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Monitoring pathogens in recreational bathing waters in Flanders, Belgium

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Samenvatting

Monitoring van zwemwater in Vlaanderen volgt de vereisten van de EU-zwemwaterrichtlijn. Deze richtlijn vereist een meetprogramma voor de indicatororganismen *Escherichia coli* en intestinale enterococcen. Deze paramaters worden gebruikt om te bepalen of het gezondheidsrisico voor zwemmers van ziekteverwekkers die afkomstig zijn van besmetting met fecaliën aanvaardbaar laag is. Deze fecale indicatororganismen komen (relatief) goed overeen met ziekteverwekkers uit faeces van mensen of warmbloedige dieren. Daarnaast wordt, wanneer een potentieel risico op cyanobacteriën is vastgesteld in het zwemwaterprofiel, monitoring van cyanobacteriën toegepast. Echter, naast ziekteverwekkers van fecale herkomst of cyanobacteriën kunnen er ook andere ziekteverwekkers aanwezig zijn in zwemwater. Deze kunnen aanvullende gezondheidsrisico's voor waterrecreanten opleveren, die niet worden "afgedekt" met de huidige zwemwatermonitoring .

In dit onderzoek is bepaald of het huidige monitoringprogramma van zwemwater aanvulling behoeft om voldoende bescherming te bieden aan zwemmers en andere waterrecreanten in Vlaanderen. De verwachte impact van klimaatverandering op zwemwaterpathogenen in Vlaanderen is ook geëvalueerd om mogelijke veranderingen in het voorkomen van zwemwaterpathogenen in de toekomst te evalueren. De monitoringprogramma's van andere EU-lidstaten werden beschouwd om de monitoringpraktijk van Vlaanderen mee te vergelijken. Ten slotte werden de risicodeterminanten van schadelijke algenbloei geïdentificeerd.

Vijftien pathogenen die relevant zijn voor Vlaanderen werden beoordeeld: *Campylobacter*, adenovirus, norovirus, *Cryptosporidium, Giardia*, *Vibrio*, *Naegleria fowleri, Acanthamoeba, Trichobilharzia, Leptospira*, species and toxins of cyanobacteria, *Clostridium botulinum* toxin, *Pseudomonas aeruginosa, Aeromonas* and *Plesiomonas*. De lijst omvat een reeks relevante recreatiewater-pathogenen (virussen, bacteriën, protozoa, amoeben, cyanobacteriën, toxines, platwormen) en ziekten (gastro-intestinaal; oor-, oog-, wond- en luchtweginfecties; huidirritatie, neurologische aandoeningen) en pathogenen die verschillende zwemwaterproblemen vertegenwoordigen (fecale besmetting, eutrofiëring, thermische vervuiling, onevenwichtige ecosystemen).

Voor elk van de ziekteverwekkers is een Excel-matrix (*Pathogen_Matrix.xlsx*) gevuld met de algemene informatie, gezondheidseffecten via zwemwater, relevantie voor Vlaanderen, beschikbaarheid van methoden voor detectie in zwemwater, beheersmaatregelen, en verwachte effecten van klimaatverandering op het voorkomen in Vlaanderen. Deze informatie is gebaseerd op relevante publicaties en gericht literatuuronderzoek. Ook is beoordeeld, op een schaal van laag naar hoog, hoe sterk het beschikbare bewijs is. Op basis van deze informatie zijn aanbevelingen over het huidige monitoringprogramma en aanpassingen daarvan opgesteld.

Aanbevelingen

<u>Proactieve monitoring</u> - Er is voldoende reden om de huidige monitoring voor *E. coli* en enterococcen te handhaven, vanwege de gezondheidsklachten door infecties met fecale ziekteverwekkers zoals *Campylobacter* en de classificatie van sommige Vlaamse zwemwaterlocaties als goed of aanvaardbaar. Dit beschermt zwemmers tegen infecties door pathogene darmbacteriën, zoals *Campylobacter, Salmonella, Shigella*, enteropathogene *E. coli* enz. De monitoring van *E. coli* en enterococcen is echter minder geschikt om zwemmers te beschermen tegen infecties met virale en parasitaire protozoa, omdat die lang in water overleven dan deze indicatorbacteriën. Het toevoegen van colifagen als parameter aan het huidige meetprogramma voor de zwemwaterkwaliteit zal de bescherming tegen gezondheidsrisico's van virussen verbeteren. Aanbevolen wordt om te onderzoeken wat de toegevoegde waarde is van monitoring van colifagen in Vlaams recreatiewater.

Voor cyanobacteriën bevelen we aan om de gelaagde aanpak die in Nederland wordt toegepast te overwegen. Een gezamenlijke Vlaams-Nederlandse workshop zou nuttig zijn om de voor- en nadelen van zowel het Vlaamse als Nederlandse cyano-protocol te vergelijken en de waterschappen bij deze evaluatie te betrekken. Daarnaast wordt aanbevolen om de ontwikkeling van de soortsamenstelling van cyanobacteriën in Vlaamse zwemwateren te onderzoeken en te evalueren of het nodig is om de microcystine-analyse aan te vullen met andere toxines, zoals cylindrospermopsin (zoals recent geïntroduceerd door de US EPA). Specifiek **bevelen we aan te onderzoeken of cylindropsermopsine voorkomt in Vlaams zwemwater bij bloei van cyanobacteriën in Vlaanderen, om te kunnen beoordelen of monitoring van cylindrospermopsine, naast microcystine, zinvol is.** We raden ook aan om te evalueren of de strengere richtlijn die de US EPA voor microcystine heeft opgesteld (8 µg /l) beter geschikt is dan de huidige Vlaamse richtlijn om de gezondheid van de zwemmers in Vlaanderen te beschermen (US EPA, 2019).

Reactieve monitoring - Voor de gezondheidsrisico's die niet door de proactieve monitoring worden gedekt bevelen we reactieve monitoring aan, gebaseerd op de huidige surveillance van ziekten in Vlaanderen of op meldingen van gezondheidsklachten of problemen (zoals het aantreffen van veel dode vogels of vissen) bij een bepaalde zwemlocatie. Dergelijke meldingen dienen te worden gevolgd door onderzoek en evaluatie van de rol van het zwemwater en, als de verdenking van de rol van zwemwater voldoende sterk is, door monitoring van de aanwezigheid van de specifieke ziekteverwekker in het verdachte zwemwater, ter onderbouwing van maatregelen om nieuwe ziektegevallen te voorkomen. Er zijn gespecialiseerde laboratoria die beschikken over methoden voor de detectie van darmbacteriën, virussen en protozoa, *Vibrio, Naegleria fowleri, Acanthamoeba, Trichobilharzia, Leptospira,* soorten en toxines van cyanobacteriën, *Clostridium botulinum* toxine, *Pseudomonas aeruginosa, Aeromonas en Plesiomonas.* Aangezien uitbraken van ziekten door zwemwater altijd een snelle reactie vereisen, raden we aan om een lijst met contactgegevens te hebben van de laboratoria die ervaring hebben met watermonitoring voor de verschillende pathogenen / toxines.

Gezondheidsklachten van zwemmers kunnen ook worden gemeld bij andere belanghebbenden (eigenaar / exploitant / beheerder van strand, provincie, gemeente). Voor de registratie van deze klachten heeft Nederland een vragenlijstsysteem ontwikkeld, waarbij het Rijksinstituut voor Volksgezondheid en Milieu (RIVM) aan het einde van het badseizoen een (digitale) vragenlijst stuurt met het verzoek aan Gemeentelijke Gezondheidsdiensten (jurisdictie over infectieziekten) en provincies (jurisdictie zwemwaterkwaliteit) om gezondheidsklachten via zwemwater te registreren die zij gedurende het badseizoen hebben ontvangen. Het RIVM verzamelt deze informatie in een jaarlijks overzicht. Implementatie van een dergelijke, actief surveillancesysteem verbetert het vermogen om veel voorkomende, milde gezondheidsproblemen via zwemwater, zoals zwemmersjeuk, gezondheidsklachten door cyanobacteriën of diarree, op te sporen, te registreren en te onderzoeken.

Er wordt niet aanbevolen het monitoringprogramma van zwemwater nu aan te passen vanwege klimaatverandering. De effecten van klimaatverandering op het voorkomen van ziekteverwekkers in zwemwater is inherent onzeker. De passieve surveillance van meldingsplichtige ziektes aangevuld met een registratiesysteem voor gezondheidsklachten door zwemwater, zoals in de vorige paragraaf aanbevolen, kunnen gebruikt worden om waar te nemen of er veranderingen optreden in de frequentie of intensiteit van infecties in zwemwateren in Vlaanderen. Als daar aanwijzingen uit naar voren komen kan opnieuw worden beoordeeld of aanpassing van het meetprogramma nodig is. Ook de aanbeveling om onderzoek uit te voeren naar het voorkomen van cylindrospermopsine is een voorbeeld van anticipatie op de mogelijke gevolgen van klimaatverandering.

De praktijk in andere EU-lidstaten
De EU-lidstaten rapporteerden allen dat ze het meetprogramma uit de Europese zwemwaterrichtlijn volgen. De meeste lidstaten doen geen aanvullende, specifieke meetinspanningen naar de overige ziekteverwekkers die in deze studie worden beschreven. Een aantal lidstaten rapporteerde dat ze aanvullende activiteiten ondernemen: Hongarije, Italië, Spanje en het Verenigd Koninkrijk meldden specifieke monitoring voor cyanobacteriën/toxines. Duitsland en Spanje geven aan dat er specifieke studies zijn gedaan naar *Vibrio* en op basis daarvan

waarschuwingen voor zwemmers hebben uitgevaardigd, maar deze landen doen geen proactieve monitoring van *Vibrio*. Finland en Nederland hebben hun meldingssystemen uitgebreid om gevoeliger zwemwater gerelateerde ziekten te kunnen signaleren. Zweden onderzocht de geschiktheid van bacteriofagen als surrogaat, maar voerde dit niet in. Frankrijk onderzocht het risico voor *Naegleria fowleri* en vond het te laag om een monitoringprogramma' in te voeren.

Risicodeterminanten van HAB (Harmful Algal Blooms)
Blootstelling aan HAB-toxines in recreatiewater kan optreden via inname tijdens het recreëren; contact van delen van het lichaam die met water in aanraking komen dat HAB-toxines bevat tijdens recreatieve activiteiten zoals zwemmen, waden of waterskiën en inademing van vervuilde aerosolen tijdens het recreëren in of bij de zwemlocatie met een HAB. Indirect kan blootstelling plaatsvinden door consumptie van schelpdieren waarin HAB-toxines ophopen. Als gevolg van eutrofiëring en klimaatverandering nemen HAB wereldwijd toe in frequentie, omvang en duur. Nutriëntgehaltes, temperatuur, opgeloste kooldioxide, zoutgehalte en mengregime zijn de belangrijkste factoren die geassocieerd zijn met het optreden van HAB.

Summary

Monitoring in Flanders follows the requirements of the EU Bathing Water Directive (EU BWD) which requires monitoring for faecal indicator bacteria (FIB) *Escherichia coli* and Intestinal Enterococci to protect bathers against health effects of faecal pollution of bathing waters. In addition, if a potential risk has been identified in the bathing water profile, appropriate monitoring for and management of cyanobacteria is implemented. However, it is known that while faecal indicator organisms correspond (relatively) well with pathogenic organisms that originate from faecal contamination, several pathogens do not originate from faecal contamination, but can present in bathing water as a result of natural processes. These pathogens are not "covered" by monitoring for FIB.

This research assessed whether the current bathing water monitoring program offers sufficient protection for recreational water users in Flanders. The expected impacts of climate change on the presence of bathing water pathogens in Flanders was also assessed to determine any relevant changes in bathing water health risks in the future. The bathing water monitoring programs and policies to the non-faecal pathogens of EU member states were reviewed to compare the monitoring practices of Flanders to others. Finally, the risk determinants of harmful algal blooms were identified.

Fifteen pathogens relevant to Flanders were assessed: *Campylobacter*, adenovirus, norovirus, *Cryptosporidium, Giardia*, *Vibrio*, *Naegleria fowleri, Acanthamoeba, Trichobilharzia, Leptospira*, species and toxins of cyanobacteria, *Clostridium botulinum* toxin, *Pseudomonas aeruginosa, Aeromonas* and *Plesiomonas*. The list covers a range of relevant recreational water pathogens (viruses, bacteria, protozoa, amoebae, cyanobacteria, toxins, flukes) and illnesses (gastrointestinal; ear, eye, wound and respiratory infections; skin irritation; neurological disorders) and pathogens that represent different bathing water challenges (faecal contamination, nutrient contamination, thermal pollution, unbalanced ecosystems).

For each of the pathogens an excel matrix (*Pathogen_Matrix.xlsx*) was filled with the general pathogen information, health effects in recreational waters, relevance for Flanders, monitoring practices, risk reduction and control measures and expected impacts of climate change on the proliferation in Flanders. This information was extracted from key review publications and dedicated literature searches. The evidence for recommendations were graded on a scale from low to high certainty of evidence. Recommendations regarding the current monitoring program are summarized.

Recommendations

Proactive monitoring - There is sufficient rationale to maintain the current monitoring for *E. coli* and enterococci, due to the health risks associated with faecal pathogens and the good or sufficient classification of some Flemish bathing sites. This will protect bathers against bathing waterborne infections by enteric bacterial pathogens, such as *Campylobacter, Salmonella, Shigella,* Enteropathogenic *E. coli* etc. However, the monitoring of *E. coli* and enterococci is less suited to protect bathers against infections with viral and protozoan parasites that persist longer in water. Adding coliphages as parameter to the current bathing water quality monitoring program is expected to improve the protection against virus-associated health risks. **As a first step, we recommend to undertake research to determine the added value of monitoring coliphages in Flemish recreational waters.**

For cyanobacteria we recommend considering the tiered approach used in the Netherlands. A Flanders-Netherlands workshop on the pros and cons of the respective cyanoprotocols could be helpful in raising awareness and engage water authorities in this evaluation. Another recommendation, also in light of climate change, is to survey the development of the composition of cyanobacterial species present in Flemish bathing waters, and to

evaluate if it is necessary to complement microcystin analysis with other toxins, such as cylindrospermopsin (as recently introduced by the US EPA). We specifically recommend to undertake research to determine the presence of cylindrospermopsin in cyanobacterial blooms to determine the added value in monitoring cylindrospermopsin in addition to microcystin in Flanders. We also recommend to evaluate whether the stricter guideline for microcystin as issued by the US EPA (8 µg/L) is most appropriate in protecting the health of the bathers in Flanders.

Reactive monitoring – Reactive monitoring is defined as monitoring that is triggered by notification of a potential problem (such as large numbers of dead birds or fish) or (a cluster of) health complaints via bathing water, usually at a particular bathing beach. From the health risks that are not covered by the proactive monitoring, we recommend that the current system of disease surveillance is used. Notification of a (cluster of) health complaints is to be followed by investigation and evaluation and monitoring of the presence of the specific pathogen in the suspected bathing water to underpin measures to prevent new disease cases. Methods exist in specialized laboratories for the detection of enteric bacteria, viruses and protozoa, *Vibrio*, *Naegleria fowleri, Acanthamoeba, Trichobilharzia, Leptospira*, species and toxins of cyanobacteria, *Clostridium botulinum* toxin, *Pseudomonas aeruginosa, Aeromonas* and *Plesiomonas.* Since outbreaks of diseases through bathing water always require rapid action, we recommend to have a list with contact details of the laboratories that are experienced in water monitoring for the different pathogens/toxins.

Health complaints of bathers may also be communicated to other stakeholders (owner/operator/manager of beach, province, council). For surveillance of these complaints, the Netherlands has developed a questionnaire system, where the National Institute of Public Health and the Environment (RIVM) sends a (digital) questionnaire at the end of the bathing season requesting local health departments (infectious disease jurisdiction) and provinces (bathing water quality jurisdiction) to enter the bathing water related health complaints they have received/noted. RIVM compiles this information into an annual surveillance overview. Implementation of a more active surveillance system will improve the ability to detect, notify and survey the occurrence of common, mild health problems associated with bathing waters, such as swimmer's itch, cyanobacterial health complaints, and diarrhoea.

No changes to the monitoring program are recommended to take into account climate change. This is due to the inherent uncertainty of the effects of climate change and the recommendation to complement the disease notification system with a bathing water health complaints surveillance system would observe climate induced changes in the frequency or intensity of infections in bathing waters in Flanders. In this manner, changes to the monitoring program are based on specific, local evidence of the risk for specific pathogens. The recommendation to investigate the presence of cylindrospermopsin is another example of how to anticipate the potential impact of climate change.

Review of practices in EU member states

The EU member states report to monitor bathing water according to the EU BWD, but many do not have a dedicated monitoring policy towards the pathogens evaluated in this study. Several member states indicated to have additional policies. Hungary, Italy, Spain and the UK reported specific monitoring for cyanobacteria/toxins. Germany and Spain reported specific studies and warnings for *Vibrio*, though they have no specific monitoring program. Finland and the Netherlands have expanded their notification systems to capture more bathing water related diseases. Sweden looked into the suitability of bacteriophages as a surrogate, though did not implement it. France investigated the risk for *N. fowleri* and found it low and did not pursue a monitoring program.

Risk determinants of harmful algal blooms (HAB)

Exposure to HAB toxins from recreational water sources can occur via oral exposure (incidental ingestion while recreating); dermal exposure (contact of exposed parts of the body with water containing HAB toxins during recreational activities such as swimming, wading, or water skiing); and inhalation exposure to contaminated aerosols (while recreating). Indirectly, exposure can occur through consumption of (sea)food in which HAB toxins accumulated. Due to nutrient enrichment (eutrophication) and climate change, HABs tend to increase in frequency, magnitude and duration worldwide. Nutrients, temperature, dissolved carbon dioxide, salinity and mixing regime were the most important associated drivers for HABs.

Contents

List of Abbreviations

ANSES	Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (French Agency for Food, Environmental and Occupational Health & Safety)
CSO	Combined Sewer Overflow
DEET	Diethyltoluamide
EU BWD	European Union Bathing Water Directive
FIB	Faecal Indicator Bacteria
HAB	Harmful Algal Bloom
HIV	Human Immunodeficiency Virus
NL	Netherlands
NSP	Natural swimming pool
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QMRA	Quantitative Microbial Risk Assessment
(q)PCR	(Quantitative) Polymerase Chain Reaction
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute of Public Health)
TAK	Title-Abstract-Keyword
TDI	Tolerable daily intake
US EPA	United States Environmental Protection Agency
VAZG	Vlaams Agentschap Zorg & Gezondheid (Flemish Agency for Care & Health)
VMM	Vlaamse Milieumaatschappij (Flanders Environmental Agency)

1 Introduction

1.1 Initial Request

On 27-03-2019 the Vlaams Agentschap Zorg en Gezonheid (VAZG) contacted KWR with a request for quotation to provide a literature study on pathogenic organisms in open swimming waters in Flanders (English translation):

> *"During the swimming season, the water from licensed open swimming ponds and the bathing waters on the coast is routinely sampled and analyzed for indicator bacteria for faecal contamination: E. coli and intestinal enterococci. The concentrations for E. coli and intestinal enterococci provide insight into the risks that a holiday maker runs for mainly gastroenteritis, and to a lesser extent eye and ear infections. The current European Bathing Water Directive (EU BWD) assumes a tolerated risk of disease of around 5-10%. Environmental legislation (Vlarem) provides that "natural swimming pools" are included as swimming pools subject to a permit under section 32 of the Vlarem classification list. Natural swimming pools are circulation pools that are completely separated from ground and surface water and are connected to one ecological purification system. The water from the natural swimming pools must be systematically sampled and analyzed for E. coli and intestinal enterococci and Pseudomonas aeruginosa.*
>
> *It is known that the indicator organisms used for assessing bathing water quality correspond relatively well with possible other pathogenic germs due to faecal contamination and that the standards used provide an acceptable estimate of the pathogenic capacity of the water in faecal contamination. However, the indicator organisms used do not correlate (or do not correlate well) with a series of other pathogenic organisms with a potential risk of health effects in aquatic scavengers.*
>
> *In recent years, a number of recreational water-related infectious diseases such as leptospirosis and vibriosis have been reported despite good current bathing water quality where the faecal contaminant indicator parameters met the standard for good current bathing water quality. Almost certainly the number of reported infectious diseases related to water recreation is underreported.*
>
> *The literature study concerns the water of open swimming ponds and coastal water as well as natural swimming ponds.*
>
> *The starting point for this study is the question of whether the current surveillance, the new Bathing Water Directive and Vlarem II, offers sufficient protection to the water recreationists. After all, in bathing water that meets the standards on the basis of the faecal indicators, pathogenic bacteria, protozoa or viruses may still be present in concentrations that exceed the minimum infectious dose with an expected water intake."*

1.2 Current Monitoring in Flanders

Monitoring in Flanders follows the requirements of the EU BWD. The EU BWD requires monitoring for indicator organisms *Escherichia coli* and Intestinal Enterococci (Appendix, Figure 1). Furthermore, where a potential risk has been identified in the bathing water profile, appropriate monitoring for and management of cyanobacteria. The EU BWD requires a minimum of four samples during the bathing season, including a sample shortly before the start of the bathing season.

Sampling of bathing waters in Flanders is contracted out to the Flanders Environmental Agency (VMM), who report the results to VAZG. Bathing water samples are analysed for *E. coli* and intestinal enterococci by various labs in

Flanders. In addition to sampling, sporadic monitoring for dead fish and birds is done at recreational water sites, in addition to visual monitoring for trash/litter. Flanders used a tiered approach for monitoring for cyanobacteria. To monitor for the presence of cyanobacteria blooms, bathing waters are visited biweekly and inspected visually for the presence of cyanobacteria layers and presence of cyanobacterial flocs in water samples. When scum layers are observed (or reported by citizens or municipalities) the bathing water is closed for swimming (or bathers are warned) and samples are taken to test for microcystin and cyano-chlorophyll by the responsible water authority. Swimming is prohibited until the concentration of microcystin drops below 20 µg/L and cyano-chlorophyll drops below 75 µg/L and visible blooms have dispersed (see Appendix V, p. 44).

For each official bathing site, a bathing water profile is required within the EU BWD which describes the characteristics of the bathing water (physical, geographical and hydrological) and descriptions of potential sources of pollution in the catchment which may affect bather health (Directive 2006/7/EC of the European Parliament and of the Council, 2006). Profiles also require an assessment of the potential for proliferation of cyanobacteria, macro-algae and/or phytoplankton and short-term pollution. Bathing sites are classified as excellent, good, sufficient or poor based on the average water quality over the previous four years of monitoring. In 2018, Flanders reported 89 official bathing sites; 42 along the coast and 47 inland (European Environment Agency, 2019a). Bathing waters in Flanders are for the majority classified as excellent, with less than ten sites classified as good and two as sufficient in 2018 (European Environment Agency, 2019a).

1.3 Research Requirements

KWR was asked to provide answers to the following questions

1. For which pathogenic micro-organisms, possibly present in bathing water in the Flanders region, is there no surveillance, directly or indirectly, via the indicator parameters in the current Bathing Water legislation?
2. What are the health risks of the pathogenic microorganisms in recreational water that are not monitored (directly or indirectly) via indicator parameters?
3. What criteria support monitoring of pathogenic microorganisms that are not monitored (directly or indirectly) via indicator parameters and an adjustment of the current monitoring program?
4. Is there sufficient information available to follow up the results of the monitoring program and possible interventions (minimum infectious dose, dose response linked to cut-off values, feasibility (logistics, financial, etc.))?
5. What risk determinants and monitoring practices are used by other EU Member States?
6. What are the risk determinants for the occurrence of Harmful Algal Blooms (HABs)?
7. What are the impacts of climate change on the presence of pathogenic microorganisms in bathing waters in Flanders?
8. What elements support an adjustment of current monitoring program to mitigate possible impacts of climate change?
9. Grading of evidence and strength of the recommendations, where possible.

2 Study Methodology

2.1 Pathogens in recreational waters

2.1.1 Indicator Organisms

The EU BWD asks for bathing water quality monitoring using bacteria that indicate to what extend the bathing water is contaminated with faeces of humans or (warm-blooded) animals: *Escherichia coli* and enterococci. The use of these faecal indicator bacteria (FIB) originates from the late 19^{th}/early 20^{th} Century, the time of the recognition that diseases such as cholera and typhoid were waterborne. Over the decades, we have learned that faecal contamination is not only associated with bacterial diseases, but also with viral and protozoan diseases. Viruses and protozoa behave differently in water, are more persistent and survive water treatment better than FIB. This means that the FIB are not always a good indicator of health risk associated with faecal contamination (Kauppinen et al., 2017).

In addition, several pathogens do not originate from faecal contamination but can be present in bathing water because their natural habitat is water and they grow to high concentrations in surface waters that are eutrophic (contaminated with nutrients), such as cyanobacteria, or because waters are thermally polluted (such as *Naegleria fowleri*) or the ecosystem is unbalanced (*Trichobilharzia*). These pathogens are not "covered" by monitoring for FIB.

2.1.2 Recreational Waters

For the context of this research, recreational waters are defined as fresh and coastal waters used for recreational purposes (e.g. swimming, surfing, water skiing, white water sports, underwater diving, sailing, boating), including rivers, lakes, natural swimming pools and coastal waters. Swimming pools, natural hot springs, interactive water features and paddling pools were not considered in this research (de Roda Husman et al., 2010; WHO, 2003).

2.1.3 Selection of Pathogens

A long list of (recreational) water associated pathogens was extracted from key publications, including de Roda Husman & Schets, 2010; Pond, 2005; RIVM, 2018; WHO, 2003 and the Global water pathogens project (publication dates between 2017-2019) (Appendix Table 7). From this a short list of pathogens was created. We excluded pathogens a) from tropical climates that are not relevant to Flanders, b) that are relevant for swimming pools but not for natural surface waters, c) for which transmission is through contact with animal faeces, d) transmission via bathing is not reported or e) the transmission route is unclear (Appendix Table 6). For enteric pathogens (pathogens associated with contamination of bathing water with human or animal faeces) we selected reference pathogens: *Campylobacter* for enteric bacteria, Norovirus and Adenovirus for human enteric viruses and *Cryptosporidium* and *Giardia* for human enteric protozoan parasites. These reference pathogens are the most prevalent pathogens amongst their group and control of these pathogens implies control of the other enteric pathogens from their group. This resulted in a list of 15 pathogens (Table 1) which covers a range of relevant recreational water pathogens (viruses, bacteria, protozoa, amoebae, cyanobacteria, toxins, flukes) and illnesses (gastrointestinal; ear, eye, wound and respiratory infections; skin irritation, neurological disorders) and pathogens that represent different bathing water challenges (faecal contamination, nutrient contamination, thermal pollution, unbalanced ecosystems).

Table 1 Pathogen short-list for review including pathogen type and origin

Pathogen	Pathogen Type	Bathing water challenge
Acanthamoeba	Free-living amoebae	Thermal pollution
Adenovirus	Virus	Faecal
Aeromonas	Bacteria	Nutrient pollution
Campylobacter	Bacteria	Faecal
Clostridium botulinum	Bacteria	Bird/fish death
Cryptosporidium	Protozoa	Faecal
Cyanobacteria	Bacteria	Nutrient pollution
Giardia	Protozoa	Faecal
Leptospira	Bacteria	Rats/rodents
Naegleria fowleri	Free-living amoebae	Thermal pollution
Norovirus	Virus	Faecal
Plesiomonas	Bacteria	Nutrient pollution
Pseudomonas aeruginosa	Bacteria	Nutrient pollution
Trichobilharzia	Fluke	Unbalanced ecosystem
Vibrio	Bacteria	Faecal, Non-faecal

2.2 Pathogen Matrix

For each of the 15 pathogens list in Table 1, an excel table was filled out with the following information;

2.2.1 General information

A general description of the pathogen was given, including the physiology, occurrence in the environment, whether the pathogen is of faecal origin, relevant species for bathing water, the conditions for growth (e.g. temperature, hosts) and whether the pathogen is relevant for fresh and/or coastal bathing waters.

2.2.2 Health Effects

The common health effects due to exposure via recreational waters were listed. Based on the health effects, a rating of the severity of the illness caused for each pathogen was given, ranging from minor to very severe. It was also noted whether the illness was likely to be underreported. The likelihood of underreporting took into account whether the pathogen was on the list of notifiable diseases in Flanders[1], if the disease had mild-moderate symptoms not requiring immediate medical attention (e.g. self-limiting diarrhoea), or if symptoms could be caused by multiple exposure routes or if the exposure route is not likely to be reported in patient history.

Vulnerable populations were indicated for the pathogens, for example the elderly, children under 5, immunocompromised patients and/or individuals with other medical issues (e.g. HIV, liver disease). Relevant bathing water behaviours that increased risk of exposure were also indicated in this category (e.g. wearing contact lenses while swimming) and a separate category for exposure mechanism in bathing water. Finally, when available, the incubation period and the infectious dose or dose response was also indicated for each pathogen.

[1] In addition to the list of notifiable diseases, if a pathogen causes a serious infection which has an epidemic character or is a danger of causing an epidemic, then the pathogen will also be notified (*Ministerieel besluit tot bepaling van de lijst van infecties die gemeld moeten worden en tot delegatie van de bevoegdheid om ambtenaren-artsen en ambtenaren aan te wijzen*, 2009)

2.2.3 Relevance for Flanders

The relevance for Flanders was determined by compiling relevant incidences in recreational waters. The focus was on incidences in Flanders, Belgium and the Netherlands, however when not available, international incidences were also included. From the rate of incidences in Flanders and Europe and the severity of the disease, a rating for the relevance of the pathogen for bathing waters in Flanders was given, ranging from very low to high.

2.2.4 Monitoring

The current monitoring (EU BWD and/or Vlarem II) for each pathogen was indicated and to what extent the pathogen is monitored by faecal indicator bacteria (FIB). A summary of the current methods for monitoring the pathogen are given, including direct monitoring (e.g. culture, molecular methods), indirect monitoring (e.g. monitoring toxins) and/or environmental monitoring (e.g. visible cyanobacteria blooms, dead fish/birds).

Costs of monitoring

Goal of the cost estimation is to determine the feasibility of implementing the monitoring for a certain goal. Currently most methods for alternative monitoring are only performed by specialized labs. The current cost of an analysis by a specialized laboratory may not be representative for the future costs when the method is implemented on a large scale by routine laboratories. Costs for reactive ad-hoc monitoring of these parameters are estimated based on current costs of a specialised lab. In addition the costs for routine monitoring program(s) are estimated taking into account the possibilities of optimising a method. Current costs of weekly monitoring faecal indicator bacteria (FIB) in 100 ml samples are the reference for highly optimized weekly monitoring by professional sampling companies and routine analysis laboratories. Costs per sample are therefore low, in the order of €15-€50 per sample. Costs of alternative monitoring will depend on:

- Whether the method has already been developed (is there a standard)
- The availability and costs of materials, which depends on the number of samples per year in Flanders, and if this is only bathing water or also other sectors
- The complexity of the method and the amount of labour per sample (basic culture or plaque methods, complex culture or plaque methods, PCR, microscopic etc.)
- The required biosafety level of the laboratory (generally BSL2, specific pathogens BSL3)
- The number of analysis per year, more samples allow for more optimization
- If samples can be combined (combine labour for multiple samples is more efficient)
- If samples are planned or ad-hoc
- The sampling volume and concentration methods

This illustrates that the cost of monitoring not only depends on the analysed organism or parameter, but also on the design of the monitoring and whether it's routine planned or reactive monitoring. Therefore costs per sample were estimated for both routine and reactive monitoring. For routine monitoring a number of 26 samples per bathing site (89 sites) per year and several bathing sites per laboratory are assumed. The sample processing has been fully optimized. Routine laboratories can only implement basic culture methods and PCR methods. More complex methods will only be estimated for reactive monitoring by specialized laboratories.

For reactive monitoring it is assumed that a single site is monitored regularly for a limited period. Samples are taken on an ad hoc basis, allowing little room for optimising planning. Immediate analysis is required, limiting the opportunity for combining samples. Besides the costs for analysis, extra costs will be included for the special logistics, such as collecting these extra samples, coordination and communication of the results.

The costs of developing a method won't impact the costs per sample on the long term, but may form a barrier to start implementation of a monitoring program. Therefore the costs to reach a standardized method implemented in the routine or specialized laboratory are also estimated separately. This includes the development, validation, lab implementation. Due to the uncertainty involved, the costs are expressed in three categories (Table 2).

Table 2 Cost categories for routine and reactive monitoring and method development

	Routine monitoring €/sample	Reactive monitoring €/sample	Method development[1] €
€	10-100	100-500	25,000-100,000
€€	100-1,000	500-1,500	50,000-200,000
€€€	1,000-5,000	1,500-5,000	150,000-300,000

[1] Crude estimation, costs for method development and validation may differ depending on number of labs involved and complexity of the method

Multiple analysis methods are mentioned for several pathogens, e.g. culture and molecular methods. The interpretation of the outcome of the methods differ as culture detects viable/infectious organisms whereas molecular methods detect the presence of DNA or RNA. The choice of method will depend on the situation and goal of monitoring. Therefore costs for both methods are estimated for these pathogens. Analysis often requires sample concentration and preparation. Therefore the analysed volume will impact the costs of analysis. The sample volume was chosen so that a water quality target can be demonstrated, or, if no water quality target was mentioned or derived, the commonly applied volume in reported studies was assumed.

Costs of obtaining equipment will impact the cost of implementation. However, the same equipment may be used for multiple pathogens, e.g. a PCR machine. The cost estimation didn't account for these synergies. Similarly, costs may be reduced if multiple analysis are combined, e.g. DNA extraction for various pathogens, or developing a multiplex PCR for a set of pathogens. These options for optimisation were not accounted for in the cost estimation.

Availability of Standard Methods and Water Quality Targets

Standard methods (ISO and/or NENs), if any, for monitoring each pathogen are listed and it is indicated for which context the method is valid (e.g. food, water or specifically for monitoring recreational waters). Also listed are whether a commercial laboratory would reasonably be able to test recreational water samples, or whether the monitoring methods listed above are only available from specialized research or academic laboratories.

Finally, the relevant guidelines and water quality targets (if any) for each pathogen in bathing waters are listed. Guidelines in this context mean a document which lists the type of monitoring, frequency of monitoring and water quality targets with action based on monitoring. In the case that no water quality targets currently exist we give an indication of whether, with sufficient monitoring, a health-based water quality target could be created. Criteria for creating a health-based water quality target included sufficient epidemiological or toxicological data and/or ability to perform quantitative microbial risk assessment (QMRA).

2.2.5 Risk reduction and control measures

Where possible, risk reduction and control measures for each pathogen are listed. These include whether the presence of the pathogen can be controlled, for example by prevention of faecal contamination of bathing waters (sewage diversion), reducing waste on recreational beaches to prevent pests and rodents or whether pathogens are indigenous to specific recreational water types and therefore the presence cannot be readily controlled. Specific regulation and/or guidance for controlling pathogens from relevant EU member states have also been included where available.

2.2.6 Climate change

Following the examples of de Roda Husman & Schets, 2010, Nichols, Lake, & Heaviside, 2018 and others, the effects of climate change were assessed separately for three major factors which determine the fate and behaviour of pathogens in recreational waters; temperature, precipitation and water availability. A summary of the expected effects from each factor is given for each pathogen.

Temperature

Increasing air temperature is tightly coupled to increasing surface water temperatures (de Roda Husman et al., 2010). Surface water temperature increases are affected by the type of water body, depth and inflows. Therefore local differences between water bodies may arise as a result of differences in water depth, flow and discharges from WWTP and cooling towers (de Roda Husman et al., 2010).

Changes in surface water temperatures can results in increased growth of pathogens but may also increase inactivation/die-off. For free-living pathogens that are not dependent on a host, increased temperatures can result in increased growth (de Roda Husman et al., 2010; Schijven et al., 2013). However, for pathogens dependent on a host, such as enteric pathogens, increased temperatures can result in increased die-off (Schijven et al., 2013). Changes in atmospheric temperature may also affect the length of the bathing season and/or change the seasonality of pathogens, by lengthening the time frame when pathogen concentrations are high or affecting winter concentrations (de Roda Husman et al., 2010).

Rainfall

Climate change is expected to affect both the intensity and frequency of rainfall patterns (de Roda Husman et al., 2010). Heavy rainfall events are expected to occur more often during the summer months and more intense precipitation is expected to occur more in high latitudes (e.g. Northern Europe) (de Roda Husman & Schets, 2010). With rainfall, pathogenic organisms may enter surface water by discharge from raw and treated wastewater (e.g. combined sewer overflows (CSOs)). Run-off from (agricultural) land where faecal matter from wildlife, domestic animals or manure may be present may increase the concentration of faecal pathogens in surface waters (de Roda Husman et al., 2010). Enhanced inactivation due to increased surface water temperatures is expected to be less important than increased peak concentrations of pathogens due to increased run-off (de Roda Husman et al., 2010). It is assumed that increased run-off and sewage overflows increase proportionally with increased extreme precipitation (de Roda Husman et al., 2010).

Increased intensity of precipitation will increase surface and groundwater nutrient discharge to recreational water bodies. This increased discharge may results in increased dilution, due to greater flushing volumes, however, changes in rainfall frequency may result in larger peak nutrient concentrations. Increased peak nutrient concentrations have been shown when there is increased winter and spring rainfall followed by dryer summer periods (Paerl et al., 2008). Rainfall intensity and frequency also affect the resuspension of river sediments, which can results in increased mobilization and peak concentrations of pathogens normally sequestered in bottom sediments (de Roda Husman et al., 2010).

Water Availability

With changes in precipitations patterns, water availability is expected to vary. Reduced water availability may decrease the volume of water in recreational waters, increasing the concentration of pathogens present (de Roda Husman et al., 2010). However, reduced water volumes with increased water temperatures and radiation may increase inactivation (de Roda Husman et al., 2010). Decreased volumes of water may also alter the physiochemical composition of water, such as the availability of nutrients or salinity, shifting the microbial community of recreational waters (de Roda Husman et al., 2010), or the suspended solids or algae in water, limiting penetration of radiation. Water scarcity during the summer months in the lowlands may also lead to redirection of water flows by water authorities, so other contamination sources may become more prominent for specific bathing beaches under water scarcity conditions.

2.2.7 Recommendations

Based on the above information recommendations for altering the current monitoring program are given. The recommendation took into account;

- Risk of exposure in Flanders recreational waters (assessment of historical incidences and trends specifically in Flanders and more broadly in Belgium, the Netherlands and Europe)
- Severity of disease(s) caused
- To what extent the pathogen is currently monitored and the available monitoring methods
- What health-based water quality targets are available and whether an action associated with a water quality target (e.g. negative swim advisory when concentrations above a specific limit) already exists and if a water quality target could reasonably be created if monitoring was implemented
- An order of magnitude estimation of the cost of establishing a monitoring program
- What other EU member states are currently monitoring
- Influence of climate change

2.2.8 Grading of Evidence

The evidence for recommendations were graded according to the certainty of the stated evidence, on a scale from low to high certainty of evidence. Briefly, the categories for certainty of the evidence were;

- Low certainty: Specifically found conflicting data in the literature
- Moderate certainty: Expert opinion, data with fewer than three high quality studies or uncertainty due to lack of data (e.g. underreporting of disease incidences)
- High certainty: Multiple high quality sources or data sourced from systematic reviews

2.3 Literature review and search strategy

2.3.1 General pathogen information

Information on pathogens in recreational water was collected from key publications and expert reviews (e.g. *Global Water Pathogens Project (GWPP)*, waterpathogens.org). Information from key publications was supplemented with a dedicated literature search from the Scopus database. The search terms are found in Table 3 below.

The literature reviewed was limited to studies published after 2010. Two exceptions to this were searches for publications for cyanobacteria and on disease incidences. Due to the high volume of studies published on cyanobacteria in the last decade, only reviews published since 2010 were considered. For disease incidences/outbreaks in Belgium or Flanders, all publications found were included. Articles were first screened based on title and then on abstract. Only articles published in English or Dutch were included. Full text articles were then screened and in- or excluded based on relevance and whether any new information was presented in the studies not included in the key publications. Figure 2 in the appendix shows the PRISMA diagram of the selection process for the general pathogen and climate change information.

In addition to searching Scopus, other databases were consulted to find specific data ("other sources" listed in Figure 2). Dose response information was extracted from key publications and the QMRA Wiki dose response models (qmrawiki.org). Pubmed and Google Scholar were cross-checked to find incidence reports in Europe and relevant cases from Flanders/Belgium were extracted from the *Vlaams Infectiebulletin*. Finally, overall disease incidences and country data were extracted from relevant publications from the European Centre for Disease Prevention and Control.

Table 3 Search string and pathogen name from systematic search of Scopus database. The asterisk (*) indicates a wildcard in the search characters, which will find all terms with the same root word that is followed by the asterisk. Quotations indicate keywords searched together.

Search String
(TITLE-ABS-KEY (/*PATHOGEN NAME/* AND (OR river* OR coast* OR marine OR "natural swim* pool*") AND (Europe OR Belgi* OR Fland*)))

Pathogen	*/PATHOGEN NAME/*
Acanthamoeba	Acanthamoeba
Adenovirus	Adenovirus
Aeromonas	Aeromonas
Campylobacter	Campylobact*
Clostridium botulinum	Botuli*
Cryptosporidium	Cryptosporid*
Giardia	Giardia*
Leptospira	Leptospir*
Naegleria fowleri	Fowleri
Norovirus	Norovirus
Plesiomonas	Plesiomonas
Pseudomonas aeruginosa	Pseudomonas AND aeruginosa OR "swimmer* ear"
Toxic Cyanobacteria	Cyano*
Trichobilharzia	Trichobilharzia OR "swimmer* itch"
Vibrio spp.	Vibrio

2.3.2 Climate change

Data on the effects of climate change for pathogens in recreational waters was extracted from two key review publications. de Roda Husman and Schets (2010) performed a systematic review of recreational waterborne pathogens with respect to their specific climate change dependencies and significance to public health. Nichols et al. (2018) performed a more recent systematic reviews of climate change impacts on a wide range waterborne pathogens. The study reviewed factors such as population growth, human activity (e.g. travel), weather and hydrology, in addition to the effectiveness of interventions to reduce impacts on public health.

Data from the two systematic reviews was supplemented with a limited literature search from the Scopus database. The search terms are found in Table 4 below. Search terms were based on similar systematic reviews on climate change and waterborne pathogens (e.g. Levy et al. 2016; Cann et al. 2013; Young, Smith, and Fazil 2015; Semenza and Menne 2009). The literature reviewed was limited to studies published after 2018. Articles were first screened based on title and abstract. Only articles published in English or Dutch were included. Full text articles were then screened and in- or excluded based on relevance and whether the article contained any new information on the effects of climate change. Figure 2 in the appendix shows the PRISMA diagram of the selection process for the general pathogen and climate change information.

Table 4 Keywords searched for climate change impacts. Pathogen and climate keywords searched specifically in the title-abstract-keywords (TAK) while recreational water keywords searched in all search fields of the Scopus database. The asterisk (*) indicates a wildcard in the search characters, which will find all terms with the same root word that is followed by the asterisk. Quotations indicate keywords searched together.

Keyword Categories		
Pathogen (TAK)	Climate (TAK)	Recreational waters (all)
Pathogen*	"Climate change"	Recreation*
Acanthamoeba	"Climate variability"	Bath*
Adenovirus	Temperature	Swim*
Aeromonas	Rainfall	Lake*
Campylobact*	Rain	River*
Botuli*	Run-off OR runoff	Coast*
Cryptosporid*	Precipitation	"Natural swim* pool*"
Giardia*	Climate	
Leptospir*	Weather	
Fowleri	Drought	
Norovirus	"Water scarcity"	
Plesiomonas		
Pseudomonas AND aeruginosa OR ("swimmer* ear")		
Cyano* OR "harmful algal bloom"		
Trichobilharzia OR "swimmer* itch"		
Vibrio		

2.4 EU Member state monitoring

The current monitoring by EU member states was reviewed to evaluate whether other member states have bathing water monitoring policies that differ from the minimum requirements set out by the EU BWD. EU member states bathing water websites, EU bathing water reports, example bathing water profiles and state/country legislation were been reviewed. Where necessary, Google Chrome's built in translate function was used to review the various websites and legislation not in English/Dutch.

In addition to the online review, specific bathing water experts were contacted for additional information. Experts in France, Finland, Germany, Greece, Hungary, Italy, Spain, Sweden and the UK were contacted. See appendix (p. 43) for the email template sent to EU contacts. From these contacts and the online systematic review, only those countries and monitoring practices which differ from the minimum requirements of the EU BWD are highlighted.

2.5 Risk determinants of harmful algal blooms

Risk determinants for harmful algal blooms were identified from in house knowledge (e.g. Doomen, de Hoogh, & Abrahamse, 2008; Kardinaad, 2013; Wullings, van der Linde, & Kardinaal, 2009) and recent, key publications (e.g. (Ibelings et al., 2014; Manning et al., 2017; U.S. Environmental Protection Agency, 2019). In addition, a limited literature search was performed to find review studies published (after 2014) to retrieve new, relevant information. Risk determinants for bloom formation and recommendations controlling or preventing blooms are suggested.

3 Results and Recommendations

3.1 Pathogen Matrix

The pathogen matrix has been shared as separate an Excel document (Pathogen_Matrix.xlsx).

3.2 Monitoring Recommendations

Two types of monitoring are recommended. Proactive monitoring, which refers to monitoring performed on a regular basis. The current EU BWD is an example of proactive monitoring. Reactive monitoring is defined here as monitoring that is triggered by notification of a potential problem (such as large numbers of dead birds or fish) or (a cluster of) health complaints via bathing water, usually at a particular bathing beach.

3.2.1 Proactive monitoring

Enteric pathogens A: bacteria

Proactive monitoring of *E. coli* and enterococci is embedded in the EU BWD and the Flemish bathing water regulation. This monitoring is dedicated to protect the health of bathers against pathogens that are associated with faecal contamination of bathing waters. Flanders is an urbanised region and Flemish surface waters are contaminated by discharges from wastewater treatment plants, sewer overflows and run-off from manure from agricultural lands. So the sources of faecal contamination are present in Flanders. The detection of *E. coli* and enterococci at Flemish bathing beaches and, although the majority of beaches classifies for good or excellent water quality under the Directive, part of the (inland) beaches classifies as good or sufficient (European Environment Agency, 2019b). This implied that the risk to bathers in Flanders is present and bathing water monitoring has helped to mitigate this risk, as shown by the improvement in beach classification over the years. This is sufficient rationale to maintain the current monitoring for *E. coli* and enterococci. This will protect bathers against bathing waterborne infections by enteric bacterial pathogens, such as *Campylobacter. Salmonella, Shigella,* Enteropathogenic *E. coli* etc.

Enteric pathogens B: viruses and protozoa

As indicated in section 2.4, monitoring of *E. coli* and enterococci is less suited to protect bathers against infections with viral and protozoan parasites that persist longer in water. This is most pressing for viruses, which are frequently present in bathing waters in high concentrations (Wyn-Jones et al., 2011) and can cause bathing-waterborne outbreaks (Kauppinen et al., 2017). Human pathogenic viruses originate from discharges of domestic wastewater. Several groups of bacteriophages (viruses that infect bacteria) have been long-established as adequate surrogates for human enteric viruses (Jebri et al., 2015; McMinn et al., 2017), of which the somatic coliphages are present in domestic wastewater and surface water in relatively high numbers (Jebri et al., 2015; McMinn et al., 2017), and epidemiological studies in the USA and Europe determined a relation between somatic and F+ coliphages concentration in bathing water and gastro-intestinal illness (Benjamin-Chung et al., 2017; Griffith et al., 2016; US EPA, 2015c; Wiedenmann et al., 2006). These studies can be used to derive water quality targets for coliphages. Methods for monitoring of coliphages in water are well-established and easy (Mooijman et al., 2005; Sauer et al., 2011), and available in as rapid test kits (Muniesa et al., 2018).

Adding coliphages as parameter to the current bathing water quality monitoring program is likely to improve the protection against virus-associated health risks. This is most relevant for bathing beaches that are prone to human faecal contamination, via discharges of domestic wastewater and CSOs (although also stormwater overflows may be contaminated through cross-connections with sewers, Sauer et al., 2011). **We recommend to investigate the added value of monitoring coliphages through, for example a trial monitoring program during the bathing season before full implementation of coliphage monitoring in Flanders**.

Cryptosporidium and *Giardia* have been associated with engineered and disinfected water systems (pools, spray parks) more than with bathing waters. Their concentration in bathing waters and the corresponding health risk is relatively low (Schets et al., 2008) compared to enteric viruses. No epidemiological studies have been conducted to determine the association between the concentration of *Cryptosporidium* or *Giardia* in recreational waters to derive a water quality target. A target could be derived from a QMRA on recreational water exposure. Standard methods exist for monitoring *Cryptosporidium* and *Giardia* in water (US EPA, 2012), and these have been employed for regulatory drinking water monitoring in the US and UK. The analysis requires sampling of large volumes and are labour intensive and hence expensive. Only a few studies have looked into spores of *Clostridium (perfringens)* as indicator for *Cryptosporidium* and *Giardia* or health risk (Wade et al., 2010; Wiedenmann et al., 2006), but with inconsistent results. The lower health risk, absence of a good basis for selection of an appropriate indicator and the complex and expensive methods for direct detection of *Cryptosporidium* and *Giardia* do not warrant the addition of these parameters to the routine monitoring of bathing waters.

Cyanobacteria

To monitor for the presence of cyanobacteria blooms, bathing waters are visited biweekly and inspected visually for the presence of cyanobacteria layers and presence of cyanobacterial flocs in water samples. When scum layers are observed (or reported by citizens or municipalities) the bathing water is closed for swimming (or bathers are warned) and samples are taken to test for microcystin and cyano-chlorophyll by the responsible water authority. Swimming is prohibited until the concentration of microcystin drops below 20 µg/L and cyano-chlorophyll drops below 75 µg/L and visible blooms have dispersed (see Appendix, p.45). **Our recommendation would be to consider the tiered approach used in the Netherlands** (Appendix p. 44); to do this, a Flanders-NL workshop on the pros and cons of the respective cyanoprotocols could be helpful in raising awareness and engage water authorities in this evaluation. **Another recommendation, also in light of climate change, is to survey the development of the composition of cyanobacterial species present in Flemish bathing waters, and to evaluate if it is necessary to complement microcystin analysis with other toxins, such as cylindrospermopsin (as recently introduced by the US EPA). We also recommend to evaluate whether the stricter guideline for microcystin as issued by the US EPA (8 µg microcystin/L) is most appropriate in protecting the health of the bathers in Flanders (US EPA, 2019).**

The previous guideline value of 20 µg microcystin/L was based on the tolerable daily intake (TDI) level for a 60 kg adult consuming 100 ml of water while swimming (WHO, 2003). The 20 µg microcystin/L was equivalent to 20 times the WHO provisional drinking water guideline value for microcystin-LR (WHO, 2003). The new US EPA guideline value for microcystins was calculated for a reference dose for children aged six to ten (31.8 kg), because children consume more water per unit body weight than adults, and therefore they may receive a higher dose than adults (US EPA, 2015b).

The US EPA guideline value for cylindrospermopsin was derived similarly, with an guideline value of 15 µg/L (US EPA, 2019). Cylindrospermopsin differs from microcystin in terms of both toxicological properties and environmental occurrence. Cylindrospermopsin, a cytotoxin with both hepatotoxic and neurotoxic effects, is produced from a number of cyanobacterial species and primarily affects the liver and kidneys (US EPA, 2019). Microcystins, a hepatotoxin, primarily affect the liver (US EPA, 2019). Some cylindrospermopsin-producing species do not form visible surface scums (US EPA, 2019). While microcystines tend to remain contained with the toxigenic cyanobacterial cell until the cell breaks (US EPA, 2015b), cylindrospermopsin can be retained within the cell but is usually released outside of the cell and dissolves to the water (US EPA, 2015b). Cylindrospermopsin was not included in the WHO ***Guidelines for safe recreational water environments. Volume 1: Coastal and Fresh Waters*** (WHO, 2003) because at the time of the review there was insufficient information available to calculate a TDI and therefore to derive a health based guideline value for recreational waters (Burch, 2005). However, since then a no observed adverse effect level has been identified, which was used to calculate a TDI and in turn recreational water guideline value (US EPA, 2015a). Furthermore, cylindrospermopsin has also been recognized in recent years as not isolated to tropical and subtropical regions, but also temperate regions of the world (Huisman et al., 2018; US EPA, 2015a). **For these reason, we recommend to undertake research to determine the value in monitoring both microcystin and cylindrospermopsin in Flanders**.

Other HAB species

For non-cyanobacterial HAB species, currently no routine measurements are being done for bathing waters. Monitoring and taking of measures is now done reactively (Sprick, 2013), which is sufficient as long as such blooms occur rarely and public health risks are limited. When non-cyanobacterial HABs would occur more frequently, a tiered monitoring strategy similar to cyanobacteria monitoring can be adopted.

3.2.2 Reactive monitoring

Reactive monitoring is defined here as monitoring that is triggered by notification of a potential problem (such as large numbers of dead birds or fish) or (a cluster of) health complaints via bathing water, usually at a particular bathing beach. This requires systems in place of receiving and processing notifications of potential problems or health complaints and the evaluation of the role of bathing water/a bathing beach/ a swimming event as potential source of health complaints. The system that is in place for notification of potential problems is twofold: 1) during the visit of the responsible authority for water quality sampling a visual inspection is carried out and 2) notification of the public or other bodies to city officials, city environment services, city health councils, the police, the notification point (meldpunt) on kwaliteitzwemwater.be etc. The system that is in place for health complaints is the notifiable diseases that are reported to the local health department and national disease surveillance system. Notifiable diseases in Flanders that can be associated with bathing waters are: botulism, leptospirosis, hepatitis A, enterohemorrhagic *E. coli*, poliomyelitis, cholera, (para)typhoid. It is likely that also other uncommon infections with a very serious outcome, such as with lethal brain infections by *Naegleria fowleri* or *Acanthamoeba* will be notified through this system. There is also evidence that cases of uncommon, less severe infections, such as vibriosis or swimmer's itch can be picked up through this notification system (Backer et al., 2011; Flipse et al., 2019), but it is likely that there is considerable underreporting of milder health complaints such as swimmer's itch through this notification system. **For the health risks that are not covered by the proactive monitoring, we recommend that the surveillance of diseases in Flanders is used to indicate potential bathing water-associated health complaints**. Notification of specific diseases that are potentially bathing water-associated is followed by investigation and evaluation of the (potential) association with bathing water. If there is a suspicion, the presence of the specific pathogen in the specific bathing water (European Environment Agency, 2019b; Wyn-Jones et al., 2011) and the suspicion, complemented with monitoring, should trigger measures to protect new disease cases.

The system for notification of potential problems with bathing water to local or regional authorities is active and acted upon (pers. com. Agentschap Zorg & Gezondheid). An (annual) overview of such notifications could help observe trends over time or regarding specific bathing waters. For surveillance of these notifications as well as health complaints, the Netherlands has developed a questionnaire system, where the National Institute of Public Health and the Environment (RIVM) sends a (digital) questionnaire at the end of the bathing season requesting local health departments (infectious disease jurisdiction) and provinces (bathing water quality jurisdiction) to enter the bathing water related health complaints they have received/noted. RIVM compiles this information into an annual surveillance overview (Schets et al., 2017).The questionnaire itself is not public, however the publication by Schets et al. (2017) *Gezondheidsklachten door recreatiewater in de zomers van 2014, 2015 en 2016* gives insight into the types of questions posed to the local health departments. **Implementation of a more active surveillance**

system will improve the ability to detect, notify and survey the occurrence of common, mild health problems associated with bathing waters, such as swimmer's itch, cyanobacterial health complaints and diarrhoea.

There are several advantages and difficulties embedded in the reactive monitoring approach. The main advantage is efficiency. Severe health complaints are extremely rare and mild health complaints are rare and both do not warrant allocation of extensive resources to proactive monitoring. The main disadvantage is that bathers have to become ill and the illness notified through the notifiable disease system to activate the reactive monitoring to help prevent further illness cases. A difficulty is that many of the notifiable diseases can be associated with other routes of exposure than bathing water, which may make it difficult to identify bathing water as the source with high certainty. Also, methods to detect the specific pathogens are not widespread and exist in specialised laboratories or academic centers and are not developed for routine monitoring of bathing waters. Since outbreaks of diseases through bathing water always require rapid action, it is helpful to have an up-to-date list and contact details of the laboratories that are experienced in water monitoring for the different pathogens/toxins. Methods exist (see the Pathogen matrix) for the detection of enteric bacteria, viruses and protozoa, *Vibrio*, *Naegleria fowleri, Acanthamoeba, Trichobilharzia, Leptospira* and species and toxins of cyanobacteria, *Clostridium botulinum* toxin, *Pseudomonas aeruginosa, Aeromonas, Plesiomonas.* The fact that these pathogens are not routinely tested for means that there is usually limited information available about reference levels of these pathogens in water and no guidance values are available for concentration levels that are safe or unsafe for bathing. This implies that the interpretation of the bathing water monitoring and other data and decision-making about appropriate response have to be evaluated on a case-by-case basis and by combining information obtained through epidemiological analysis of reported health complaints, sanitary inspection of the suspected bathing water and environmental monitoring. Environmental monitoring can also be used to support the decision to re-open a bathing water after a beach closure or 'don't swim' advice. When the response to notifications and the reactive monitoring are systematically logged, this generates a compendium of information about events, environmental monitoring data etc. that could assist in evaluating future notifications.

3.2.3 Specific pathogens:

Acanthamoeba
See *Naegleria fowleri.*

Botulism
Botulism is a notifiable disease and is very rare and water-associated botulism is extremely rare in Flanders. The current approach under the botulism guideline of monitoring for outbreaks of botulism among (water)animals, and removal of dead fish and birds, in combination with a ban on swimming in the affected water when botulism type B or E are detected (Vlaams Agentschap Zorg & Gezondheid, 2014), is sufficient to prevent exposure to botulism toxins. Dedicated monitoring for the concentration of botulinum toxins is usually not necessary. If a case of botulism is notified for which bathing is the suspected cause, immediate sanitary inspection of the bathing site for dead animals is warranted and, if the suspicion (based on epidemiological and sanitary investigation) is strong enough, a swim-ban should be considered.

Leptospira
Leptospirosis is a notifiable disease and is very rare in Flanders. Bathing water associated cases are a subset of these cases. Other exposure routes are contact with infected animals or animal housing or soil. If a new case of leptospirosis emerges in Flanders and the case has a history of exposure to bathing water, reactive monitoring of suspected water bodies is important to help identify the source and prevent further cases. Given the potential severity of the disease, a single case with bathing water suspicion is sufficient to trigger reactive monitoring and preventive actions. The epidemiological connection to bathing water is the key indication. For monitoring, there is no standard method, but there are specialized laboratories available that can detect pathogenic *Leptospira* species

with qPCR. When reactive monitoring is undertaken as a follow-up of cases, there are no water quality targets for safe/acceptable concentrations of pathogenic *Leptospira* in bathing water. Focusing the reactive monitoring on pathogenic *Leptospira* is important, as non-pathogenic *Leptospira* are common in water. Even then, pathogenic *Leptospira* has been detected in 35% of bathing water samples that were tested in a screening study in the Netherlands (so not triggered by a case of leptospirosis) (Becker et al., 2017). Interpretation of results of monitoring is therefore not straightforward, but can give indications about the presence of pathogenic *Leptospira* and its sources. Sanitary inspection of the bathing water, beach and surroundings can help to identify the (potential) presence of rats or other rodents, or the presence of nearby livestock that could be a source of contamination (these should also be identified in the bathing water profile). There are source tracking methods available to determine if rats or ruminants have contaminated the bathing water (Becker et al., 2017; Kardinaal, 2015). Hygiene at bathing beaches, with removal of waste is important to limit the presence of rats and other rodents around the beach area.

Naegleria fowleri

Health problems due to *N. fowleri* via bathing are extremely rare and specific to thermally polluted waters which are, by definition, not dedicated as bathing waters. A monitoring program for *Naegleri fowleri* in bathing waters is therefore not justified. If a new disease case would emerge in Flanders, the epidemiological connection to bathing water is the key indication. Given the potential severity of the disease, a single case with bathing water suspicion is sufficient to trigger reactive monitoring and preventive actions. Reactive monitoring of suspected water bodies is important to help identify the source and prevent further cases. There is no standard method, but there are specialized laboratories available. The serious health risk does warrant that bathing beaches should be kept free of thermal pollution and people should not be allowed to swim/recreate in thermally polluted waters, such as discharges of power plants or other industries. When reactive monitoring is undertaken as a follow-up of cases, there is probably no safe/acceptable concentration of *Naegleria fowleri* in bathing water (de Jonckheere, 2012).

Plesiomonas/Aeromonas

It is unclear to what extent these bacteria are causing infections through bathing water. *Plesiomonas* and *Aeromonas* are highly abundant in surface waters. A monitoring program for *Aeromonas* or *Plesiomonas* in bathing waters is therefore not justified. If a cluster of disease cases is suspected to be associated to a particular bathing water via epidemiology in Flanders, reactive monitoring of suspected water bodies is important to help identify the source and prevent further cases. Given the mild disease and uncertainties about the role of *Aeromonas* and *Plesiomonas* as enteric pathogens, a significant cluster of cases with a clear bathing water suspicion would be sufficient to trigger reactive monitoring and preventive actions. There is a standard culture method for *Aeromonas* and a (non-standard) culture method for *Plesiomonas*, and there are laboratories available. Since *Aeromonas* and *Plesiomonas* are ubiquitous in (fresh) water, the epidemiological association to (a specific) bathing water should be strong and detailed typing of isolates from cases and suspected bathing waters will be needed to confirm (or deny) the role of bathing water. No guidance levels for (un)safe concentrations of *Aeromonas* or *Plesiomonas* are available.

Pseudomonas aeruginosa

Otitis externa through bathing is rarely reported. *Pseudomonas aeruginosa* is a common water bacterium that is probably present very generally in fresh water bodies. It may proliferate faster and to higher concentrations (>100 cfu/L) in warmer water (>18°C) (Gezondheidsraad, 2001). Limited studies have not found a clear dose-response between *Pseudomonas aeruginosa* concentration in water and health risk, so it is not possible to determine safe/acceptable concentrations in bathing water. A monitoring program for *Pseudomonas aeruginosa* in bathing waters is therefore not justified. If a new disease case would be notified in Flanders, and the case history links the case to a specific bathing water, reactive monitoring of the suspected water body is important to help identify the source and prevent further cases. When a suspected bathing water is warm (>18°C) and contains increased (>100cfu/L) concentrations of *Pseudomonas aeruginosa,* advising not to swim is recommended, until the concentrations are reduced. For sampling, there is a standard method, and there are laboratories available. People that are particularly sensitive to otitis externa, such as people with chronic ear complaints, could be given more generic advise about the risk of otitis externa by swimming and other activities that involve head-immersion in (warm) surface water.

Trichobilharzia

Swimmer's itch probably occurs several times each bathing season; and is probably underreported. Symptoms are mild. Swimmer's itch occurs in fresh water, particularly shallow and clear waters. Proactive monitoring is not recommended given the mild symptoms, transient nature of *Trichobilharzia* and absence of a standard method. Methods are available for investigation of host-snail-species and for cercaria in water in a specialized laboratory. If complaints of itch are noted that may be associated to bathing water, further investigation of the suspected water for potential presence of host-snails and waterfowl may serve as a first indication and investigation of snails for infection with *Trichobilharzia* and/or the bathing water for the presence of cercaria (by PCR) can help verify the source. If swimmer's itch is identified at a bathing beach, we recommend to inform bathers about the risk. It is difficult to take remedial actions to reduce or eliminate the risk of swimmer's itch at a beach. Removing host-snails actively or by removing the vegetation that they feed on or introduction of fish that feed on these snails or limit the vegetation have been suggested (Van Donk et al., 1988). The use of molluscicides such as coppersulphate are not recommended as they produced variable results in control of swimmer's itch and affect the ecosystem at large. Personal preventative measures such as using protective suncream or DEET or recommending alternative bathing patterns (avoiding shallow areas, avoiding morning swim hours when highest risk occurs) have also been suggested (Soldánová et al., 2013).

Vibrio

Health problems caused by *Vibrio* species via bathing in Flanders are very rare. A monitoring program for *Vibrio* in Flemish bathing waters is therefore not justified. If a cluster of disease cases of *non- cholera Vibrio* (wound) infections would emerge in Flanders, reactive monitoring of suspected water bodies is important to help identify the source and prevent further cases. There is no standard method, but there are specialized laboratories available. When reactive monitoring is undertaken as a follow-up of cases, there are no water quality targets for safe/acceptable concentrations of *Vibrio* in bathing water. In the unlikely event that a *cholera* case would be notified with a case history that points to a specific bathing water, reactive monitoring of the suspected water body for the presence of *V. cholerae* should take place. If the suspicion (based on epidemiological and water quality investigation) is strong enough, a swim-ban should be considered, as well as a notification of the health system that endemic cholera is suspected.

3.2.4 Climate Change

No changes to the monitoring program are recommended to take into account climate change. This is due to the inherent uncertainty of the effects of climate change on the proliferation of pathogens in Flanders in the future. In addition, with the recommended surveillance system, changes in the observed frequency and/or intensity of reactive monitoring should trigger re-evaluation of the monitoring program. These changes can then be linked to changes in temperature, precipitation, water availability and bather behaviours. In this manner, changes to the monitoring program are based on specific, local evidence of the risk for specific pathogens.

3.2.5 Natural swimming pools

Natural swimming pools (NSPs), or natural recirculation pools, are artificially created recreational water bodies separated from surface- and groundwater with no disinfection systems (Casanovas-Massana et al., 2013). NSPs are characterized by a regeneration zone, where plants are present to treat the water biologically, and a recreation zone, where bathers have access (Giampaoli et al., 2014). The biodiversity, size of the biological population and size of the regeneration zone compared to the total volume and number of swimmers all determine the buffering capacity of the system (Giampaoli et al., 2014).

The main issue is that there is so little data published on NSPs – search of the Scopus database found only a few studies describing the microbial water quality. However the data we do have indicates increased risks as a result of small pool size (relative to other bathing water types), the potential for high bather loads (bathers/volume/time) with no protection against bather-to-bather transmission such as is required in swimming pools (Casanovas-Massana et al., 2013; Giampaoli et al., 2014), the purification techniques used that do offer limited protection against most pathogens (Bruns et al., 2019) and the influence of birds and other wildlife on the water quality (Casanovas-Massana et al., 2013). Overcrowding of a 'nature-like pond' was suspected of being the most probably cause of an outbreak of viral meningitis in 2001 in Germany (Hauri et al., 2005).

NSPs are not covered under the EU BWD and there are no EU directives dedicated to addressing the public health of NSPs (Giampaoli et al., 2014). As a result, individual countries or municipalities must determine what guidelines to use. In a review of NSPs done in 2014, guidelines from Germany, Austria, Switzerland, Italy and France were available (Giampaoli et al., 2014). In 2018 the Dutch National Institute of Public Health and the Environment (RIVM) investigated whether the microbiological quality of four semi-public natural swimming pools met the proposed requirements for public health (Schets et al., 2018). The water quality requirements were based on the German Research Society Landscape Development Landscaping (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, FLL) guidelines (FLL, 2011). The microbiology requirements were 100 CFU/100 ml for *E. coli*, 50 CFU/100 ml for intestinal enterococci, 10 CFU/100 ml for *P. aeruginosa* and <1 CFU/100 ml for *Staphylococcis aureus.* For a full overview of the water quality parameters, see appendix 1 from Schets et al. (2018).

The study found that the concentration of *E. coli* and *P. aeruginosa* were consistently low and exceeded the quality requirements only occasionally. However, in all natural swimming ponds tested, the concentration of *S. aureus* were high and exceed the requirements of <1 CFU/100 ml in 90 % of the samples (Schets et al., 2018). The study further found that the method required for the detection of *E. coli* (NEN-EN-ISO 9308-1:2014) was not suitable for natural swimming pools, as the background concentration of flora was too high (Schets et al., 2018). There were also problems with high background flora concentrations for the *P. aeruginosa* detection method (NEN-EN-ISO 16266:2008). The detection methods for both intestinal enterococci and *S. aureus* worked well. The study concluded that there was too little data to make a reliable, quantitative estimate of the possible health risk for bathers in natural swimming pools, which is in line with previous studies (Casanovas-Massana et al., 2013; Giampaoli et al., 2014).

Our recommendations in light of the limited data are to take a risk based approach to NSP in Flanders. A research could be conducted to monitor the microbial water quality over the bathing season, with an emphasis on busy/crowded swimming days when the risk is expected to be highest. A specific bathing water profile for NSPs could be drafted, included risk factors such as temperature, total number of bathers and recirculation requirements. A targeted health risk of (<5%) illness should be established.

3.3 EU Member state monitoring

The EU member states report monitoring as required by the EU BWD on their bathing water websites and in the legislation. Several member states have developed policies or conducted research into the bathing water pathogens that are studied in this report. Table 5 summarized the policies and research that were reported to us by these member states.

Table 5 EU Member states with additional monitoring than required by the EU BWD

EU Member State	Additional monitoring/warning
Finland	Finland monitors the parameters required by the EU BWD. In addition, bathing water outbreaks are now a part of the early notification system which is also used for drinking water outbreaks (T. Pitkänen, personal communication, September 11, 2019)
France	Specifically looked into *N. fowleri* and determined that the risk of exposure from bathing water was low due to the rarity of the disease. The research determined that the best course of action was to prevent exposure by limiting recreational activities in warm or heated water (ANSES, 2014).
Germany	The German Environmental Agency (Umweltbundesamt) has recommended that the public and public health officials be warned of increased risk of infection from *Vibrio vulnificus* when bathing water temperatures are above 20 °C (Szewzyk, 2009). Notification of public health officials improves the ability for doctors to recognize *V. vulnificus* as a possible cause of infections. In addition, at least one state website (Bremen), issued warnings for increased risk of exposure to *Trichobilharzia*, however no other information regarding monitoring protocols were available.
Hungary	Sampling is part of a sanitary survey, where it is also required to check for the presence of tar, glass, plastic, rubber or other waste on the beach, and the proliferation of phytoplankton and macrophytes. If previous experience or the bathing water profile indicates the risk of cyanobacterial proliferation, visual signs of algal bloom are also checked (reduced transparency, foaming, discoloration of the water). If visual signs are present, water should be sampled and tested for the following parameters: microscopic analysis of the phytoplankton, cyanobacterial cell count and chlorophyll-a. If the analysis indicates a health risk (chlorophyll a concentration is above 50 µg/L, microscopy confirming cyanobacterial dominance and the presence of potentially microcystin producing species, and the cyanobacterial count is over 100 000 cells/ml), microcystin should also be measured. The water quality target value for bathing prohibition is 20 µg/L microcystin-LR. (M. Vargha, personal communication, September 11, 2019)
Italy	Performs monitoring of toxic cyanobacteria, Ostreopsis ovata, macroalgae and phytoplankton (L. Bonadonna, personal communication, September 11, 2019)
Netherlands	The Netherlands has developed a questionnaire system, where the National Institute of Public Health and the Environment (RIVM) sends a (digital) questionnaire at the end of the bathing season requesting local health departments (infectious disease jurisdiction) and provinces (bathing water quality jurisdiction) to enter the bathing water related health complaints they have received/noted. RIVM compiles this information into an annual surveillance overview (F.M. Schets & A.M. de Roda Husman, 2017). This system improves the ability to detect, notify and survey the occurrence of common, mild health problems which may otherwise be underreported. The questionnaire itself is not public, however the publication by Schets et al. (2017) *Gezondheidsklachten door recreatiewater in de zomers van 2014, 2015 en 2016* gives insight into the types of questions posed to the local health departments. For cyanobacteria, baseline monitoring is biweekly visual inspection for cyanobacterial layers on the water body and sampling with analysis of cyanobacterial biovolume or

phycocyanine (cyano-chlorophyll) sensing (Stowa, 2012). When the layer becomes more dense and/or monitoring shows an increase of biovolume (beyond 2.5 mm^3/l) or cyano-chlorophyll (>12.5 µg/L), the monitoring frequency is increased to weekly and the water is classified as 'low health risk' and warning signs are placed to inform bathers (see Appendix p. 44). The cyano-chlorophyll analysis is accompanied by microscopic analysis to estimate the percentage of toxin-producing cyanobacteria species. The cyano-chlorophyll concentration may be 'corrected' for the percentage of non-toxin producing cyanobacteria as indicated by microscopy. When the layers become even more dense/scum and/or monitoring shows biovolume above 15 mm^3/l or cyano-chlorophyll above 75 µg/L (provided the percentage of microcystin-producing cyanobacterial species is >75%), the bathing water is classified as 'health risk' and a 'negative swimming-advice' is issued. Samples may also be analysed for microcystin and if microcystin concentration exceeds 20 µg/L, the 'health risk' classification remains. When the microcystin concentration is (or falls) below 20 µg/L, the classification is lowered to 'low health risk'. The Netherlands is in the process of updating this protocol to also incorporate PCR-based methods.

The Netherlands has a reactive monitoring approach to swimmer's itch complaints, with analysis of the presence of infected host snails and/or cercaria by PCR (Grontmij Nederland BV, 2011). For botulism via water, water authorities can be the coordinator that is notified if unexpected bird or fish mortality is observed and coordinates the response: the institution that is responsible for the specific water body removes the cadavers and delivers them to a destructor.

Spain

Our contact in Spain collected responses to our email from various districts and one district (Castilla la Mancha) reported that it monitors for *P. aeruginosa, N. fowleri/Acanthamoeba* and microcystins (M. Palau Miguel, personal communication, September 16, 2019). No further information was provided on the monitoring protocols. A study by the Andalusian Health Service, on the *Determination and characterization of Vibrio spp in surface waters of the coast of the province of Cádiz* in 2017, found a correlation between temperature and *Vibrio* concentrations. The highest counts were at 25 °C , but *Vibrio* were found in the range of 15-28 °C. The study recommended monitoring *Vibrio* spp. in seawater, however in light of the available data the risk of illness was determined to be very low and a monitoring program was not initiated (M. Palau Miguel, personal communication, September 16, 2019).

Sweden

Had investigated the use of bacteriophages for recreational monitoring but in the end did not go forward with bacteriophage monitoring (T. Westrell personal communication, August 30, 2019)

United Kingdom

"If we observe an algal bloom we will take samples to confirm species and density but these are only occasional. We make daily pollution risk forecasts at all bathing waters where we believe there is validity in doing so. These include advice against bathing where our forecasts predict reduced water quality and for most of these locations this is accompanied by beach managers displaying warning signs. Forecasts are made from rain, tide and other factors that are shown to have a relationship with water quality and are displayed on our bathing water data explorer: https://environment.data.gov.uk/bwq/profiles/" (K. Hedges, personal communication, September 11, 2019).

3.4 Risk determinants of harmful algal blooms

Phytoplankton (cyanobacteria and microalgae) occur naturally in bathing waters and sometimes grows in excessive amounts (algal blooms). When these blooms cause harm to human and animal health, aquatic ecosystems, and local economies, we refer to them as harmful algal blooms (HABs). HAB species may produce toxins that can accumulate in the water, food chain and/or in seafood. Several human diseases have been reported to be associated with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria (WHO, 2003). Exposure to HAB toxins from recreational water sources can occur via oral exposure (incidental ingestion while recreating); dermal exposure (contact of exposed parts of the body with water containing HAB toxins during recreational activities such as swimming, wading, or water skiing); and inhalation exposure to contaminated aerosols (while recreating). Indirectly, exposure can occur through consumption of (sea)food in which HAB toxins have accumulated (Wang, 2008). Due to eutrophication (nutrient enrichment) and climate change, HABs tend to increase in frequency, magnitude and duration worldwide (Brandenburg et al., 2019; Huisman et al., 2018; Wells et al., 2015). Since these processes are quite complex, we highlight the most important associated drivers here.

Nutrients

Changes in the nature of human activity (from agricultural to industrial water use) resulted in increased pollution of water resources. Already in the 1960's and 1970's, research on eutrophication of freshwater systems indicated the strong link between inorganic nutrients and algal growth (Schindler, 1974; Vollenweider, 1968). Enrichment with inorganic nutrients (e.g. ammonia, nitrate and phosphate) is a key driver of occurrence of HABs (Anderson et al., 2002; Smith et al., 2009). Furthermore, changes in nutrient supply ratios (e.g.: Si:N, N:P) may favour certain HAB species (Anderson et al., 2002). In general, HABs can be expected to increase upon eutrophication of inland waters (Paerl et al., 2001) and coastal zones (Heisler et al., 2008). In terms of management, nutrient reduction measures have proven to be among the most effective measures to control HABs (Fastner et al., 2016; Huisman et al., 2018; Paerl et al., 2001; WHO, 2003).

Temperature

Within certain biological limits, increasing temperatures increase growth rates. Hence increasing global temperatures enhance algal growth rates, including HAB species (Paerl et al., 2008). Particularly in higher latitude regions, where optimum growth temperatures typically are above annual mean temperatures, algal growth may become enhanced (Visser, Verspagen, et al., 2016). Furthermore, the period of the year during which favourable growth temperatures occur will be longer at higher latitudes. Therefore growth rates of HAB species isolated at higher latitudes consistently increase with increasing temperatures (Brandenburg et al., 2019). On the other hand, HABs have been reported to terminate once surface water temperatures fall below certain critical values (Hallegraeff et al., 1995). In addition to temperature effects on HABs, temperature changes also lead to range shifts of species: HAB species that previously only occurred at lower latitudes, such as (sub)tropical cyanobacteria and dinoflagellates, are now invading temperate regions (Wells et al., 2015).

Dissolved carbon dioxide (CO_2)

HAB species that have the ability to take up other inorganic carbon species than CO_2 can save energy, whereas species that rely on uptake of CO_2 are carbon limited, meaning that an increase of CO_2 will stimulate photosynthesis (Ibelings et al., 1998). Therefore a consistent increase in growth at elevated CO_2 levels is observed for both marine HAB species (Brandenburg et al., 2019) and cyanobacteria (Visser, Verspagen, et al., 2016).

Salinity

Species have different preferences with respect to salinity and tolerance of higher or lower salinities. Therefore, with respect to HABs, different and species-specific responses have been observed. For some brackish-water species higher salinities have been found to associate with blooms of dinoflagellate HABs (Brandenburg et al., 2017). On the other hand, increased rainfall has been reported to trigger HABs (Hallegraeff et al., 1995), although this may not only be linked to salinity but also to e.g. increased nutrient run-off. In view of the climatological and hydrological situation in Flanders, salt water intrusion (Brandenburg et al., 2017) and drought-induced increase in salinity may favour development of salt-tolerant HAB species.

Mixing regime

HABs usually develop in a stable water column. Stable water columns develop under low wind speeds, and in thermally stratified lakes. In temperate climates, climate change will cause an earlier onset of stratification in thermally stratified systems, and a longer period of thermal stratification, favouring buoyant species (Visser, Verspagen, et al., 2016). Decreasing wind speeds have been associated with bloom development (Brandenburg et al., 2017), whereas increasing wind speeds have been reported to terminate existing blooms (Hallegraeff et al., 1995). Enhanced mixing might therefore be effective in combating species that form a buoyant (scum) layer, or species that are vulnerable to disturbance by turbulence. Increased flushing (shorter residence times) and artificial mixing have indeed been proven to be effective techniques in the control of HABs (Huisman et al., 2018; Paerl et al., 2001; Visser, Ibelings, et al., 2016).

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I EU Bathing Water Directive Water quality targets

ANNEX I

For inland waters

	A	B	C	D	E
	Parameter	**Excellent quality**	**Good quality**	**Sufficient**	**Reference methods of analysis**
1	Intestinal enterococci (cfu/100 ml)	200 ([1])	400 ([1])	330 ([2])	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	500 ([1])	1 000 ([1])	900 ([2])	ISO 9308-3 or ISO 9308-1

For coastal waters and transitional waters

	A	B	C	D	E
	Parameter	**Excellent quality**	**Good quality**	**Sufficient**	**Reference methods of analysis**
1	Intestinal enterococci (cfu/100 ml)	100 ([3])	200 ([3])	185 ([4])	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	250 ([3])	500 ([3])	500 ([4])	ISO 9308-3 or ISO 9308-1

([1]) Based upon a 95-percentile evaluation. See Annex II.
([2]) Based upon a 90-percentile evaluation. See Annex II.
([3]) Based upon a 95-percentile evaluation. See Annex II.
([4]) Based upon a 90-percentile evaluation. See Annex II.

Figure 1 Required parameters for monitoring bathing waters - Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC

II Pathogen Long List

Table 6 Reasons for exclusion and exclusion code for full list of pathogens in recreational waters

Exclusion Code	Reason for Exclusion
1	Enteric pathogen that is included indirectly by the (reference pathogen), that is generally present in higher concentrations in wastewater and faecally contaminated bathing waters and equally or more persistent in water and water treatment
2	Not endemic in Flanders
3	Transmission through bathing waters not reported
4	Relevant for pools, insignificant for natural surface water
5	transmission through swimming possible, but this transmission route is reported in tropical countries but not in Flanders or other high-sanitation and hygiene countries
6	Potential for transmission via swimming, but very rare
7	Transmission is mainly through (soil in) contact with animal faeces
8	Transmission route unclear

Table 7 Full list of pathogens excluded including pathogen type and reason for exclusion

Pathogen	Pathogen Type	Exclusion Code (Table 6)
Arcobacter	Bacteria	1 (*Campylobacter*)
Ascaris spp.	Helminth	5
Balamuthia mandrillaris	Free-living amoebae	3 (source CDC)
Balantidium coli	Protist	1 (*Cryptosporidium/Giardia*)
Blastocystis	Protist	1 (*Cryptosporidium/Giardia*)
Clonorchis sinesis, opisthorchis spp., metorchis spp	Helminth	2, 3 (source CDC)
Cyclospora cayetanensis	Protist	1 (*Cryptosporidium/Giardia*)
Diphyllobothriidae	Helminth	3 (source CDC)
E. coli O157	Bacteria	1 (*Campylobacter*)
Echinococcus spp	Helminth	5, 7 (source CDC)
Entamoeba histolytica	Protist	1 (*Cryptosporidium/Giardia*)
Enteroviruses	Virus	1 (Norovirus/Adenovirus)
Epidermophyton floccosum	Fungi	4
Francisella tularensis	Bacteria	6
Guinea worm	Nematode	2
Helicobacter pylori	Bacteria	1 (*Campylobacter*)
Hepatitis A	Virus	1 (Norovirus/Adenovirus)
Heterophyidae and echinostomatidae	Helminth	3 (fish-borne, source CDC)
Hookworms	Helminth	3
Legionella spp.	Bacteria	4
Listeria	Bacteria	3
Microsporidia	Protist	1 (*Cryptosporidium/Giardia*)
Molluscipoxvirus	Virus	4
Mycobacterium	Bacteria	3
Nematodes	Nematode	5
Papillomavirus	Virus	4
Paragonimus spp.	Helminth	2, 3
Plasmodium spp	Protozoa	3
Polyomavirus	Virus	8 (source GWPP)
Rotavirus	Virus	1 (Norovirus/Adenovirus)
Salmonella typhi	Bacteria	2, 1 (*Campylobacter*)
Schistosomiasis	Trematode	2
Shigella spp.	Bacteria	1 (*Campylobacter*)
Staphylococcus	Bacteria	4
Taenia spp.	Helminth	5
Toxocara spp.	Helminth	7
Toxoplasma gondii	Protist	5, 1 (*Cryptosporidium/Giardia*)
Trachoma	Bacteria	5
Trichophyton spp.	Fungi	4
Trichuris trichiura	Helminth	3

III PRISMA Diagram

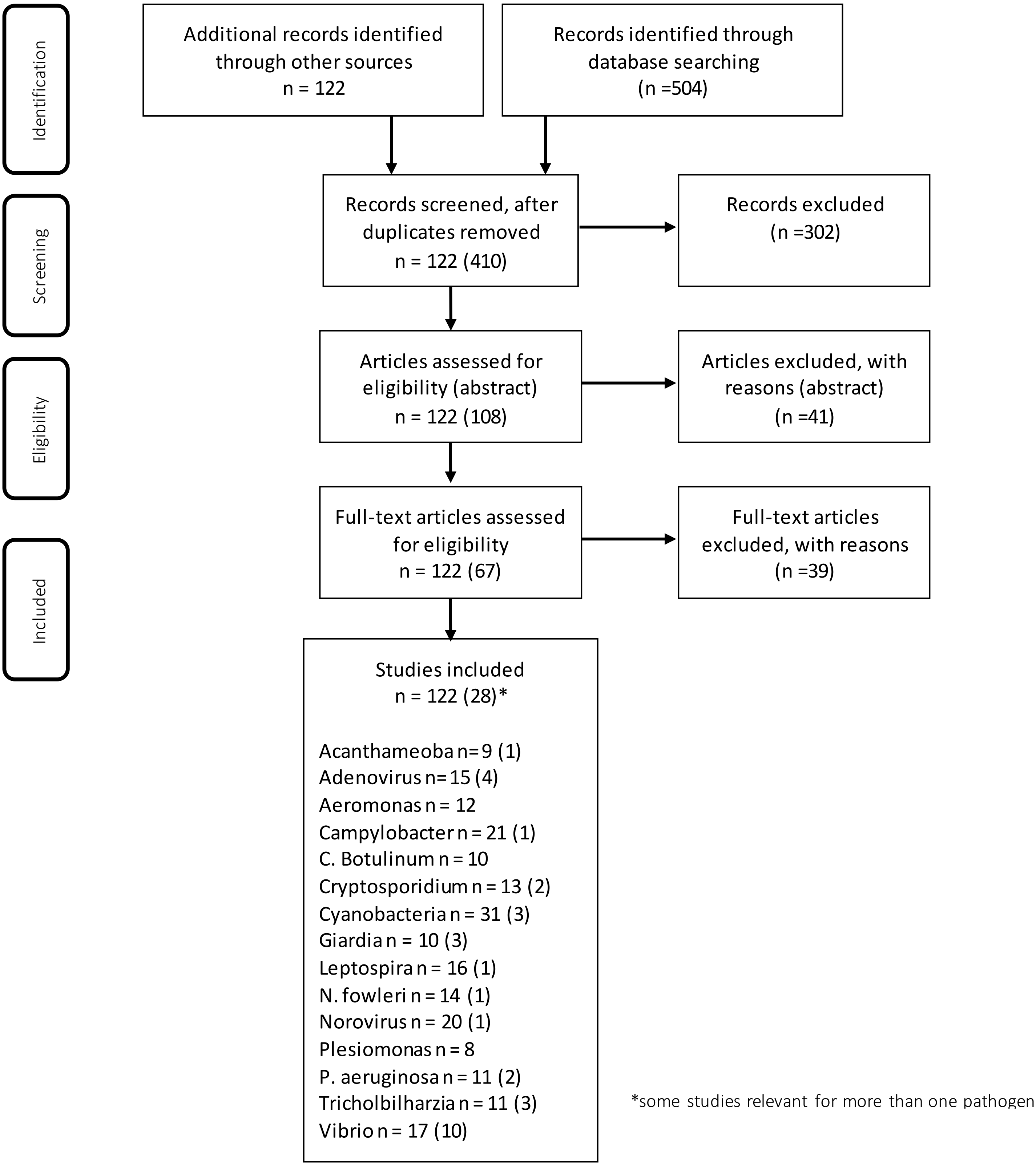


Figure 2 PRISMA diagram for literature search for pathogen information and climate change. Studies in brackets () are new studies found through limited literature search after 2010 for general pathogen information and studies found after 2018 for climate change data.

IV Email template to EU bathing water contacts

Subject: Query about bathing water safety

Dear ….

I hope you are enjoying an uneventful bathing season in your country.

We are conducting a project on bathing water safety for the Flanders (Belgium) government, particularly about microbial health hazards that are not covered by monitoring for faecal indicators. We would like to inform them about risk management practices in other European countries regarding the non-faecal bathing water hazards. We are specifically looking at:

- Toxic cyanobacteria
- Botulism
- Swimmer's itch (*Trichobilharzia*)
- *Leptospira*
- *Vibrio*
- *Pseudomonas aeruginosa*
- *Naegleria fowleri/Acantamoeba*
- *Plesiomonas/Aeromonas*

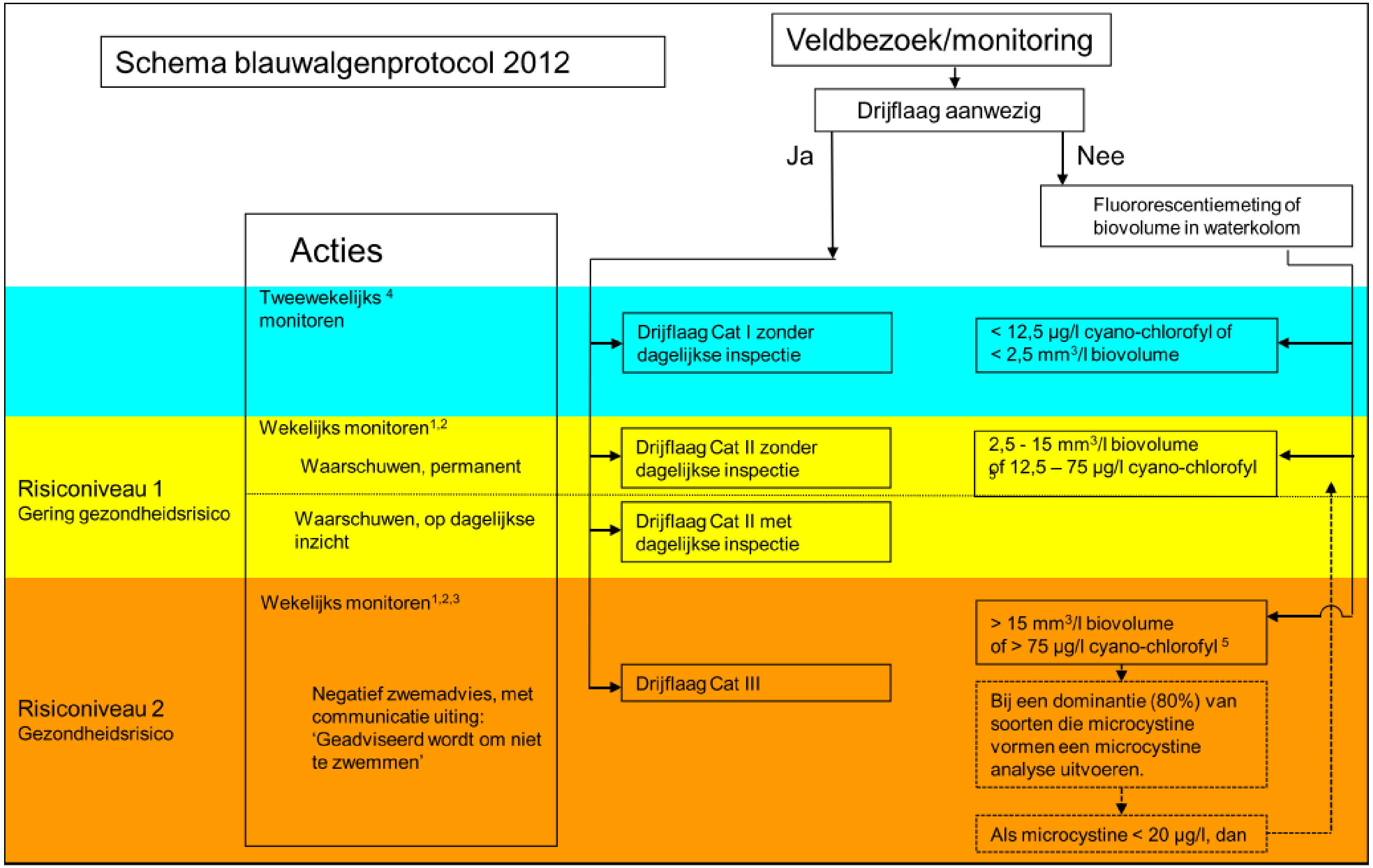
We can inform them about the practices in the Netherlands (the tiered cyanobacteria monitoring and no swim advisory approach; the monitoring for avian mortality and removal of dead birds; complaint driven monitoring for *Leptospira*/rats, or *Trichobilharzia*, Ps ear; no swim advisories in thermally polluted waters), but are less/not familiar with practices in your country.

We would highly appreciate it if you could inform us about any such practices in your country. Is there any monitoring (microbial or non-microbial (dead birds/rats/…)) beyond the requirements in the bathing water directive? We are asking several EU countries and can share the collected information with you.

Best regards,

Prof. G.J. (Gertjan) Medema, PhD

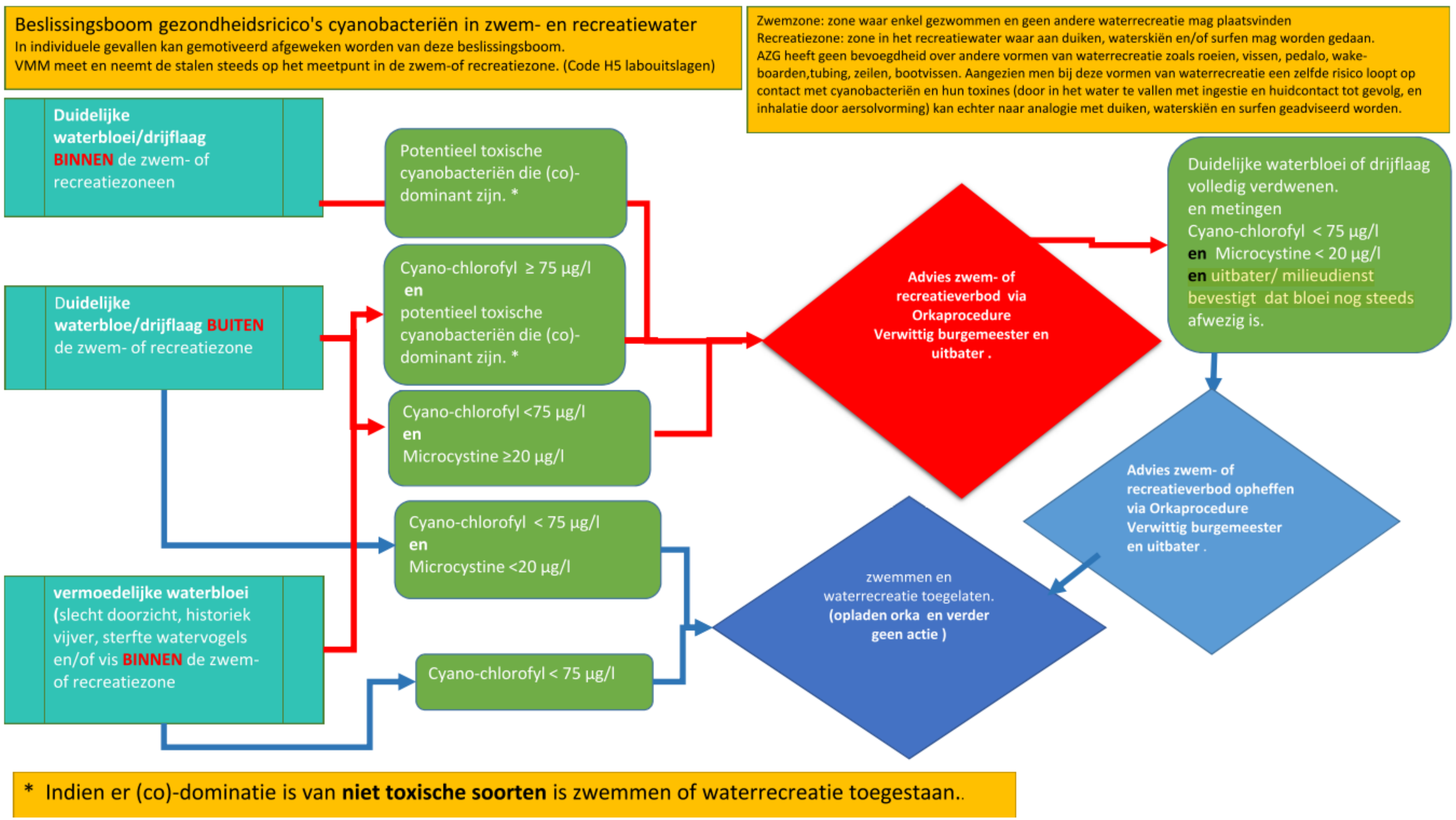
V Blauwalgenprotocol



[1] Dagelijkse visuele inspectie verdient de voorkeur
[2] Bij drijflagen van categorie II of III volstaat visuele inspectie als monitoring
[3] Wanneer Risiconiveau 2 voor langere periode geldt en de verwachting (van waterbeheerder en provincie) is dat de situatie niet zal wijzigen, kan overwogen worden de monitoringsfrequentie te verlagen naar twee wekelijks
[4] Op basis van expert judgement (bijvoorbeeld aanwezigheid drijflaag cat I, ervaring uit het verleden, verwachtingen weer) kan de monitoringsfrequentie worden verhoogd naar wekelijks.
[5] Fluorescentiemeting mag worden gebruikt, wanneer op basis van expert judgement en een quick scan van de samenstelling van blauwalgen aangenomen mag worden dat de

Source: Stowa, 2012

VI Decision tree for health risk from cyanobacteria in swimming and recreational waters



Source: P. Schapmans, personal communication, November 4, 2019