced a review.

The regional sector's Coastal Special Interest Group effectively commenced a review of some aspects of the guidelines via an Envirolink Tool grant approved in October 2016. In relation to indicator bacteria to pathogen ratio assessments, the proposed tool (McBride 2016a), currently in progress, will:

- Assess recent overseas coastal swimming-and health epidemiological studies to confirm that the existing guideline numbers used to manage human health risk in coastal waters are appropriate. If not, amendments will be recommended.
- Develop a new model for shellfish microbial contamination and associated human health risks that takes explicit account of uptake and depuration processes, for use in coastal (QMRA) studies. The tool will be used to consider if the shellfish water quality component of current guidelines could be enhanced to better reflect tolerable infection risks from consumption of raw shellfish flesh.
- Advise on the spatial scale at which guideline use is inappropriate near treated wastewater discharges, and best practise methodology for determining microbial health risks in close proximity to discharge outfalls.

A review of the freshwater component of the guidelines is dependent on a repeat national microbial survey of rivers and lakes to underpin a new QMRA. Earlier this year MfE (2017e) announced a review would be undertaken and a survey proposal was subsequently submitted to MfE by ESR with other research institutes in June 2017. At the time of finalising this paper, a formal contract to design a repeat survey was being finalised.

4.2.2 Direct pathogen measurement and characterisation

The most robust way to monitor microbial risk is to directly measure the pathogens themselves rather than rely on ratios with indicator bacteria. This has also been recommended to Auckland Council in a recent review of their SafeSwim monitoring programme, with Neale and Schollum (2016) advocating for research into the use of modern molecular techniques based on the detection of genetic material. One example is whole genome sequencing, which determines the complete DNA sequence of an organism's genome at a single time. However, such methods still have limitations in terms of understanding what the molecular outputs mean in terms of risk (e.g., genetic material may be present even when the microbe is inactive and no longer infectious).

[17] Dr Susie Wood, Senior Scientist, Cawthron Institute.

Overall, further work is needed around the development of rapid and sensitive techniques for pathogen detection. A variety of promising molecular methods are emerging (Aw and Rose 2012) but there are still limitations for water monitoring (Girones et al. 2010).

The other main barrier to routine measurements of pathogens is cost. However, costs have started to reduce (still impractical for routine monitoring across many sites) and will likely continue to do so if demand for testing increases. Monitoring pathogens, such as *Campylobacter* spp., *Cryptosporidium*, norovirus and adenovirus, at problematic or 'high risk' sites would seem a likely good starting point and will occur in the repeat national microbial freshwater survey.

4.2.3 Faecal source identification and quantification

Testing for faecal indicator bacteria alone is valuable in long-term monitoring but reliable information on the source of faecal contamination is needed to guide successful management interventions in problem catchments. Genetic and chemical-based faecal source tracking (FST) techniques are now widely used across New Zealand to help identify the causes of contamination at swimming sites (e.g., Walker et al. 2015; Cornelisen et al. 2012, Gilpin et al. 2011). However, there are not yet reliable FST markers available for some common sources of contamination, including pigs, rabbits, pigeons and shags. Further, multiple faecal sources are usually present in a catchment and a priority for research is to more accurately *quantify* the relative abundance of each source so as to guide management intervention. A 2017 AgResearch-led MBIE Endeavour Fund Research programme proposal sought to address some of these knowledge gaps, together with an evaluation of the effectiveness of new or existing mitigation options (e.g., stock exclusion, riparian buffers) in reducing microbial contamination. However, this proposal was unsuccessful.

A related consideration is that faecal sources are not equal in the health risk they pose to humans at a given *E. coli* or enterococci concentration. For example, a survey of several waterfowl species in New Zealand found that although ducks produced the highest loadings of *E. coli* and enterococci indicator bacteria per bird, Canada geese produced the highest loadings of *Camplylobacter* spp. per bird (Moriarty et al. 2011). Determining the actual human health risk associated with a faecal contaminant source requires a Quantitative Microbial Risk Assessment (QMRA). There have been considerable advances in these assessments in recent years and a growing application of QMRA in New Zealand. ESR is currently working with DairyNZ to develop a model that makes use of New Zealand-specific data to estimate the relative risk to human health risk from different animal sources of faecal contamination (Moriarty, pers. comm. 2017).

4.2.4 Faecal indicators for estuarine waters

It is unclear from the existing national guidelines whether *E. coli* or enterococci should be tested on samples from estuarine waters for public health management and environmental state reporting (Bolton-Ritchie et al. 2013). Currently some councils test for *E. coli*, some test for enterococci (e.g., GWRC), and some (e.g., Environment Canterbury) test for both indicator bacteria and use the poorer of the two results to inform management. Advice on the most appropriate indicator to use for brackish waters is included in the current Envirolink Tool grant addressing coastal water quality guidelines (McBride 2016a).

A broader concern in estuarine waters relates to the fact that some bacteria, including the favoured freshwater indicator, *E. coli*, are more rapidly inactivated in saline waters owing to the action of salt on sunlight-damaged cells (e.g., Sinton et al. 2002). Furthermore, particles generally in such waters, probably including microbes, become flocculated and tend to settle owing to neutralisation of repulsive surface charges by salt ions. Microbial contaminants of river plumes in these saline waters are probably fairly rapidly attenuated by these (currently poorly understood) processes. However, at the same time the overall microbial hazard is increased in saline waters because of a wider range of recreational activities, such as collection of bivalve shellfish (e.g., cockles, mussels) that concentrate microbial contaminants by filter-feeding.

4.2.5 Cyanobacteria

Considerable research has been carried out into cyanobacteria since the current interim national guidelines were released in 2009. This is particularly the case for benthic cyanobacteria, with GWRC completing a detailed assessment of 10 years of monitoring and investigations data (Heath & Greenfield (2016) and MfE commissioning several technical reports as part of developing the NPS-FM National Objectives Framework. These reports include a literature review to summarise existing knowledge (Wood et al. 2014) and an assessment of the environmental drivers of *Phormidium* blooms to inform the management of human health risk related to swimming in rivers (Wood et al. 2017). Despite this, considerable research gaps remain – MfE's Benthic Cyanobacteria Working Group recently identified several projects of high priority to better understand the causes of *Phormidium* blooms:

- Inoculation experiments in a range of stream types across the country;
- Further research into the role of fine sediment (e.g., as a source of nutrients); and
- Obtaining more high resolution (weekly) monitoring data.

The guidance for lakes, where cyanobacteria blooms are largely planktonic in nature, also needs updating. The toxin quota (toxin per cell) that form the basis of the interim planktonic guidelines were calculated from five strains from one lake. There is now considerably more data, and the guidelines need to be updated (Wood pers. comm. 2017). These updates need to address the composition and toxicity of picocyanobacteria which are present in some lakes such as Lake Ellesmere Te Waihora.

Methods are also now available to screen samples for genes involved in toxin production, allowing for cost effective assessment of the presence of potentially toxic cyanobacteria. This should be included in an update of the interim guidelines because it would allow councils to determine which of the thresholds to apply to specific lakes or water bodies (Wood pers. comm. 2017).

4.3 Consistent, statistically robust methods to measure and report on state and trends

Council reporting of state and trends through time should focus on both primary measures of human health risk for fresh waters outlined in the NPS-FM; microbial water quality and cyanobacteria. In coastal waters, the emphasis should be on microbial water quality with attention given also to marine biotoxins.

4.3.1 Microbial water quality

The appropriate reporting measure(s), statistic(s), and sample record size and length for microbial water quality state and trends need to be revisited. This is a high priority given multiple measures and sample sizes are currently in use across the national guidelines, NPS-FM, LAWA and individual council reporting. Similarly, there is some 'bias' to current state reporting in some regions owing to water sampling targeting certain weather and/or tidal conditions or data analysis excluding some rainfall affected data (Bolton-Ritchie et al. 2013).

It is critical that the measures adopted are robust and consistent so that councils can demonstrate to the public and central government:

- The current state of microbial water quality at recreational sites across the region;
- Accurate tracking of meaningful changes in microbial water quality through time; and
- The effectiveness of policies implemented to maintain or improve microbial water quality.

Some useful statistical guidance is available in relation to *E. coli* and the NPS-FM (McBride 2016b) but this guidance pre-dates the recent (MfE 2017b) NPS-FM amendments. Moreover, this guidance does not address matters relating to determining and tracking changes in SFRGs. Given microbial water quality is strongly influenced by upstream catchment land use and weather conditions, accurate information on these must be collected and regularly assessed alongside microbial data.

With the recommended move towards use of predictive tools, consideration will need to be given as to how these tools can be used in 'accounting' situations. Models have the potential to provide more accurate estimates of the amount of time the health risk at a site was acceptable for swimming than inferences from weekly surveillance spot samples.

4.3.2 Cyanobacteria and toxins

Advice is required on appropriate measures to report the extent and frequency of cyanobacteria blooms and marine biotoxins. A key knowledge gap that impedes cyanobacteria reporting at present, particularly for benthic cyanobacteria, is uncertainty of health risk at different levels of streambed cover (Wood, pers. comm. 2017).

4.3.3 National reporting

Aggregating regional data sets for the purposes of national state and trend reporting is a key interest for central government but is of less importance to councils who need monitoring to reflect local usage, needs and resourcing which differ between regions (e.g. length of swimming season). In any case, robust national reporting is currently hindered by a number of considerations, including the selection of a suite of sites that represent recreational waters across New Zealand and ensuring that the data from each region are gathered, assessed and presented in a consistent manner.

First, however, central government needs to clearly define its reporting purpose(s). Existing council recreational water quality programmes deliberately, and appropriately, target places where people are known to swim and recreate during summer. If the government's priority is to report on the proportion of swimmable 4th order rivers across all of New Zealand (MfE 2017b), then one option may be to utilise a subset of council SoE sites, which tend to be monitored monthly year-round and are therefore more widely dispersed geographically. In the case of coastal waters, for reporting to be representative of all New Zealand's coastal waters, regardless of whether areas are actively used for recreation, additional funding would be required for new 'remote' sites given existing council networks target popular recreation sites. This is also potentially where having proxies and remote sensing would come into play.

4.4 Clear and accessible information for the public

Informing the public of the potential health risks associated with partaking in recreation needs to be considered separately from reporting on state and trends through time. The former is time-critical and requires appropriate communication methods that, for freshwaters at least, represent the combined risk associated with both microbial water quality and cyanobacteria. This may require the establishment of a basic 'health index' for reporting. The use of 'suitability for recreation' type indices should be further investigated because these recognise that water quality doesn't really 'pass' or 'fail', but rather varies on a continuum (Lopes et al. 2016, Nagels et al. 2001). A minimum operator approach (Smith 1990) would likely need to apply for fresh water where the most limiting of the two scores for *E. coli* and cyanobacteria would become the combined index score so as to safeguard public health.

4.4.1 LAWA

LAWA has proven a popular and successful platform for providing information to the public on recreational water quality across New Zealand. For example, there were over 30,200 views during the first weekend after the coastal recreational water quality launch in December 2014, with around 200 views per day on average for the rest of the summer bathing season. The recently revised 'Can I swim here?' module has also proven popular, with 30,900 visitors to LAWA since it was launched on 19 December 2016. This module has also increased the number of visitors to LAWA to around 300 per day on average (A Loughnan, pers. comm. 2017)[18].

There are a number of enhancements that could be made to improve the information on LAWA, some of which cannot be made until other issues are addressed. The highest priority is determining the most meaningful measure to report overall microbial risk that is statistically robust and people can both understand and trust. Another priority is confirming and applying the most appropriate indicator bacteria to estuarine sites.

Additional consideration should be – and, in some cases, is already being – given to:

- Reporting of cyanobacteria abundance (lakes) or cover (rivers), actual (from monitoring) or potential (from past monitoring or observations);
- Developing a potential 'health index' for reporting, with basic categories from 'very low' through to 'very high' and an additional category for "unknown" which might apply, for example, where cyanobacteria cover is not known;
- Providing 'metadata' relevant to microbial water quality, primarily forecasted rainfall and wind, which could be linked with a basic predictive microbial outlook forecast for the site(s) to which it relates (where councils can semi-quantitatively categorise the likely risk);
- Adding an icon and supporting information, once a suitable method has been determined, to demonstrate if microbial water quality at a site is improving over time (e.g., through use of a rolling statistic over a period of 3-5 years); and
- Including information on other properties of relevance to recreational water use, where available, such as visual clarity (or turbidity) and nuisance periphyton or macrophyte (aquatic) plant growth.

4.4.2 Other methods

Communication is best achieved via a suite of media. In addition to LAWA and council reporting, greater use of mobile technology is needed such as text alerts, favourite sites on an app or a mobile friendly 'push notification'. In very high usage areas, 'fire warning' type signage or, as used overseas in Scotland and parts of Europe, electronic signage could be erected at the site. Electronic signage spans 23 sites across Scotland to provide real-time predictions of swimming water quality during the summer (SEPA 2016).

[18] Abi Loughnan, Project Manager – Environmental Monitoring and Reporting (EMaR), Otago Regional Council.

4.5 Empowering the public to take personal responsibility

There is a growing movement in New Zealand, as there is overseas, for local communities to get involved with environmental assessments, including water quality (Peters et al. 2015). The strong public interest in water quality could be harnessed to the benefit of both the regional sector and the public, with van Hunen et al. (2017) finding that – despite some challenges – there are multiple benefits for regional authorities in supporting community volunteer monitoring of fresh water in New Zealand. Councils have limited networks and resources and simply cannot monitor everywhere people choose to recreate.

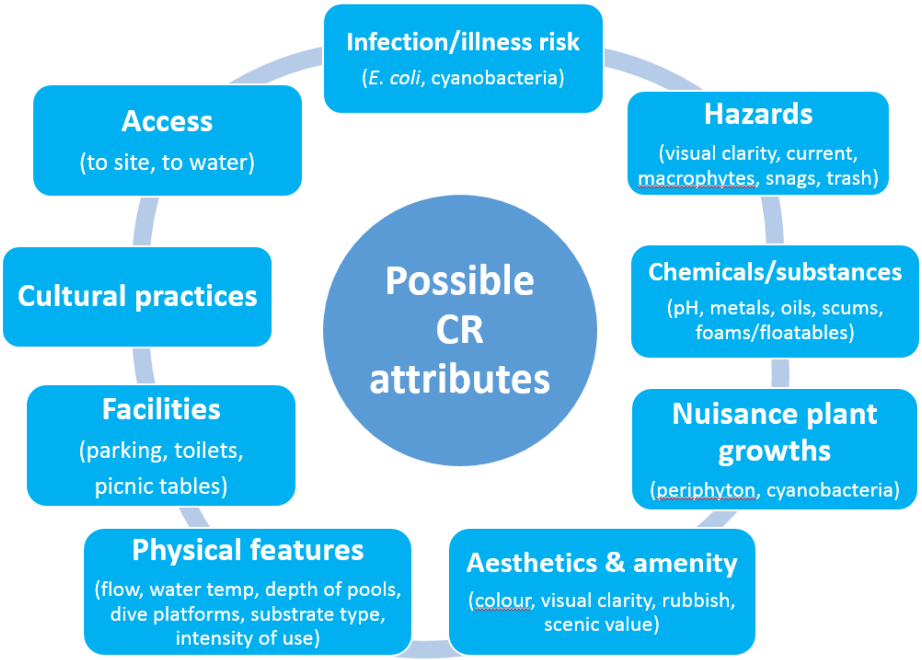
Supporting citizen science-based initiatives would both educate the public about water quality and empower individuals to take personal responsibility in assessing potential risks associated with contact recreation. Recent research by NIWA has already shown that community groups can perform *E. coli* (and other) testing of fresh waters using simplified test kits that produce results comparable to council samples being tested in IANZ accredited labs (Storey et al. 2016). Research is continuing in this area, with different *E. coli* kit methods such as petrifilm, sanita kun, peel plate and Aquagenx's *E. coli* Compartment Bag Test (CBT) being compared against laboratory Colilert and membrane filtration tests in the laboratory (R Stott[19] pers. comm. 2017, Storey et al. 2016). Iwi groups are also involved, with the Cawthron Institute currently working with Tiakina te Taiao to develop iwi science water monitoring using the Aquagenx's CBT. This monitoring is a way to increase coverage of waterways and to ensure sites that are important to iwi are monitored (J Banks[20], pers. comm. 2017).

With some initial training and periodic quality assurance checks, community volunteers should also be able to identify and estimate cyanobacteria abundance, particularly coverage of *Phormidium* mats in rivers. In addition, community monitoring could be expanded to include additional properties relevant to the 'recreational experience' such as visual water clarity, nuisance plant growth and rubbish. The amendments to Appendix 1 of the NPS-FM (MfE 2017b) specifically acknowledge that, in addition to pathogens, cyanobacteria and toxicants, visual clarity, deposited sediment and plant growth (macrophytes, periphyton and phytoplankton) are *"matters to take into account for a healthy water body for human use"*. The Gluckman (2017) paper also acknowledges the importance of considering a range of characteristics when assessing a water body's suitability for swimming, citing examples such as depth, temperature, current strength and nuisance weeds or algae in addition to human health risks from pathogens and cyanobacteria.

Figure 4 illustrates some of the 'attributes' that together determine overall suitability for contact recreation in fresh waters. These include both in and out of water attributes. In some cases, the community may wish to assess and report on locally-specific attributes, such as 'lake snow' algae (*Lindavia intermedia*) which can be a skin irritant to swimmers and a nuisance for recreational fishers in some Otago and South Canterbury lakes.[21]

While monitoring would need to be based around hands-on 'do it yourself' assessments, in the future as a group's understanding of catchment and weather impacts on water quality improves, it might be possible for some community groups to contribute to simple predictive assessments. In any case, some on-site data will still need to be collected in the future and community groups could be well placed to contribute. Collected information could potentially be displayed on LAWA.

[19] Dr Rebecca Stott, Environmental Health – Microbiology Scientist, NIWA.
[20] Dr Jonathan Banks, Senior Scientist, Cawthron Institute.
[21] http://www.orc.govt.nz/Information-and-Services/Pest-Control/Plant-pests/Lake-Snow/ Accessed 24 May 2017.



(After Milne & Davies-Colley (2016) and synthesised from Booth et al. 2010a & b, 2012)

Figure 4: Examples of contact recreation (CR) attributes identified in community surveys and assessments. Some of these attributes relate to both primary and secondary contact recreation (e.g., access, facilities). Infection/illness risk and hazards are *core* attributes for primary contact recreation 'health and safety' considerations.

5 How do we measure success?

Measuring and reporting success must relate directly to the monitoring objectives. Reporting at present is confusing for the public because monitoring information may be being used in reporting on objectives for which the monitoring was not originally designed (e.g., national reporting). Implementation of recent amendments to the NPS-FM looks set to add to this confusion and highlights that there are multiple audiences wanting recreation-related information. Central government's reporting needs are not the same as those of the general public, nor those of a regional authority in relation to plan effectiveness assessments and catchment management.

5.1 Informing the public of potential health risks

Informing the public of potential health risks posed by contact with the water on a day-to-day basis is dependent on robust surveillance information, ideally from predictions or forecasting that have been validated through actual water sampling data. Timely notification of contamination events, such as sewer overflows, must be built into surveillance information along with any information about other risks to human health, notably cyanobacteria in fresh waters.

Grading information is also useful for informing the public of potential health risks – in general. For example, sites with SFRGs that reflect low catchment contaminant risks and good water quality indicate to the public that, typically, these locations are likely to be safer for contact recreation than sites with a poor grade. However, to be more representative of potential human health risks at a site, the scope of SFRGs need to be broadened beyond microbial water quality considerations for rivers and lakes affected by cyanobacteria.

5.2 State and trends

Assessing state and trends through time in the suitability of water for contact recreation should be based on robust and consistently applied statistical measures to facilitate meaningful inter-regional and national reporting comparisons. We recommend:

- State reporting focuses on the percentage of that time human health risk at representative sites is acceptable (e.g., 'green' or 'alert' surveillance mode for indicator bacteria and cyanobacteria density or coverage), with consideration given to climatic conditions (e.g., base state on three to five rolling 'summer' seasons to obtain sufficient data and reduce the influence of a particularly dry or wet year on current annual reporting); and
- Trend reporting focuses on a meaningful downward (improving) or upward (deteriorating) trend in indicator bacteria counts through time (using bacterial counts).

A trend may not be 'recreationally important' (e.g., it may not result in a grading or attribute state change) but still offers valuable information on an improvement or deterioration that might at some point require intervention.

Further work is needed to define the target population(s) for reporting, a "representative" network of sites (e.g., land use vs popularity), a "meaningful" trend, and the method of trend analysis. State and trends could be assessed on an individual attribute basis but caution would be needed on making conclusions about 'swimmability'. An overall index that combines a suite of relevant attributes, including both human health (e.g., *E. coli* and cyanobacteria for rivers) and other attributes such as visual water clarity, nuisance algae and deposited sediment would provide for holistic state reporting that more closely aligns with how iwi and the general public view recreation. The Waikato River Authority report cards (Williamson et al. 2016) provide a good example of integrated reporting.

5.3 Policy effectiveness

Assessment of the effectiveness of both national policy (e.g., the NPS-FM) and regional policy (e.g., regional plans and non-statutory catchment management strategies) may require specifically tailored measures. This is particularly the case at the regional level where differences in community priorities or values may result in different success measures (e.g., poor visual clarity may pose a greater hazard than cyanobacteria in some fresh waters or a community may value a litter-free beach highly and want monitoring of litter).

In many cases, assessments may be based on state and trend reporting. Depending on the policy, assessments may need to be attribute based (e.g., the effectiveness of stock exclusion on reducing *E. coli* vs the effectiveness of river flow management-related policies on cyanobacteria bloom occurrence).

A change in grade (e.g., SFRGs) or attribute state (e.g., *E. coli* or planktonic cyanobacteria under the NPS-FM) could also be used as a policy effectiveness reporting measure. However, the concept of "fuzzy boundaries" must be factored into the assessment. This is essentially where the grade or attribute state of a recreation site sits close to the boundary of a higher or lower grade and a small shift in the statistic (e.g., 95th percentile) from recent monitoring data results in a change in grade or attribute state, despite there being no meaningful increase or decrease in attribute state over the reporting period. McBride (2016b) recommends this 'false state change' be addressed by applying a tolerance interval limit; effectively a percentile inflated or deflated a little to take account of statistical sampling error. This error decreases with increasing sample size, highlighting the need for a robust minimum number of sample results to be used in the assessment. McBride and Soller (2017) suggest in the order of 60 samples.

6 How do we move forward? Priority research needs and actions

The following table summarises research and actions underway or needed to address the five key areas of change proposed to recreational water quality monitoring and reporting.

Change required	Priority research/actions	Framework/mechanisms for progress
Provide more **timely information** on health risk – • Near real-time monitoring	• Promote the development and testing of faster microbial analysis • Promote the use of molecular techniques for rapid screening for the presence of cyanotoxins • Promote the use of visual assessment methods (i.e., fixed cameras to determine *Phormidium* abundance.	Partner with research and laboratory providers. Some work underway (e.g., NIWA and Coliminder, Cawthron and cyanotoxin screening, Victoria University & UAVs)
• Continuous monitoring of proxies such as river flow, salinity, turbidity, tryptophan	• Analyse existing council microbial water quality datasets against site and catchment characteristics under different environmental conditions (e.g., flow, rainfall, tides, freshwater plume dispersion, wind) to investigate simple preliminary predictive-type assessments • Field test proxies for forecasting and prediction	In-house staff and/or Envirolink advice grants
• Predictive forecasting	• Develop and demonstrate cost-effective prototypes • Develop guidance on forecasting validation requirements and future reporting based on predictive approaches • Consider modelling needs for river plumes across the fresh-saltwater interface	A number of forecasting examples already exist or are proposed. These need to be shared and built upon through partnership with commercial and/or research providers. Utilise Envirolink Advice Grants (e.g., to establish regional examples of predictive assessments) and Envirolink Tool funding (e.g., for national guidance)
Update the scientific basis of existing national guidance	• Repeat the 1998/99 national freshwater microbial survey to reassess indicator to pathogen ratios • Reassess the robustness of existing enterococci guidance for coastal waters	• ESR has a contract with MfE to lead the design of a survey starting in summer 2018/19 that involves a suite of research organisations and strong regional council input • Subject of current Envirolink Tool grant with NIWA

	• Determine the appropriate microbial indicator for brackish waters	• Subject of current Envirolink Tool grant with NIWA
	• Improve guidance for determining safe shellfish collection and consumption	• Subject of current Envirolink Tool grant with NIWA
	• Obtain advice on how to assess microbial health risk downstream of treated wastewater discharges	• Subject of current Envirolink Tool grant with NIWA
	• Develop more cost-effective direct measurements of pathogens	• Partner with research providers, advocate needs to commercial laboratories, implement testing in problem catchments
	• Extend the suite of faecal source identification markers and improve quantification of the relative abundance of faecal sources	• Partner with research providers – a recent AgResearch-led MBIE Endeavour Fund Research Programme bid would have addressed some aspects but the bid was unsuccessful
	• Seek development of site-specific microbial guidance that reflects the risk profile present at a site (e.g., sites impacted by gulls could have a higher *E. coli* threshold than sites impacted by dairy contamination)	• Two areas for future development through partnership with research providers (e.g., ESR). Dependent on other research first, including the repeat national freshwater microbial survey and further work extending the suite of faecal source markers and quantifying the relative abundance of different sources of faecal contamination
	• Evaluate mitigation options to address microbial contamination	• Partner with research providers. A 2017 AgResearch-led MBIE Endeavour Fund Research Programme bid would have addressed some aspects but the bid was unsuccessful
	• Continue research into the drivers of benthic cyanobacteria blooms (e.g., the role of fine sediment) and update the existing interim national guidelines	• MfE has funded initial drivers work by Cawthron under the NPS-FM but further funding is required. National guidance should attempt to extend to evaluating risks to dogs
	• Improve understanding of the composition and toxicity of picocyanobacteria in lakes	• Partner with research providers, Envirolink
	• Evaluate potential mitigation options to address cyanobacteria bloom occurrence	• Partner with research providers, Envirolink

	• Develop a protocol for monitoring site selection • Work with Central Government to identify and implement reporting methods relevant to their specific needs • Confirm statistical measures and methods, and minimum data set sizes for state and trend reporting, including assessment of 'false state switching' ('fuzzy boundaries') for SFRG and attribute state reporting • Review operational issues associated with the existing microbial water quality guidelines affecting inter-regional consistency, including sample frequency and duration, rainfall/weather, and treatment of follow-up surveillance monitoring data • Obtain advice on appropriate reporting measures for cyanobacteria blooms • Revisit the applicability, implementation and reporting of SFRGs and the potential to broaden grading to include cyanobacteria for freshwaters	Develop a NEMS for Recreational Water Quality Monitoring and Reporting through Envirolink Tools and/or revision of the existing national microbial water quality guidelines in partnership with central government. Operational issues with the guidelines are already well documented (e.g., Bolton-Ritchie et al. 2013) and scoped previously with MfE. Guidance for cyanobacteria monitoring and reporting needs revisiting; monitoring aspects for wadeable rivers will be addressed in the NEMS for periphyton currently in development. Discussion is required with Central Government to resolve tensions between public health and general state and trend reporting. Similar tension exist within regions between SoE and recreational water quality *E. coli* data sets.

Ensure **information for the public is clear and accessible** (and appropriate for use)	• Improve and expand the scope of the LAWA *"Can I swim here?"* recreation module to:
	  o Ensure the most meaningful statistic is use to report overall microbial risk
	  o Include reporting of actual or potential cyanobacteria abundance
	  o Include an overall 'health for recreation index' – for freshwater this should combine both *E. coli* and cyanobacteria measures
	  o Provide relevant metadata (e.g., forecast rainfall) and information on other relevant attributes (e.g., visual water clarity)
	  o Add information on trends coupled with relevant climate information
	
	• Investigate greater use of mobile technology and, at high usage
		• Improvements module scoped and some aspects in process of implementation through the Environmental Monitoring and Reporting (EMaR) initiative. Full implementation dependent on addressing reporting measure, statistical and index considerations
		
		• Some investigations by a few regions – coordinate effort through the EMaR initiative

	sites, electronic signage, to communicate information • Consider social science assessment of risk communication	• Partner with research providers, Envirolink
Empower the public to take personal responsibility and provide opportunities for citizen science initiatives	• Continue to educate the public about water quality and develop more education tools • Actively investigate and support citizen science-based opportunities and initiatives • Develop index-based tools suitable for public reporting and accommodating citizen-science monitoring results on LAWA	• Various mechanisms in place (e.g., leaflets, LAWA) but their effectiveness needs examining • Various initiatives underway but none focussed solely on recreation-based assessments. Look to partner with research providers active in this space (e.g., NIWA, Cawthron, Landcare). • Partner with research providers, Envirolink. NIWA and potentially others may have done some work in this area but more is needed

7 Conclusions and recommendations

Recreational activities in fresh and near-shore coastal waters inherently carry risk. To protect public health we need scientifically robust, yet cost-effective, ways to measure human health risks, and timely, clear and consistent communication of these risks. Reliable information on the source of faecal contamination is also needed to guide successful management interventions in problem catchments.

The scientific basis of some aspects of the existing microbial water quality guidelines requires urgent review. The guidelines are underpinned by almost 20-year old science. More recent research has established that the public health risks posed by different sources of faecal pollution are not equal. However, the source of faecal pollution is not considered in council reporting of weekly surveillance monitoring results. This 'one size fits all' approach means that the risk of microbial infection in fresh waters or illness in coastal waters may be currently under, or more likely, over-stated. This approach also has economic ramifications in terms of policy development, catchment 'clean up' initiatives and monitoring.

Provision of timely information on health risk demands a deliberate advance beyond traditional spot-based water sampling and laboratory testing approach to near real-time monitoring and forecasting. It also requires platforms that are easy to access and have clear messages that, for freshwater at least, also consider risks associated with cyanobacteria abundance and perhaps poor water clarity.

Reporting of recreational water quality needs to be reviewed, with consideration given to statistically robust measures and the needs of different audiences. There is a tension between reporting for public health and more general state of the environment purposes that needs to be resolved.

To improve recreational water quality monitoring and reporting in New Zealand, we recommend that the regional sector:

1. Advocates and directs through the EMaR initiative development and implementation of near real-time monitoring, continuous monitoring of proxies, and forecasting of microbial water quality and freshwater cyanobacteria blooms as a priority.

2. Continues discussions with Central Government to have the existing national guidelines for both microbial water quality and cyanobacteria revised, and broadened to –
    - reflect the improved state of scientific understanding since these guidelines were released,
    - clarify the roles and responsibilities of the different organisations involved in recreational water quality monitoring, and
    - form a single, integrated and coherent set of recreational water quality guidelines for New Zealand that also include other hazards (e.g., poor water clarity) and attributes of relevance to the broader recreational experience (e.g., amenity aspects such as nuisance periphyton cover).
3. Actively participates in the design and implementation of the proposed repeat freshwater microbial survey needed to inform an update of the existing national guidelines.
4. Develops a NEMS for recreational water quality monitoring and reporting, with emphasis given to site selection, sampling frequency and conditions (e.g., during rainfall), test methods, and reporting measures.
5. Establishes with Central Government an appropriate site network and methodology for national scale reporting of state and trends in recreational water quality attributes.
6. Further clarifies, as a high priority, with Central Government the role of the national microbial water quality guidelines in relation to recent amendments to the NPS-FM.
7. Invests in further improvements of the LAWA *"Can I swim here?"* recreation module to improve its current scope and scientific robustness.
8. Updates the relevant SIG research strategies and the overarching Regional Council Science Research & Technology Strategy to direct and incentivise research providers to focus their efforts on research that will advance the needs identified in Section 6 of this paper.
9. Promotes a move away from a primary focus on indicator bacteria test results to one that takes into account site/catchment characteristics and faecal contaminant source knowledge as well as other factors that may impact on human health (e.g., cyanobacteria, marine toxins) or the wider recreational experience (e.g., visual water clarity, nuisance plant growth, water colour, rubbish).
10. Promotes the direct monitoring of pathogens and application of faecal source tracking and QMRA approaches to address recurring or significant microbial contamination at recreation sites.
11. Actively supports community-based initiatives that –
    - empower the public to take personal responsibility in assessing potential health risks associated with contact recreation activities, and
    - provide opportunities for community volunteers to monitor a suite of properties that affect recreational use of fresh and coastal waters.

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