Technical Report for Narrative Review in support of the NHMRC Recreational Water Quality Guidelines: Microbial Risks

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Executive Summary

Background

The National Health and Medical Research Council (NHMRC) has commissioned Ecos Environmental Consulting P/L (Ecos) to conduct this Technical Report as part of a narrative review on microbial risks in recreational waters that will be used to update the *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) (the Guidelines).

Microbial risks in recreational waters may arise from a range of point and non-point (diffuse) sources in the catchment area of the particular recreational water body. For the update to the Australian recreational water guidelines, NHMRC considers it important to determine if there are any site-specific issues that could lead to higher exposures or types of microbial pathogens that may be problematic in most recreational water use situations.

Methods

The review process followed a research protocol methodology developed specifically for this narrative review (O'Connor, 2020). The protocol involved a systematic search of several international databases of primary scientific research literature (Scopus, Web of Science, PubMed, Google Scholar) using search strings constructed from an extensive key word list. In addition to primary research literature, a search of grey literature, including existing recreational water quality guidelines and/or reports, was undertaken.

The search strings were constructed to identify literature citations relevant to a primary research question and two secondary research questions supplied by NHMRC's Recreational Water Quality Advisory Committee (the Committee). The primary research question was:

> *How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?*

The secondary questions were:

(i). What are the indicators/surrogates of this/these risk/s?

(ii). What are the current practices to minimise or manage this/these risk/s?

To assist in appropriate assessment of the literature, the search results were classified into two broad categories; (i) primary studies that were largely peer-reviewed journal articles and (ii) grey literature which were mainly regulatory guidelines or technical guidance publications produced by federal and state agencies in support of regulatory compliance goals.

The publication date-range for inclusion was from 2003 to October 30th, 2020.

The methodological quality of grey literature was assessed using administrative and technical criteria via an assessment tool which was developed by NHMRC based on common domains for assessing guidelines and systematic reviews such as the Appraisal of Guidelines, Research and Evaluation (AGREE) tool. For primary studies, a critical appraisal tool was used to undertake a quality assessment. The tool was

based on approaches described by the Critical Appraisal Skills Program (CASP, Oxford CVTH, 2020) with a risk of bias rating similar to that used in the US Office of Health Assessment and Translation (OHAT) Risk-of-Bias Tool (OHAT, 2015).

A process based on the OHAT approach to using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system was used to assess the certainty of the body of evidence from primary studies and permit upgrading or downgrading of the body of evidence, as appropriate (OHAT, 2019).

Results

Searches for grey literature identified 38 documents. Each document was evaluated for its relevance to the primary and secondary research questions and if not relevant was screened out. This process identified 16 grey literature documents relevant to the primary and secondary research questions. Following quality assessments, 10 documents were considered ineligible on quality grounds, leaving six grey literature documents for evaluation and synthesis.

For primary studies, search results by database yielded 7381 citations initially and after removal of duplicates the numbers was 2563. Further screening using relevancy and logical exclusion criteria (e.g. limiting studies to comparable Organisation for Economic Co-operation and Development [OECD] countries) to control the volume of literature to review, identified 42 studies for final detailed assessment. These studies were assessed for eligibility on the basis of quality, including risk of bias, which resulted in 13 studies remaining for evaluation and synthesis.

For the six grey literature documents and 13 primary studies eligible for evaluation, data for evaluation was extracted from each document into standard forms developed for the purpose. The information contained in the quality assessment and data extraction forms was used in the accompanying Evidence Evaluation Report for this narrative review (O'Connor, 2022).

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Glossary

ADWG	Australian Drinking Water Guidelines
AGREE	Appraisal of Guidelines for Research and Evaluation
AGWR	Australian Guidelines for Water Recycling
AHMC	Australian Health Ministers Conference
AMR/AMRB	Antimicrobial resistance / Antimicrobial resistant bacteria
BAV	Beach action value
BMDL	Benchmark dose level
BWD	Bathing Water Directive
CASP	Critical Appraisal Skills Programme
CDC	Centre for Disease Control and Prevention
CI	Confidence interval
CRD	Centre for Reviews and Dissemination
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	Combined sewer overflow
DALY	Disability-adjusted life years
DEFRA	Department for Environment, Food and Rural Affairs
DNA	Deoxyribonucleic acid
DWO	Dry weather overflow
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
EDC	Endocrine-disrupting chemical
EEA	European Environment Agency
EER	Experiment-wise error rate
enHealth	Environmental Health Standing Committee
EPA	Environmental Protection Agency
EPHC	Environment Protection and Heritage Council
EU	European Union
FIB	Faecal indicator bacteria
FIO	Faecal indicator organism
GI	Gastrointestinal illness
GRADE	Grading of Recommendations Assessment, Development and Evaluation
GWPP	Global Water Pathogen Project
HAdV	Human Adenovirus
HTS	High-throughput sequencing
ISO	International Organization for Standardization
LLOQ	Lower limit of quantification
MAC	Microbial water assessment categories
MoA	Mode of action
MRC	British Medical Research Council
MST	Microbial source tracking
NHMRC	National Health and Medical Research Council
NIWA	National Institute of Water and Atmospheric Research
NoV	Norovirus
NRMMC	National Resource Management Ministerial Council

NSW DPIE	New South Wales Department of Planning, Industry and Environment
NZ MoE	New Zealand Ministry of Environment
NZ MoH	New Zealand Ministry of Health
OECD	Organisation for Economic Co-operation and Development
OHAT	Office of Health Assessment and Translation
OR	Odds ratio
OTU	Operational taxonomic units
PAH	Polycyclic aromatic hydrocarbons
PCR/qPCR	Polymerase Chain Reaction / Quantitative Polymerase Chain Reaction
PECO	Population, Exposure, Comparator, Outcome
PHE	Public Health England
PLOQ	Process limit of quantification
POD	Point of departure
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QMRA	Quantitative Microbial Risk Assessment
RBT	Risk-based threshold
RCIT	Recreational Criteria Implementation Tools
RCT	Randomised controlled trial
RfD	Reference dose
RI	Respiratory illness
RNA	Ribonucleic acid
RoB	Risk of bias
RSD	Relative standard deviations
RWQAC	Recreational Water Quality Advisory Committee (the Committee)
RWQC	Recreational Water Quality Criteria
SEPP	State Environment Protection Policy
STP	Sewage treatment plant
TTC	Threshold of toxicological concern
UNEP	United Nations Environment Programme
UNEP MAP	United Nations Environment Programme Mediterranean Action Plan
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
WHO	World Health Organization
WWO	Wet weather overflows
WWTP	Wastewater Treatment Plant

1 Introduction

The National Health and Medical Research Council (NHMRC) has commissioned Ecos Environmental Consulting P/L to develop research protocols and conduct narrative reviews on two of four research topics that will be used to update the *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) (the Guidelines).

The two research topics to be addressed by Ecos are Microbial Risks and Chemical Hazards (the other two topics Cyanobacteria and algae, and Free-living Organisms will be addressed elsewhere). This document addresses Microbial Risks.

Ecos previously developed a research protocol to guide the review of the evidence (O'Connor, 2020) which set out the methods to be used for the review including the research questions, population groups, health outcomes of interest, and a structured search and evaluation strategy. This Technical Report documents the results obtained using the described methods and contains the detail (e.g. lists of search results, pages of search strings, tabulated reviews of key references) that would otherwise make the related Evidence Evaluation Report difficult to read.

1.1. Purpose and objectives of review

The purpose of the Microbial Risks review is to inform the update to Chapter 5 of 2008 NHMRC Guidelines (NHMRC, 2008) and any relevant sections throughout the rest of the document with respect to the microbial risks associated with the recreational use of water. Specifically, the review will provide NHMRC with an independent body of evidence to assure that the revision of the Guidelines is based on the most up-to-date and relevant scientific literature.

2 Research Protocol

2.1. Review period

Publications from 2003 onwards were considered for the review. Although the existing 2008 NHMRC Guidelines were published in 2008, extending the date range back earlier was done to assist in locating any documents that may have been overlooked, or have become recognised as being of greater importance since that time, or missed the cut-off period during the preparation of the Guidelines.

2.2. Definitions

In this Technical Report, “microbial risk” refers to risk associated with the contamination of the water by frank human pathogens, mostly of faecal origin, and excludes risk associated with free-living microorganisms such as saprozoic bacteria and protozoa which are generally considered as opportunistic pathogens (these are to be covered in separate reviews).

Definitions of types, uses and users of recreational water is given in **Appendix 1**.

2.3. Research Question/s

The research questions that form the basis of this review were developed by the NHMRC Recreational Water Advisory Committee (the Committee). There is one primary question and two secondary questions.

2.3.1. Primary question

The primary question is: *How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?*

To answer the primary question the Committee provided the following guidance points:

- Provide examples of what is done in Australian and international jurisdictions and their reasoning.
- Determine what is done in other settings and how this relates to the Australian context.
- Determine how specific target populations such as children, immunocompromised or the elderly are impacted.
- Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).
- Identify gaps and opportunities to design a risk assessment framework that would provide an estimation of the risk truly reflective of adverse health outcomes in various settings relevant to the Australian context.

2.3.2. Secondary questions

The secondary questions are:

(i) *What are the indicators/surrogates of this/these risk/s?*

Committee guidance points:

- Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters
- Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.

(ii) *What are the current practices to minimise or manage this/these risk/s?*

Committee guidance points:

- Provide examples of how mitigation strategies have been developed based on scientific evidence.
- Provide examples/case studies of how this is achieved/implemented in settings relevant to the Australian context.

2.4. Search Strategy and Selection of Evidence

2.4.1. Overview

The specific steps involved in finding and selecting the evidence for review were:

- Preparation of a list of keywords (search terms) (Appendix 2) for approval by the Committee;
- Classification of the list into logical categories related to population, location, study type, property or attribute, method, health outcome, carrier (type of water), exposure pathway (includes split into sub-categories) and source. The classification was performed to assist in composing search strings;
- Development of search strings based on the keywords and preparing combinations of strings to create search strategies;
- Using the composed search strategies to search key life-science literature databases (Scopus, Web of Science, PubMed) and the general technical literature database, Google Scholar;
- In addition to the above literature, a search of grey literature, including existing recreational water quality guidelines and/or reports, was undertaken based on a list provided by members of the Committee (Appendix 3) plus a search of websites of key international environmental and public health agencies (e.g. WHO, US EPA);
- Lists of retrieved publications were exported to Microsoft Excel spreadsheets and sorted and filtered based on relevancy and quality, including risk of bias, using methods described in detail in subsequent sections below; and
- Shortlisted literature was imported from Excel into a bibliographic software package (Zotero) for management of associated PDF documents and for reporting on the results of the literature search.
- The shortlisted literature was subject to further screening during the quality assessment steps (Sections 2.5 and 2.6).

2.4.2. Keywords and search strings

An extensive list of keywords relevant to recreational water quality (Appendix 2) was composed and included in the research protocol (O'Connor, 2020) which was approved by the Committee. To aid in the effectiveness of the search process, the keyword list was classified into logical categories consistent with a risk assessment exposure pathway approach (Table 2-1). Categories included were population, location, study type, property or attribute, method, health outcome, carrier (type of water), exposure pathway (includes split into sub-categories) and source.

For each category, search strings composed of a series of keywords that described related sub-categories of items. Within search strings, keywords were linked by the logical operators "OR" or "AND" as appropriate. Quotation marks were used to encapsulate keywords that consisted of more than one word. Certain groups of keywords that were variations of a root term were represented by an asterisk (*) which acted as a wildcard for any of those terms (e.g. gastro* for gastroenteritis, gastrointestinal).

Table 2-1. Keywords, search categories, and search strings

No.	Category	Strings
1	Population	"aboriginal" OR "infant*" OR "children" OR "pregnant women" OR "angler*" OR "athlete*" OR "diver*" OR "elderly" OR "immunocompromised" OR "indigenous" OR "kayaker*" OR "surfer*" OR "Torres Strait Islander" OR "tourist*"
2	Definition	"analysis" OR "classification" OR "exposure" OR "jurisdiction" OR "legislation" OR "prevention" OR "recreation" OR "recreational water quality" OR "water recreation" OR "risk" OR "risk assessment" OR "source vulnerability"
3	Study type	"cohort study" OR "cross-sectional study" OR "diagnostic test study" OR "systematic review" OR "epidemiology" OR "control" OR "standards" OR "recreational guidelines"
4	Location	"recreational water*" OR coast* OR "dam" OR estuar* OR freshwater* OR "lake" OR "river" OR "saline water*" OR beach* OR "water park*" OR "marine" OR "pool" OR "surface water*" OR "watershed" OR "catchment" OR "wetland"
5.1	Outcomes1	"adverse effect*" OR "allergic reaction*" OR "amoebiasis" OR "antimicrobal resistance" OR "dermal irritation" OR dermatologic* OR "diarrhea" OR "diarrhoea" OR "disease" OR "enteric fever*" OR "eye irritation" OR "fever" OR "flu-like" OR gastro*
5.2	Outcomes2	"hay fever-like" OR "headache" OR "health" OR "health effect*" OR "health outcome*" OR "hepatotoxicity illness*" OR "induction of asthma" OR "inhalation-related symptoms" OR "leptospirosis" OR "nausea" OR "symptoms" OR "vomiting" OR "respiratory"
5.3	Outcomes3	"outbreak*" OR "pneumonia-like symptoms" OR "pruritis" OR "randomised controlled trial" OR "salmonellosis" OR "shigellosis" OR "shortness of breath" OR ("skin" AND (rash* OR irritation)) OR "ocular"
6	Methods	"16s microbial community fingerprinting" OR "direct pathogen monitoring" OR "QMRA" OR "quantitative microbial risk assessment" OR "source tracking" OR "microbial source tracking" OR "DALY" OR "disability adjusted life year" OR "dose-response" OR "case control study"
7	Exposure pathway 1	"ingestion" OR "inhalation" OR neurologic* OR "neurotoxicity" OR "non-point source pollution" OR "oral" OR "point source pollution" OR "primary contact recreation" OR recreation* OR "recreational exposure" OR "secondary contact recreation"
8	Exposure pathway 2	"f?ecal discharge" OR "aerosols" OR "accidental f?ecal discharge" OR "sewage" OR "stormwater" OR "water contamination" OR "water pollution" OR ("f?ecal" AND ("contamination" OR "pollution" OR sample*))
9	Exposure pathway 3	cattle* OR "waterfowl" OR "zoonotic" OR "domestic animals" OR "livestock" OR seagull* OR gull* OR "wildlife"
10	Exposure pathway 4	bather* OR "bather acquired" OR "bather shedding" OR "bathing" OR "bathing beach*"

No.	Category	Strings
11.1	Exposure pathway 5.1	"angling" OR ("body-" AND ("boarding" OR "surfing")) OR "bodyboarding" OR "bodysurfing" OR "boating" OR "canoeing" OR "diving" OR "fishing" OR ("fishing" AND ("canoe" OR "kayak" OR "riverbank" OR "shoreline" OR "wading")) OR "jet skiing" OR "jet-skiing"
11.2	Exposure pathway 5.2	"outfall" OR "paddling" OR "parasailing" OR "pentathlon" OR "rowing" OR "sail boarding" OR "sailing" OR "sand" OR "scuba" OR "sea kayaking" OR "snorkelling" OR "spearfishing" OR "sunbathing" OR "surfing" OR "kayaking" OR "kiteboarding"
11.3	Exposure pathway 5.3	"swimmer acquired" OR "swimming" OR "triathlon" OR "wading" OR "wakeboarding" OR "water skiing" OR "water-skiing" OR "water sports" OR "wave-boarding" OR "whitewater canoeing" OR "wind surfing" OR "wind-surfing" OR "kitesurfing"
12	Source organism 1	"viruses" OR microb* OR "pathogen" OR "waterborne" OR "waterborne diseases"
13	Source organism 2	adenovirus* OR "astrovirus" OR "bacteriophages" OR "caliciviruses" OR "echovirus" OR "enteroviruses" OR ("Hepatitis" AND ("A" OR "E")) OR "norovirus" OR "norwalk virus" OR "papillomavirus" OR "polioviruses" OR "polyomavirus" OR "rotavirus" OR "sapovirus"
14	Source organism 3	"Balantidium" OR "Blastocystis" OR "Cryptosporidium" OR "Cyclospora cayetanensis" OR "Cystoisospora belli" OR "Isospora belli" OR "Entamoeba histolytica" OR "Giardia" OR "Microsporidia" OR "protozoa" OR "Toxoplasma gondii"
15	Source organism 4	"antibiotic resistant bacteria" OR "Acinetobacter" OR "Aeromonas" OR "Bacteroides" OR "Moraxella" OR "Pseudomonas aeruginosa" OR "Stenotrophomonas"
16.1	Source organism 5.1	"Arcobacter" OR bacteria* OR "bacteriodales" OR "Campylobacter" OR "Cholera biotypes" OR "Clostridium perfringens" OR ("*E. coli*" AND ("diarrhoeagenic" OR "enteropathic" OR "enterotoxigenic" OR "O157:H7"))
16.2	Source organism 5.2	"*E. coli*" OR "enterococci" OR "Enterococcus" OR "Escherichia coli" OR "Helicobacter pylori" OR "Leptospira" OR "Salmonella" OR "Shigella" OR "Vibrio" OR "Yersinia"
17	Source organism 6	"Ascaris" OR "Clonorchis sinensis" OR "Diphyllobothriidae" OR Echino* OR "Heterophyidae" OR "Hookworms" OR "Intestinal Flukes" OR "Liver Flukes" OR "Metorchis" OR "Opisthorchis" OR "Paragonimus" OR "Schistosoma" OR "Taenia" OR "Toxocara"
18	Source organism 7	"Trichuris trichiura" OR (("non-microbial" OR f?ecal) AND "indicator*") OR "FIB"

Table footnotes: "*" = wildcard, i.e. accept any following characters, "?" = ignore character if present, e.g. ignore the "a" in "faecal".

2.4.3. Scientific literature databases

The following life science databases were searched for primary research studies: Scopus, Web of Science, and PubMed. Access to these subscription databases was via Royal Melbourne Institute of Technology University library services. Using the keywords above, searches were also made of the general technical literature database, Google Scholar.

Literature types

To assist in appropriate assessment of the literature, the search results were classified into two broad categories; (i) primary studies that were peer-reviewed journal articles and (ii) grey literature which refers to literature produced by organisations other than conventional academic journal publishers and includes reviews, regulatory guidelines or technical guidance publications produced by federal and state agencies in support of regulatory compliance goals.

2.4.4. Inclusion and exclusion criteria

When conducting the literature search exercise, the criteria for literature inclusion or exclusion were:

- English language studies only were included;
- Human health outcomes only were included
- Publication date-range for inclusion was from 2003 onwards. As noted earlier the date range for review was extended back to 2003 which is five years prior to the publication of the 2008 NHMRC Guidelines. Extending the date range back earlier was done to assist in locating any documents that may have been overlooked or have become recognised as being of greater importance since that time or missed the cut-off period during the preparation of the guidelines;
- Peer reviewed publications only were considered, except for certain grey literature reports and guidelines from reputable international and national agencies (e.g. WHO, US EPA, State and Commonwealth Departments of Health, State EPAs) (see Section 2.4.7). It is likely that such documents have undergone a peer-review process, however the process is not always clearly documented;
- Relevancy – clearly irrelevant studies were excluded, e.g. studies on dental hygiene.
- The study location was a developed country (excluding external territories) that was listed as a member of the OECD on the OECD website: (http:// http://www.oecd.org/about/members-and-partners/). This decision was made to make the workload more manageable within the resources available for this review.

However, since initial search results yielded a very large selection of potentially relevant studies, the Committee approved some additional changes to the research protocol in the relation to the primary research question (Table 2-2) to reduce the large volume of literature required for review.

Table 2-2. Changes to the microbial risks research protocol to reduce the review workload.

Initial research protocol	Changes	NHMRC specifications
Method: Review relevant primary studies to answer the primary research question. *Literature search period*: Include all relevant primary studies (Australian and international) from 2003 onwards that meet inclusion criteria.	The method was modified to allow for reviews to be used instead of primary studies over certain time periods. Literature search periods were amended accordingly to reflect the time coverage of the reviews. This reduced the number of primary studies to be assessed. *International data:* Use three reviews (King, Exley, et al., 2014; US EPA, 2017; WHO, 2018a) to cover the period up to 1 Jan 2017. Use primary studies from the literature search from 1 Jan 2017 to 30 Nov 2020. *Australian data:* Include all primary studies/reports found from 1 Jan 2003 to 30 Nov 2020	The selected reviews were appraised using the appropriate screening criteria outlined in this section (2.4). This includes assessing relevance for the Australian context and scope of the NHMRC Guidelines and the quality of the review process itself. The reviews were cross-checked against the results of the literature search to ensure that they cover the period 2003-2017. Any relevant primary studies/reports from this period not listed in the reviews was also screened for eligibility. The findings from the reviews are included in a Summary of Findings table in the Evidence Evaluation Report, alongside the findings from the review of primary studies.

Apart from the exclusions listed above, all study other types were included (e.g. local and international surveys; peer-reviewed publications or government reports or guidelines for indicators). The resulting list of studies was subject to further screening and filtering based on more refined criteria for quality as described in Section 2.5 below.

2.4.5. Use of existing guidance or reviews to address secondary research questions

Another step to manage the review workload, which was described in section 2.10 of the Microbial Risks research protocol (O'Connor, 2020), was to address the secondary research questions by reviewing only existing guidance or reviews rather than the primary research literature.

2.4.6. Validation of search methods

The search strategies were trialled and refined before undertaking the final full searches. The trialling process involved removal of certain keywords that caused excessive harvesting of literature. For example, the word "reservoir" was added to the keyword list to prior to searching to capture water recreation literature associated with water supply reservoirs. Unfortunately, the term is widely used in the health literature to denote "reservoirs of infection" and led to excessive harvesting of literature unrelated to the primary and secondary research questions. Hence the term was subsequently removed from the keyword list.

2.4.7. Grey literature (guidelines)

In addition to the grey literature list provided by members of the Committee (Appendix 3) and similar literature identified in the scientific literature databases, searches were also undertaken of the websites of the following international organisations:

- British Medical Research Council (MRC)
- Centre for Disease Control and Prevention (CDC)
- Environment Canada
- European Centre for Disease Prevention and Control (ECDC)
- European Environment Agency (EEA)
- Health Canada
- New Zealand Ministry of Health (NZ MoH)
- Public Health England (PHE)
- United Nations Environment Programme (UNEP)
- United Nations Environment Programme Mediterranean Action Plan (UNEP MAP)
- United States Environment Protection Agency (US EPA)
- World Health Organization (WHO)

It was not possible to search the websites of the above organisations using the search terms and search strings described for the major database searches as these were too long and complicated for the simple search engines associated with each website. Furthermore, each website held a narrow list of publications that could be more readily accessed using a greatly shortened list of key words. After some trial and error, the

following list was used to search websites of the above organisations: “recreational water”, “bathing water”, “ambient water quality”, “recreational guidelines”, “standards”, and “water quality”. Search results were focussed on the first 40 titles of reports and documents retrieved in each case.

2.4.8. Documentation of search results

Search results were exported to Microsoft Excel spreadsheets and sorted and filtered based on relevancy and quality, including risk of bias. Search results also recorded which publications were excluded and the justification/criteria for exclusion (Section 0).

Shortlisted literature was imported from Excel into the bibliographic software package Zotero (www.zotero.org) for management of associated PDF documents and for reporting on the results of the literature search.

2.4.9. Population, Exposure, Comparator, Outcome (PECO) table

A PECO table is a method for constructing a search strategy on a strongly evidence-based approach. PECO stands for Population, Exposure, Comparator, and Outcomes; factors that need to be defined at the outset to provide pillars for addressing the question(s) being asked (Morgan, Whaley, et al., 2018).

The key details on the populations that were reviewed to answer the research questions, including any susceptible populations or groups and justification for including them are described in the PECO table (Table 2-3). The PECO table also lists all relevant exposure pathways, comparator populations and health outcomes that were considered.

Table 2-3. Population, Exposure, Comparator, Outcome (PECO) table

Element	Criteria
Population	The general population was considered, as is the usual case for all NHMRC water guidelines. Individuals with underlying medical conditions aside from general immune suppression were out of scope but the following subgroups were considered as to whether they may require separate guidance in the updated Guidelines: • Elderly • Infants and children • Pregnant women • Immunocompromised individuals • Indigenous Australians (Aboriginal and Torres Strait Islander peoples) • Any groups that might be exposed more frequently e.g. geographic location, socioeconomic status, lifestyle/occupational exposure. • Sub-groups with unusual exposure patterns making them more susceptible (e.g. athletes such as regular ocean swimmers and surfers, people or age-groups practicing energetic water-based activities) due to larger volumes of water ingested and/or inhaled, different frequency of exposure, etc. The review considered all studies that involved healthy human subjects of any age who have had recreational exposure to natural waters.
Exposure (and comparator)	Hazards and sources: The review focussed on prioritised microbial exposure organisms/pathways as outlined below and agreed by the Committee to keep the work within project resources. While the literature search will retrieve all publications addressing risks to human health from microbial organisms in Australian recreational waters, studies that were out of scope of this review were collated separately and supplied to the Committee for their reference.

Element	Criteria

	Organisms of interest:
	• Exposure to microbes (bacteria/viruses etc.) responsible for gastrointestinal and respiratory illnesses (compared to no exposure if possible/reported)
	  ○ The focus of the review was risks from frank human enteric pathogens including bacteria, viruses, and protozoa and indicators from such groups (e.g. *E. coli*, somatic coliphage, etc.) or derived from these groups (e.g. biochemical or molecular indicators).
	  ○ The Committee has requested that, despite being out of scope, literature on exposure to opportunistic pathogens be included in the literature search, screened against inclusion/exclusion criteria and any retained material passed onto the Committee for their consideration.
	  ○ Similarly, studies that demonstrated transmission routes that were out of scope of the NHMRC Guidelines (e.g. soil transmission) were not included, in the review. However, the Committee requested that relevant literature on helminths retrieved from the literature search be collated and forwarded to the committee for their further consideration.
	
	Exposure settings –included all exposures to recreational waters as per the definition in Appendix 1. Specific types of recreational water body and recreational activities are described below.
	
	Recreational water bodies
	• Marine:
	  ○ beaches from the high tide waterline down
	  ○ coastal waters near land and thus influenced by land-based sources
	  ○ estuaries, including tidally influenced estuarine beaches
	• Freshwater
	  ○ Flowing waters (streams, creeks, canals, and rivers)
	  ○ Wetlands, lakes and reservoirs
	  ○ Beaches on rivers and lakes from the waterline down
	Recreational activities
	• Type of recreational activities to be covered by degree of contact as defined in the existing 2008 NHMRC Guidelines and as advised by the Committee (NHMRC, 2008)).
	  ○ *Whole-body contact (primary contact)* — activity in which the whole body or the face and trunk are frequently immersed, or the face is frequently wet by spray, and where it is likely that some water will be swallowed or inhaled, or come into contact with ears, nasal passages, mucous membranes or cuts in the skin (e.g. swimming, bathing, diving, surfing, wave-boarding, body-boarding, wind-surfing, water parks or whitewater canoeing).
	  ○ *Incidental contact (secondary contact)* — activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (e.g. boating, wading, sailing, kayaking and fishing), and including occasional and inadvertent immersion through slipping or being swept into the water by a wave.
	  ○ *No contact (aesthetic uses)* — activity in which there is normally no contact with water (e.g. angling from shore), or where water is incidental to the activity (such as walking on a beach).
	• Most types of water-based recreational activities should fit under the above categories. Activities may include:
	  ○ Swimming

Element	Criteria
	○ Surfing ○ Water skiing ○ Jet skiing ○ Diving, including snorkelling, scuba and activities such as spearfishing ○ Kiteboarding, and kitesurfing ○ Parasailing (from the beach or behind a boat) ○ Sail boarding and wind surfing ○ Kayaking and canoeing, including sea kayaking ○ Rowing ○ Fishing from a kayak or canoe ○ Fishing from a shoreline or riverbank with wading ○ Angling from the shore (no contact) ○ Sunbathing (no contact) ○ Other aesthetic uses, e.g. walking along the beach, etc. *Exclusions* • Studies investigating illnesses acquired from chemically treated recreational water (e.g. swimming pools, spas, hot tubs) will be excluded. • Health outcomes as a result of domestic exposure (e.g. drinking water or water used for washing) or occupational exposure to natural waters will also be excluded unless a study is clearly valuable in terms of protecting a subgroup. *Exposure pathways* • The exposure pathways considered for this review were oral ingestion of water and inhalation of aerosols. Other pathways were excluded from the review but relevant studies were retrieved as part of the literature search and considered separately by the Committee. Reasons for inclusions and exclusions are given below. ○ The main exposure pathways for frank human enteric pathogens is considered to be the oral ingestion pathway. ○ Inhalation of aerosols may be a significant exposure pathway in some recreational water exposure scenarios (e.g. jet skiing). ○ Other exposure pathways such as dermal, ocular or aural exposures are considered to be more significant with respect to opportunistic pathogens which are out of scope of this review. Relevant studies on opportunistic pathogens through all exposure pathways will be retrieved in the preliminary literature search as noted above and collated separately for review by the Committee if required. *Comparative Populations* • The comparative populations are human populations with: ○ No contact with natural waters. ○ Different levels of recreational exposure (e.g. no head immersion). ○ Recreational exposure to different grades of polluted water.
Outcomes	*Relevant health outcomes* Relevant health outcomes of interest for this review are: • Probability of illness per exposure (including gastrointestinal illness, highly credible gastrointestinal illness, respiratory illness, acute febrile respiratory illness). Note that gastrointestinal illness is the most commonly identified problem and also has formed the rationale for water quality criteria world-wide (Fewtrell and Kay, 2015), • Probability of infection per exposure • Any other adverse health effects (e.g. throat infections). The health outcomes may be:

Element	Criteria
	• Self-reported cases of illness (such as gastrointestinal symptoms) following natural recreational water exposure • Confirmed diagnosis of infection following exposure.

Study Type	The review considered:
	• Reviews of recreational water quality risk monitoring and management focussing on:
	  ○ Identification and evaluation of existing methodologies for health risk assessment for chemical exposures; and
	  ○ Site-specific case studies.
	• Existing recreational water quality guidelines/reports. A listing of reports supplied by the Committee is included in Appendix 3.
	• Grey literature, reports and guidelines from reputable international and national agencies (e.g. WHO, US EPA, State and Commonwealth Departments of Health, State EPAs, environmental agencies of OECD member countries where such documents are available in English, etc.)
	Where possible, the above studies would be categorised according to a selected list of Critical Appraisal Skills Programme (CASP) study types as follows:
	1. Case control study
	2. Cohort study
	3. Diagnostic test study
	4. Systematic review
	5. Qualitative research
	6. Randomised controlled trial (RCT)
	7. Cross-sectional study (mix of case-control and cohort)
	8. Quantitative research
	Study categories were used to guide a critical appraisal of study quality and selection for the review as described in the following sections.

2.5. Evidence collection

2.5.1. Classification of the evidence

In section 2.4.3 two broad classes of literature were described, namely (i) grey literature and (ii) primary studies. For the purposes of quality assessment, primary studies were further classified according to type of research protocol involved.

2.5.1.1. Grey literature

Grey literature documents are generally structured as larger documents seeking to integrate a wide range of topics in support of national regulatory goals (e.g. US EPA documents), more general international guidance (e.g. WHO documents) or strategic reviews for particular agencies in order to support subsequent regulations or guidance. In comparison, primary studies are mainly focused on the results of original research undertaken in response to narrowly focused study objectives. For the purposes of this technical report and corresponding evidence evaluation report, grey literature, although it may be constructed around reviews of the literature should not be confused with the term “systematic review” used in the primary studies classification below as systematic reviews generally have a much narrower focus and are published in peer-reviewed journals. Grey literature are also usually overseen by expert committees convened by national or international authorities and have many

contributing authors, whereas systematic reviews may frequently be carried out by individual researchers or small groups of researchers.

Consequently, the quality assessment criteria for grey literature (Section 2.5.1.1) were different from those of primary studies due to the different structure and purposes of each class of study.

2.5.1.2. Primary studies

The quality of each study to be included was assessed using the CASP (Critical Appraisal Skills Programme, Oxford CTVH, 2020)[1] quality assessment protocols for observational studies. The studies were categorised according to a selected list of CASP study types (Table 2-4). These study categories were used to guide a critical appraisal of study quality and selection for the review.

Table 2-4. Primary studies CASP classifications and definitions. Definitions are from CASP unless otherwise stated.

Category	Definitions (from CASP glossary unless otherwise stated)
1. Systematic review	Systematic review is a review in which evidence (in the form of original research) on a topic has been systematically identified, appraised, and summarised according to predetermined criteria.†
2. Qualitative research	Qualitative research uses individual in-depth interviews, focus groups or questionnaires to collect, analyse and interpret data on what people do and say. It reports on the meanings, concepts, definitions, characteristics, metaphors, symbols, and descriptions of things. It is often exploratory and open-ended. For this review, the CASP Qualitative Research category was extended to include observational studies that measured or predicted concentrations of contaminants in recreational water environments and on the basis of those concentrations inferred the extent of exposure and against health guidelines (e.g. QMRAs).§
3. Case control study	A case-control study is an epidemiological study that is used to identify risk factors for a medical condition. This type of study compares a group of patients who have that condition with a group of patients that do not have it and looks back in time to see how the characteristics of the two groups differ.
4. Cohort study	An observational study in which a group of people with a particular exposure (e.g. a putative risk factor or protective factor) and a group of people without this exposure are followed over time. The outcomes of the people in the exposed group are compared to the outcomes of the people in the unexposed group to see if the exposure is associated with particular outcomes (e.g. getting cancer or length of life).
5. Diagnostic test study	A diagnostic test study documents the results of testing to confirm or determine the presence of disease in an individual or group of individuals suspected of having a disease, usually following the report of symptoms, or based on other medical test results. In the context of microbial risks to recreational water quality, a diagnostic test study may seek to determine the identity of the pathogen responsible for an outbreak event.*
6. Randomised controlled trial	Randomised controlled trial (RCT) is a trial in which participants are randomly assigned to one of two or more groups: the experimental group or groups receive the intervention or interventions being tested; the comparison group (control group) receive usual care or no treatment or a placebo. The groups are then followed up to see if there are any differences between the results. This helps in assessing the effectiveness of the intervention.
7. Cross-sectional study (mix of case-control and cohort)	A cross-sectional study involves collection of information (e.g. the presence or absence of disease and other variables of interest) from a defined population at one point in time. It documents the prevalence of disease at that time. **
8. Quantitative research	Quantitative research uses statistical methods to count and measure outcomes from a study. The outcomes are usually objective and predetermined. A large number of participants are usually involved to ensure that the results are statistically significant.

[1] For further information on each CASP checklist see https://casp-uk.net/casp-tools-checklists/

† This category should not be confused with the grey literature described in this report. Grey literature documents are generally structured as larger documents seeking to integrate a wide range of topics in support of national regulatory goals or more general international guidance.
* Definition derived from the following sources: Cochrane.org, Wikipedia, BMJ Best Practice: https://www.cochrane.org/news/what-are-diagnostic-test-accuracy-reviews, https://bestpractice.bmj.com/info/toolkit/learn-ebm/diagnostic-test-studies-assessment-and-critical-appraisal/, https://en.wikipedia.org/wiki/Medical_test.
** definition derived from the following sources: Cochrane.org, Wikipedia, BMJ Best Practice, and Mann (2003).
§ This definition also provided consistency with the narrative review of Chemical Hazards being undertaken for NHMRC.

Note that while the CASP classification for Quantitative Research was considered appropriate for certain types of epidemiological studies, this did not include Quantitative Microbial Risk Assessments (QMRAs) which focus on predicting concentrations of pathogens or FIB (and thus the extent of exposure) and comparing the predictions against health guidelines. For this review, it was considered that QMRA studies were more appropriately classified as Qualitative Research studies. The consequence of a classification of a study as either "Qualitative Research" or "Quantitative Research" leads to a slightly different set of CASP questions against which the paper is assessed. These questions are given in Appendix 4.

2.5.2. Quality assessment (by types)

2.5.2.1. Grey literature

The methodological quality of grey literature was assessed using administrative and technical criteria in the assessment form shown in Table 2-5. The criteria listed in the form were based on common domains that have been evaluated in several existing tools for assessing guidelines and systematic reviews (e.g. AGREE tool: Brouwers, Kerkvliet, et al., 2016; AGREE Next Steps Consortium, 2017). Based on the responses in the form a decision was made on whether the document should be included or excluded from the review.

In addition to this formal quality assessment approach, the close inspection of the full text document afforded at this stage in some cases indicated that the evidence contained in the document was not relevant to answering the primary and/or secondary research questions. Where that was the case, the document was classed as "Excluded from further review" and the reason for the exclusion noted in the table.

Table 2-5. Form for administrative and technical criteria for assessing existing guidance or reviews. Criteria have been colour-coded to assess minimum requirements as follows: 'Must have', 'Should have' or 'May have'. Y/N/NA =Yes, No, or Not Applicable.

	Criteria	Y/N/NA	Notes
Overall guidance/advice development process			
	Are the key stages of the organisation's advice development processes compatible with Australian processes?		
	Are the administrative processes documented and publicly available?		
	Was the work overseen by an expert advisory committee? Are potential conflicts of interest of committee members declared, managed and/or reported?		
	Are funding sources declared?		
	Was there public consultation on this work? If so, provide details.		
	Is the advice peer reviewed? If so, is the peer review outcome documented and/or published?		
	Was the guidance/advice developed or updated recently? Provide details.		

	Criteria	Y/N/NA	Notes
Evidence review parameters			
	Are decisions about scope, definitions and evidence review parameters documented and publicly available?		
	Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?		
	Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?		
	If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?		
	Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?		
	Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?		
	Can grey literature such as government reports and policy documents be included?		
	Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?		
Evidence search			
	Are databases and other sources of evidence specified?		
	Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?		
	Is it specified what date range the literature search covers? Is there a justification?		
	Are search terms and/or search strings specified?		
	Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?		
Critical appraisal methods and tools			
	Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?		
	Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.		
	Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.		
Derivation of health-based guideline values			
	Is there justification for the choice of uncertainty and safety factors?		
	Are the parameter value assumptions documented and explained?		
	Are the mathematical workings/algorithms clearly documented and explained?		
	Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?		
	Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?		
	If expert judgement is required, is the process documented and published?		
	Is dose response modelling (e.g. BMDL) routinely used?		
	Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?		
	If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?		
Comments			
	Reviewer's comments		
	Useful for answering primary research question?		*Decision on inclusion or exclusion*
	Useful for answering secondary research questions?		

2.5.2.2. Primary studies

Critical appraisal of evidence

As noted above, the CASP study categories were used to guide a critical appraisal of study quality and eligibility for the review.

The CASP protocol considers three broad issues in appraising a study:

(i) Are the results of the study valid?
(ii) What are the results?
(iii) Will the results help locally?

Depending on the type of study 10 to 13 questions are posed within the three categories above that are designed to assist the reviewer to consider the issues systematically. The first two to three questions are screening questions and can be answered quickly. If the answer to each is "yes", it is worth proceeding with the remaining questions. There is some degree of overlap between the questions and the reviewer is asked to record a "yes", "no" or "can't tell" to most of the questions. A number of supporting hints or prompts are listed for each question which are designed to remind the reviewer why the question is important (Appendix 4). Answers and reasons to all questions are recorded in a tabular form for each reviewed document (Appendix 4). The response to the first few questions can be used as a filter to exclude studies that do not address a clearly focussed issue or use appropriate methodologies.

2.5.2.3. Risk of bias assessment for primary studies

Primary data studies selected for review were assessed for internal validity, which is also known as "risk of bias". For reference, "bias" is defined by OHAT (2019)[2] as: "*a systematic error, or deviation from the truth, in results or inferences. Biases can operate in either direction: different biases can lead to underestimation or overestimation of the true effect. Biases can vary in magnitude: some are small (and trivial compared with the observed effect), and some are substantial (so that an apparent finding may be entirely due to bias)*".

Further, the process of evaluating individual studies for risk of bias involves "the assessment of whether the design and conduct of a study compromised the credibility of the link between exposure and outcome" (OHAT, 2015).

The OHAT Risk-of-Bias Tool (OHAT (2015)) provides rigorous protocols that can be applied to case control studies, cohort studies, diagnostic test studies, randomised controlled trials, and cross-sectional studies. For these study types it was originally planned to apply the OHAT Risk-of-Bias Tool (OHAT, 2015) and to develop similar risk of bias assessment criteria for the remaining categories of systematic reviews, qualitative and quantitative studies. However, it was determined that the OHAT tool was not suitable for many of the shortlisted studies remaining after the screening process. Consequently, the CASP critical appraisal tools were used to conduct quality assessments for all study types because they were simpler and more efficient to use

[2] Office of Health Assessment and Translation of the US National Toxicology Program (https://www.niehs.nih.gov/research/atniehs/dntp/assoc/ohat/index.cfm)

systematically across different study types. While not completely overlapping, the CASP tools apply similar questions relating to some of the key OHAT risk of bias domains for evaluating the internal validity of a primary study and the quality of its research findings. The complete list of CASP queries is presented in Appendix 4.

The OHAT Risk-of-Bias Tool (OHAT, 2015) provides a colour-coded visual scheme to summarise risk of bias assessments and this scheme was applied based on the response to the CASP questions (Table 2-6). The combination of the two critical appraisal tools allowed for a reasonable assessment of study quality within the resources available for the review.

Table 2-6. OHAT Risk of bias scheme categories (OHAT, 2015)

Symbol	Description
++	***Definitely Low** risk of bias*:
	There is direct evidence of low risk of bias practices. May include specific examples of relevant low risk of bias practices.
+	***Probably Low** risk of bias*:
	There is indirect evidence of low risk of bias practices **OR** it is deemed that deviations from low risk of bias practices for these criteria during the study would not appreciably bias results, including consideration of direction and magnitude of bias.
-	***Probably High** risk of bias*:
	There is indirect evidence of high risk of bias practices If there is insufficient information provided about relevant risk of bias practices, "not reported" or "NR" may be used instead of the minus symbol "-".
--	***Definitely High** risk of bias*:
	There is direct evidence of high risk of bias practices. May include specific examples of relevant high risk of bias practices.

Studies that had a high risk of bias or serious concerns with study quality were excluded from the review and the removal was recorded with justification in the PRISMA flow diagram.

Once a determination of risk of bias for each domain was made, a visual summary of the risk of bias ratings for the included studies was prepared and used in the next stage of the critical appraisal process to determine overall risk of bias across the body of evidence (see Evidence Evaluation Report, also OHAT Handbook Table 9, OHAT, 2019).

2.6. Process for extracting and presenting data

2.6.1. Data extraction

2.6.1.1. Grey literature

Documentation of the attributes of the shortlisted grey literature in support of responses to the primary and secondary search questions were recorded using the form shown in Table 2-7 designed specifically for this review. The form is cross-referenced with a classification of study quality and risk of bias (see section 2.5). The form aided construction of an integrated report on each publication.

Table 2-7. Data extraction form for grey literature.

Item	Guidance	Grey Literature ID
Study summary		
Aim/objectives of study		
Author's conclusion: interpretation of results		
Research Questions	**Committee Guidance**	
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.	
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/implemented in settings relevant to the Australian context.	
Reviewer's comments and overall assessment		
Reviewer's comment		
Overall Assessment		

2.6.1.2. Primary studies

Documentation of the attributes of the shortlisted primary research literature in support of responses to the primary search question were recorded using the form shown in Table 2-8 which is based loosely on the PRISMA approach (Moher, Liberati, et al., 2009). The form includes bibliographic information (e.g. authors, year of publication), year(s) of study period, country of study, study characteristics etc.) and is cross-referenced with a classification of study quality and risk of bias (see section 2.5). The form aided construction an integrated report on each publication and calculation of summary statistics on the publication attributes.

Table 2-8. Data extraction and presentation form for primary research literature.

Category	Study ID	Data
Study attributes	Authors	
	Title	
	Publication Title	
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	
	Publication date	
	Publication Source	
	Peer reviewed	
	Country of origin	
	Source of funding	
	Possible conflicts of interest	
General	Filter	
	Does study clearly address the primary research question?	
	Australian jurisdiction	
	Does paper describe reasoning clearly	
	Does overseas experience relate to Australian context	
	Subgroups considered (e.g. children, immunocompromised, elderly, indigenous)	
	Main risk associated factor?	
	CASP classification	
	marine, estuarine or freshwater	
	DOI http://dx.doi.org/	
Study characteristics	Aim/objectives of study	
	Study type/design	
	Study duration	
Population characteristics	Population/s studied	
	Selection criteria for population	
	Subgroups reported	
	Size of study	
Exposure and setting	Type of water source/water body	
	Exposure scenario	
	Exposure pathway	
	Source of infection/contamination	
	Causal organisms	
	Comparison group(s)	
Study methods	Water quality measurement used	
	Method of microorganism isolation and enumeration (if applicable)	
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	
	Limits of reporting for the organism of concern	
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	
Statistics	Statistical methods used	
	Details on statistical analysis (if any)	
	Relative risk/odds ratio, confidence interval?	
Results	Outcome	
	How outcome was assessed	
	Method of measurement	
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	
Author's conclusion	Interpretation of results	
	Assessment of uncertainty (if any)	
Reviewer comments	Reviewer comments	
	Results included/excluded in review (if applicable)	
	Notes on study quality e.g. gaps, methods	

Process for assessing the body of evidence

The evidence collected and appraised for each research question was grouped by study type and outcome where possible and summarised in an Evidence Summary table that assigned the level of certainty (or confidence) in that body of evidence. Due to the different nature and quality of evidence between grey literature and primary studies different approaches were required to review and evaluate the body of evidence for each type of literature. The methodology for assessment and results of the assessment are described in the Microbial Risks Evidence Evaluation Report (O'Connor, 2022).

3 Literature search results

3.1. Grey literature

Searches for grey literature (using the method described in Section 2.4.7) identified 38 documents. Twelve documents were screened out on the basis that they were non-Australian studies and preceded the agreed cut-off date for inclusion, whilst each of the remaining documents was evaluated for its relevance to the primary and secondary research questions and if not relevant was screened out.

This process identified 16 documents relevant to the primary and secondary research questions (i.e., microbial risks in recreational water). Each of the 16 shortlisted documents was further assessed for eligibility by a full-text quality assessment process described in Section 2.5.2 which resulted in 10 documents being screened out on quality grounds. The final list of six grey literature documents retained by meeting the quality criteria are described in Section 4.1 whilst the 10 excluded documents are listed in Section 7.1.

The screening process is summarised graphically in Figure 3-1.

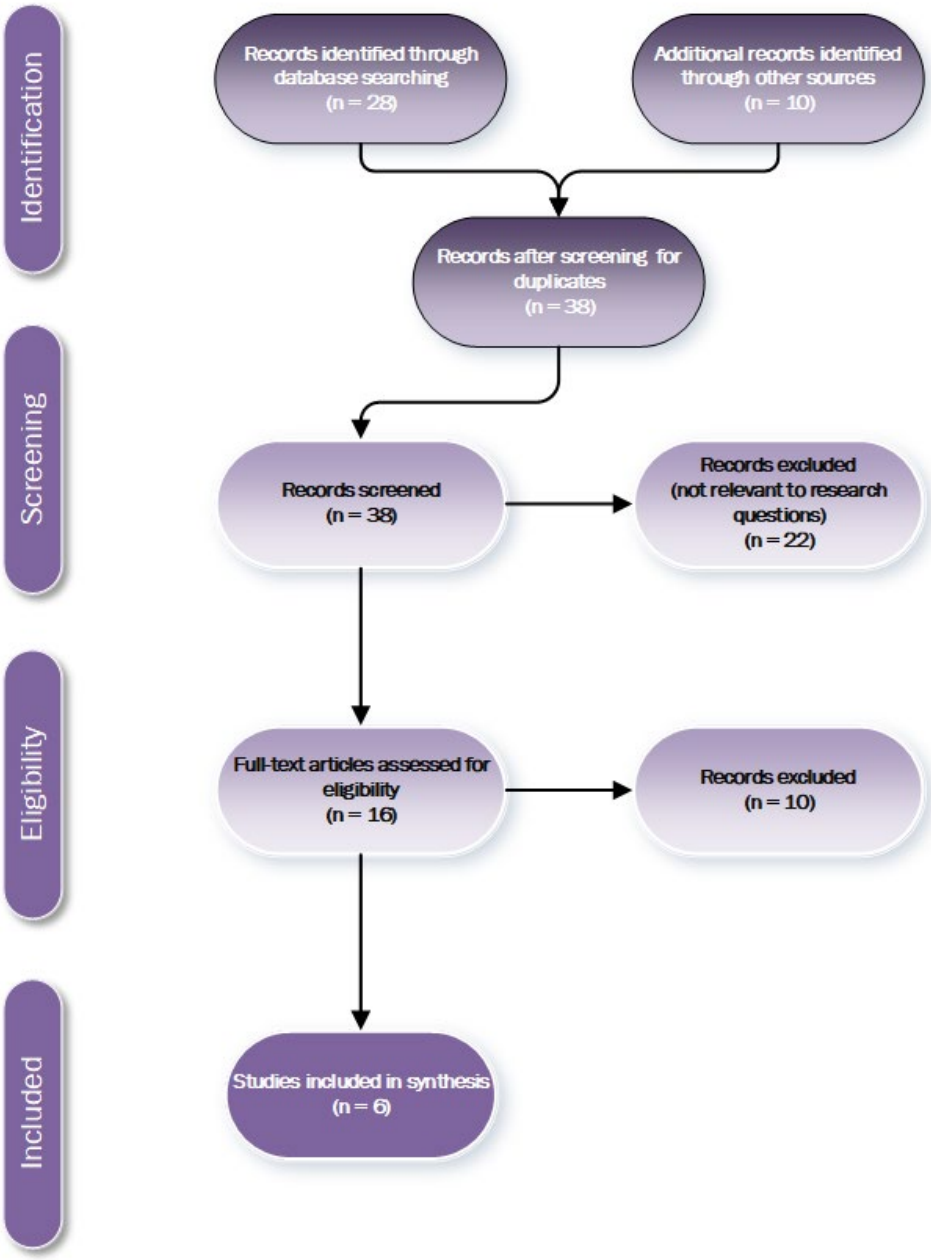

Figure 3-1. PRISMA summary of the citation review process for grey literature

3.2. Primary studies

Search results by database yielded 7381 citations initially and after removal of duplicates within each database (i.e. Scopus, Web of Science, PubMed) this number was reduced to 3629 citations (Table 3-1). After combining the lists, further removal of citations that were duplicated between the databases brought the number of citations

down to 2563 (Table 3-2). Text recognition script in the programming language, R, was used to identify duplicates at this stage, although some duplicate records remained due to minor character differences that the script was not able to detect. These duplicates were removed in later screening using Excel tools (described in the next section).

Table 3-1. Primary literature search results summary by database and search strategies (further details of keywords, search categories, and search strings are given in Table 2-1).

Database	Search in key words, title and abstract unless specified (2003-2020)	Records
Scopus	population (1) + location (4) in title + definition (2) + study type (3) + Outcomes (5.1-3 or) + population related exposure way (7 or 10 or 11)	848
	location (4) in title + definition (2) + study type (3) + Source organism (12-18 or) + method (6)	573
	population (1) + location (4) in title + definition (2) + study type (3) + population related exposure way (7or10or11) + Source organism (12-18 or)	671
	location (4) in title + definition (2) + study type (3) + exposure pathways (8-9 or) + Source organism (12-18 or)	3,304
	Initial Number of Records	5,396
	Following removal of duplicates	1916
Web of Science	population (1) + location (4) in title + definition (2) + study type (3) + Outcomes (5.1-3 or) + population related exposure way (7 or 10 or 11)	121
	location (4) in title + definition (2) + Source organism (12-18 or) + method (6)	359
	location (4) in title + definition (2) + study type (3) + exposure pathways (7-11 or) in all field + Source organism (12-18 or)	632
	Initial number of citations	1112
	Following removal of duplicates	909
PubMed	population (1) + location (4) in title + definition (2) + study type (3) + Outcomes (5.1-3 or) + population related exposure way (7 or 10 or 11)	70
	location (4) in title + definition (2) + Source organism (12-18 or) + method (6)	247
	location (4) in title + definition (2) + study type (3) + exposure pathways (7-11 or) in all field + Source organism (12-18 or)	316
	Initial Number of Records	633
	Following removal of duplicates	566
Google Scholar	Searching Strategy - Google scholar - list of words selected: recreational water; surface water; risk assessment; exposure; Escherichia coli; health risk; microbial source tracking; microbial risk assessment; swimming .pool; quantitative microbial risk; faecal pollution; fecal pollution prevalence; coastal; beach*; gastro*; marine. First 25 pages visited. 240 records obtained	240
	Initial Number of Records	240
	Following removal of duplicates	238

* A computer script was developed and used to remove records with duplicated fields at about 90% efficiency. Some duplicates remained after this process due to small differences (e.g. typographical differences or mistakes) and were removed in subsequent more detailed screening.

Table 3-2. Primary literature search summary

Item	Scopus	Web of Sci	Pub Med	Google Scholar	Totals
Initial no. of citations	5396	1112	633	240	7381
Following removal of duplicates (via autotext screening)	1916	909	566	238	3629
Lists combined and between list duplicates removed (via autotext screening)					2563

3.2.1. Screening process and PRISMA diagram

All citations retrieved from the literature search were downloaded from the source database as CSV formatted files (i.e. comma separated values). These files were imported into a bibliographic database using the Zotero bibliographic software program which was used to manage the citations and assisted in generating citation records in a standard format. Standard format CSV files were exported from Zotero to Microsoft Excel which was used for sorting and filtering citations based on relevance.

The combined list of citations from the literature search, after removal of duplicates was subjected to an iterative screening process via a number of steps (Table 3-4). The first steps involved screening titles for relevancy and exclusion of non-OECD citations. At this stage, an additional 29 citations were added from lists supplied by the Committee. The next screening stages involved removal of non-Australian studies that were cited in the key reviews, or were non-Australian studies addressing a topic explicitly addressed in the key reviews (Table 3-3). These and other reasons for exclusion are given in Table 3-4 and the process is summarised graphically in Figure 3-2.

Table 3-3. Topics explicitly addressed in key reviews

Topic	Key review document
Emerging/wider issue - antimicrobial resistance (AMR)	WHO 2018
Faecal Indicator Organism (FIO) *E. coli*	WHO 2018
FIO enterococci	WHO 2018
Microbial Source Tracking (MST)	US EPA 2017
MST methods	US EPA 2017
MST methods, Quantitative PCR (qPCR) for FIB	US EPA 2017
QMRA	US EPA 2017, WHO 2018
qPCR methods	US EPA 2017
Recreational Criteria Implementation Tools (RCIT) Predictive/Deterministic Modelling	US EPA 2017
RCIT Statistical Approaches for Predictive Estimates of Water Quality	US EPA 2017
Viral indicators	WHO 2018

Table 3-4. Breakdown of screening and review strategy for primary studies

Description	Running total (n)	Exclusions (n)
Records identified through database searching	2563	n/a
After screening of titles for relevancy	462	2101
After exclusion of non-OECD citations	321	141
Additions :29 citations stemming from a list combined from lists supplied by members of the Committee (121 citations) or relevant citations in Water Res.V44 (5 citations excluding 1 overlap)	350	29
Summary: Primary studies published between 1st Jan 2003 and 30th Oct 2020 deemed as having relevant titles	350	
Final screening stage - exclusions		
Non-Australian study addressing a topic explicitly addressed in existing review (see Table 2-3)	265	85
Basic sanitary survey	259	6
Comment on another paper	256	3
Non-Australian study cited in key review (see Table 2-3)	162	94
Not a recreational water study	153	9
Not peer reviewed	150	3

Description	Running total (n)	Exclusions (n)
Not relevant to primary research question	110	40
Obsolete	94	16
Out of scope	42	52
Study does not describe reasoning clearly		
Full-text articles assessed for eligibility	**42**	n/a
After exclusion of citations based on risk of bias	13	29
Studies included synthesis	**13**	-

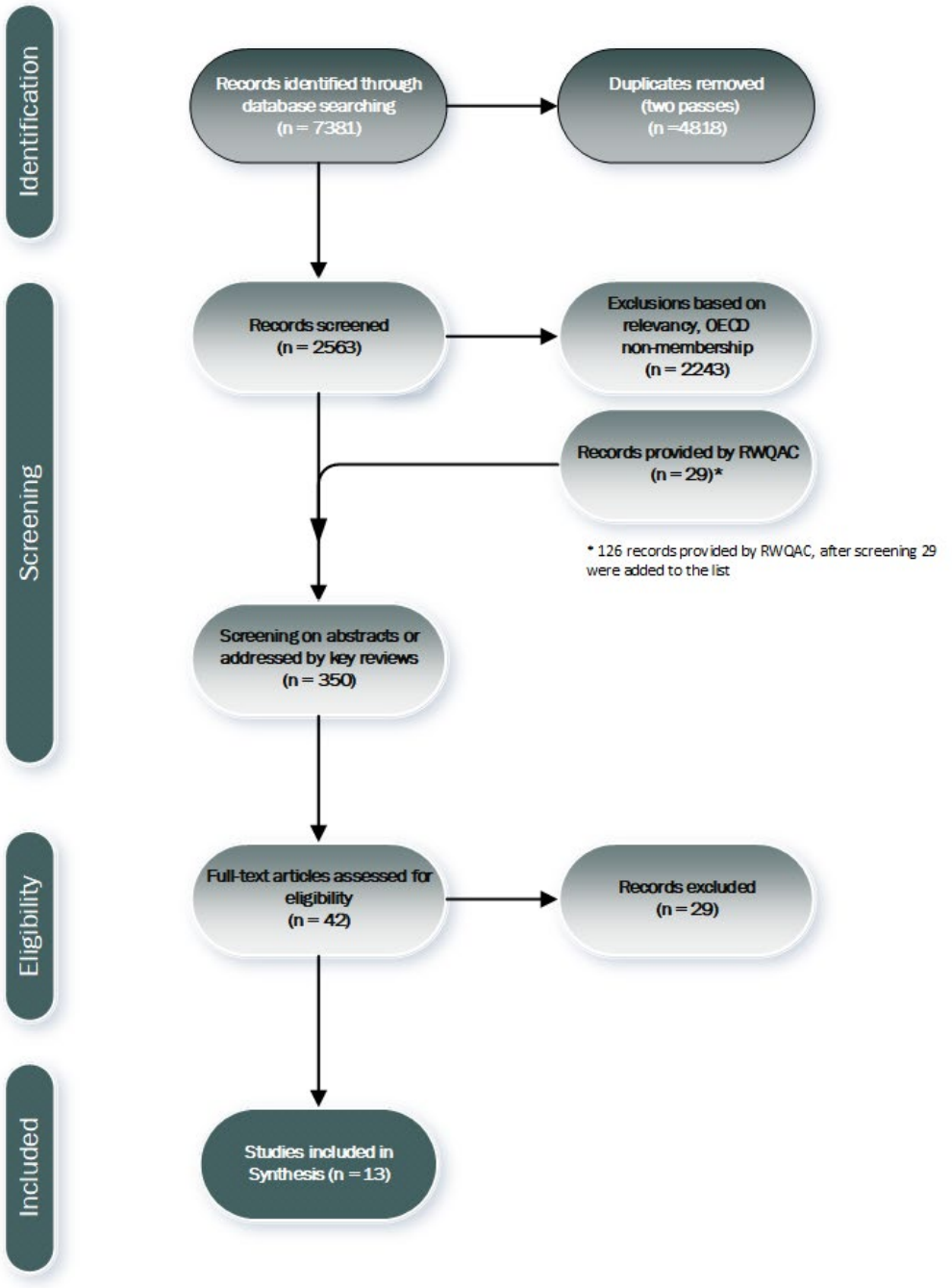

Figure 3-2. PRISMA summary of the citation review process for primary studies

4 Full list of included studies

4.1. Grey literature

Table 4-1. List of included grey literature after screening and quality assessment

ID	Title	Type of Study
G3: EPA Victoria (2021)	EPA Victoria, 2021. Quantitative Microbial Risk Assessment (QMRA) for assessing risks to recreational users in Port Phillip Bay. EPA Publication 2007, June 2021. Environment Protection Authority, Victoria.	Report
G4: King et al. (2014)	King, S., Exley, J., Winpenny, E., Alves, L., Henham, M.-L., Larkin, J., 2014. The health risks of bathing in recreational waters. A rapid evidence assessment of water quality and gastrointestinal illness. Final report WT1530. A report of research carried out by RAND Europe, on behalf of the UK Department for Environment, Farming and Rural Affairs (DEFRA). United Kingdom.	Review
G8: NHMRC (2008)	NHMRC, 2008. Guidelines for managing risks in recreational water. National Health and Medical Research Council (Australia).	Guidelines
G11: NSW DPIE (2020)	NSW DPIE, 2020. Protocol for Assessment and Management of Microbial Risks in Recreational Waters. NSW Department of Planning, Industry & Environment, [online]	Guidelines
G13: US EPA (2017)	US EPA, 2017. 2017 Five-Year Review of the 2012 Recreational Water Quality Criteria (No. Office of Water 823-R-18-001). US Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC, United States.	Review
G16: WHO (2018)	WHO, 2018. WHO recommendations on scientific, analytical and epidemiological developments relevant to the parameters for bathing water quality in the Bathing Water Directive (2006/7/EC): Recommendations. World Health Organization.	Review

4.2. Primary studies

Table 4-2. List of included primary studies after consideration of risk or bias

Study ID	Citation	CASP classification
J2: Ahmed, Hamilton, et al., (2018)	Ahmed, W., Hamilton, K. A., Lobos, A., Hughes, B., Staley, C., Sadowsky, M. J., and Harwood, V. J. (2018) Quantitative microbial risk assessment of microbial source tracking markers in recreational water contaminated with fresh untreated and secondary treated sewage. Environment International, 117, 243–249. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85047077932&doi=10.1016%2fj.envint.2018.05.012&partnerID=40&md5=c97413bc0249240d20d0a19774172eeb.	Qualitative research
J3: Ahmed, Payyappat, et al., (2019)	Ahmed, W., Payyappat, S., Cassidy, M., and Besley, C. (2019) Enhanced insights from human and animal host-associated molecular marker genes in a freshwater lake receiving wet weather overflows. Scientific Reports, 9(1), 12503. [online] http://www.ncbi.nlm.nih.gov/pubmed/31467317.	Qualitative research
J4: Ahmed, Payyappat, et al., (2020)	Ahmed, W., Payyappat, S., Cassidy, M., Harrison, N., and Besley, C. (2020) Sewage-associated marker genes illustrate the impact of wet weather overflows and dry weather leakage in urban estuarine waters of Sydney, Australia. The Science of the Total Environment, 705, 135390. [online] http://www.ncbi.nlm.nih.gov/pubmed/31838427.	Qualitative research
J5: Ahmed, Zhang, et al., (2019)	Ahmed, W., Zhang, Q., Kozak, S., Beale, D., Gyawali, P., Sadowsky, M. J., and Simpson, S. (2019) Comparative decay of sewage-associated marker genes in beach water and sediment in a subtropical region. Water Research, 149, 511–521. [online] http://www.ncbi.nlm.nih.gov/pubmed/30500686.	Qualitative research

Study ID	Citation	CASP classification
J6: Arnold, Schiff, et al., (2017)	Arnold, B. F., Schiff, K. C., Ercumen, A., Benjamin-Chung, J., Steele, J. A., Griffith, J. F., Steinberg, S. J., Smith, P., McGee, C. D., Wilson, R., Nelsen, C., Weisberg, S. B., and Colford, J. M., Jr. (2017) Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions. American Journal of Epidemiology, 186(7), 866–875. [online] https://doi.org/10.1093/aje/kwx019 (Accessed March 10, 2021).	Cohort study
J15: Gitter, Mena, et al., (2020)	Gitter, A., Mena, K. D., Wagner, K. L., Boellstorff, D. E., Borel, K. E., Gregory, L. F., Gentry, T. J., and Karthikeyan, R. (2020) Human health risks associated with recreational waters: Preliminary approach of integrating quantitative microbial risk assessment with microbial source tracking. Water (Switzerland), 12(2). [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85081546265&doi=10.3390%2fw12020327&partnerID=40&md5=f48942230d1dbe0b5426d168ad1f982d.	Qualitative research
J18: Henry, Schang, et al., (2016)	Henry, R., Schang, C., Coutts, S., Kolotelo, P., Prosser, T., Crosbie, N., Grant, T., Cottam, D., O'Brien, P., Deletic, A., and McCarthy, D. (2016) Into the deep: Evaluation of SourceTracker for assessment of faecal contamination of coastal waters. Water Research, 93, 242–253. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-84958973030&doi=10.1016%2fj.watres.2016.02.029&partnerID=40&md5=857b1be61a85ed86ed706842b9f6584f.	Qualitative research
J20: Kelly, Feng, et al., (2018)	Kelly, E. A., Feng, Z., Gidley, M. L., Sinigalliano, C. D., Kumar, N., Donahue, A. G., Reniers, A. J. H. M., and Solo-Gabriele, H. M. (2018) Effect of beach management policies on recreational water quality. Journal of Environmental Management, 212, 266–277. [online] https://repository.tudelft.nl/islandora/object/uuid%3A4cae77ec-45fd-4029-b8e5-5c3e68015b34/datastream/OBJ/download.	Qualitative research
J23: Lugg, Cook, et al., (2012)	Lugg, R. S. W., Cook, A., and Devine, B. (2012) "Estimating 95th Percentiles from Microbial Sampling: A Novel Approach to Standardising their Application to Recreational Waters" in D. Kay and C. Fricker (eds.), The Significance of Faecal Indicators in Water: A Global Perspective. Cambridge, RSC Publishing, 62–71. [online] http://ebook.rsc.org/?DOI=10.1039/9781849735421-00062 (Accessed December 17, 2014).	Qualitative research
J30:Robins, Farkas, et al., (2019)	Robins, P. E., Farkas, K., Cooper, D., Malham, S. K., and Jones, D. L. (2019) Viral dispersal in the coastal zone: A method to quantify water quality risk. Environment International, 126, 430–442. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85062216772&doi=10.1016%2fj.envint.2019.02.042&partnerID=40&md5=72fcd9a789a4b4dd475a16a0e31978dc.	Qualitative research
J34: Russo, Eftim, et al., (2020)	Russo, G. S., Eftim, S. E., Goldstone, A. E., Dufour, A. P., Nappier, S. P., and Wade, T. J. (2020) Evaluating health risks associated with exposure to ambient surface waters during recreational activities: A systematic review and meta-analysis. Water Research, 176. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85082875333&doi=10.1016%2fj.watres.2020.115729&partnerID=40&md5=b8d28f8b8576aa1d50ad124e4649f95f.	Systematic review
J35: Schoen, Boehm, et al., (2020)	Schoen, M. E., Boehm, A. B., Soller, J., and Shanks, O. C. (2020) Contamination scenario matters when using viral and bacterial human-associated genetic markers as indicators of health risk in untreated sewage-impacted recreational waters. Environmental Science & Technology. [online] http://www.ncbi.nlm.nih.gov/pubmed/32969642.	Qualitative research
J36: Shrestha and Dorevitch, (2019)	Shrestha, A. and Dorevitch, S. (2019) Evaluation of rapid qPCR method for quantification of *E. coli* at non-point source impacted Lake Michigan beaches. Water Research, 156, 395–403. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85063941252&doi=10.1016%2fj.watres.2019.03.034&partnerID=40&md5=8d0a3a8e1bd9c65175f11c60ca03b025.	Qualitative research

5 Completed quality assessment and data extraction for the included grey literature

5.1. G3: EPA Victoria (2021)

5.1.1. Quality assessment

Criteria	Assessment	G3: EPAV 2021, QMRA for Port Phillip Bay
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	This study was a QMRA undertaken by a team of experienced microbial risk consultants hired by EPA Victoria. Its purpose was to better understand the health risks associated with water-based recreation in Port Phillip Bay. The study also makes significant reference to the 2008 NHMRC Guidelines. Given that context it is arguable that it is compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	No evidence is supplied to indicate that this would be the case
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	Yes	The original version supplied by the Committee was a draft dated 2019. However, the reviewer noted that a revised and final version of the document was released on the EPA Victoria website in June 2021. Although this is past the cut-off date for the literature search undertaken for this review, since it was a later version of the same document, and the reviewer had not yet reviewed the document, the 2021 version is the document assessed here.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported

Criteria	Assessment	G3: EPAV 2021, QMRA for Port Phillip Bay
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Whilst reference is made to high quality scientific literature, the study does not use or adopt review findings or risk assessments from other organisations.
Can grey literature such as government reports and policy documents be included?	Yes	Such documents are listed in the reference section.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Statistical details for probabilities of illness given infection, and dose response models are given in Appendices D and E.
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	Yes	Dose response modelling is used in the context of quantitative microbial risk assessment.
Has the organisation's policy for dealing with substances for which a non-threshold mode of	n/a	Not reported

Criteria	Assessment	G3: EPAV 2021, QMRA for Port Phillip Bay
action may be applicable in humans been articulated and recorded?		
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	This study is a QMRA for assessing risks to recreational users in Port Phillip Bay and although a grey literature document, it is not a detailed review study. Since it provides an important recent Australian example of monitoring, assessing and predicting risks to recreational water users, it is useful in providing information for the primary and secondary research questions	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*Yes*	*Include in review*

5.1.2. Data extraction

Question	Committee Guidance	G3: EPAV 2021, QMRA for Port Phillip Bay
Study summary		
Aim/objectives of study		To better understand the health risks associated with water-based recreation in Port Phillip Bay, EPA Victoria commissioned QMRAs at three popular beaches in the bay, combined with microbial source tracking at each location over the summer season 2017-2018. The results of the QMRA aimed to inform assessments of risk from microbial contamination for recreational uses as well as the human health risk assessment process. Objectives: (i) to ascertain whether indicators and pathogen densities could predict risks of illness at the three beach locations (Altona, Elwood and Frankston) within Port Phillip Bay, Melbourne, Victoria. (ii) to compare the probability of illness from water-based recreational activities at three beach locations within the Bay, as calculated using a QMRA approach, to the risk portrayed by SEPP (Waters) and the NHMRC 2008 Guidelines. (iii) to investigate what factor(s) could impact the level of risk in the Bay (iv) to provide an example of how a QMRA could be conducted and provide parameters and key assumptions for future application. These four objectives overlap with Primary and Secondary Research Questions. Objectives (ii) to (iv) align with the primary question, whilst Objective (i) aligns with the secondary questions.
Author's conclusion: interpretation of results		Summary The QMRA showed that the probabilities of contracting an illness via primary or secondary contact recreation were very low compared to the rates of illness expected using the SEPP (Waters) and NHMRC interpretation. Mean probabilities of illness for primary and secondary contact recreation were 0.33% and 0.05% respectively. These probabilities are much lower than the probabilities above 10% that would have been predicted by the 2008 NHMRC Guidelines.
Research Questions		

Question	Committee Guidance	G3: EPAV 2021, QMRA for Port Phillip Bay
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	Baseline QMRA Primary contact recreation The baseline QMRA for primary contact recreation predicted a mean probability of illness (p(ill)) of 0.33% [95th percentile 1.07%] per exposure event, mostly due to norovirus 0.23% [0.82%] (which had a highly uncertain dose-response model). Adenoviruses contributed the next highest proportion of total risks at 0.07% [0.23%], whilst bacteria and protozoa had p(ill) at or below 0.01%. This baseline QMRA suggests that the beaches were: • in category 1 (swim safely) with a predicted probability of illness of ≤1% per primary contact recreational exposure about 94% of the time • in category 2 (swim at your own risk) with a probability of illness between 1% and 10% only 6% of the time, and • never in category 3 (do not swim). Secondary contact recreation For secondary recreation, the modelled 100,000 exposures resulted in 48 predicted illnesses, which equates to a mean probability of illness of 0.05%. As with the primary contact QMRA, most of this probability was derived from the norovirus dose-response model which appears conservative. The predicted probability of illness 95th percentile was 0.18%. QMRA Sensitivity analyses To summarise, adjustment of the Cryptosporidium and adenovirus dose response relationships did not change the outcomes significantly or result in reduced probabilities of illnesses per contact event. Regardless of the dose-response model chosen, the 95th percentile probability of enteric illness due to a single primary contract recreational event rarely exceeded 2.02% (95th percentile). The QMRA conducted for primary and secondary contact recreational events using data collected from Altona, Elwood and Frankston beaches during the swimming season 2017-2018 showed that the probabilities of contracting an illness were very low compared to the rates of illness expected using the SEPP (Waters) (gazette.vic.gov.au/gazette/ Gazettes2018/GG2018S499.pdf) and NHMRC interpretation (NHMRC 2008). Furthermore, the probabilities of contracting an illness were comparable to those found in the limited number of epidemiological studies with similar water body-types and pollution sources. This study suggested that the current practice of using indicators testing could not accurately predict the densities of pathogens in Port Phillip Bay. *E. coli* and enterococci correlated with the calculated rates of gastrointestinal illnesses due to a primary contact event. However, meaningful bay-specific objectives could not be directly derived from this relationship.
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include	Microbial source tracking EPA Victoria (2021) used microbial source tracking (MST) techniques to identify sources of microbial contamination and assess risks to recreational waters. The authors state (p.29) that on average, sewage and dog faeces were the highest contributors to faecal pollution at the beaches, although elsewhere (p.35) it is stated that the main contributions to faecal contamination were of avian and canine origins (which carry comparatively lower risks to human health). Data in Table 6 on p.29 suggests that human sewage, canine and avian sources are all significant although contributions vary with site. On average, 13% of the total faecal contamination originated from a human source, which is believed to drive the risk at each of the three beaches studied. The total proportion of human sewage in samples ranged from less-than-detection to 0.29%, with an average of 0.03% across all sites.

Question	Committee Guidance	G3: EPAV 2021, QMRA for Port Phillip Bay
	how this relationship been demonstrated in settings relevant to Australia.	The study used the qPCR marker Bacteroides HF183/BacR287 as an indicator of human sewage and found that there was a statistically significant correlation between the concentrations of the qPCR marker and the proportion of the microbial communities in the beach samples that were like human sewage (p=0.008). Similarly there was a significant correlation between enterococci concentrations and the proportion of the microbial community within the beach samples that were like human sewage communities (p=0.004). There was also a statistically significant relationship between enterococci concentrations and the total proportion of faecal microbial communities (p<0.001), perhaps confirming that enterococci provide an estimate of the overall level of faecal contamination. Human sources identified during the sanitary survey included bather shedding (release), toilet facilities, sewage treatment plant (STP) outfalls, STP by-passes, sewage overflows, sewage chokes, and boats.
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/implement-ed in settings relevant to the Australian context.	Indicator organism testing assumes that 100% of the faecal material is of human origin. However, this source tracking study showed that human faeces only contributed an average of 13% of the total faecal contamination and the main contributors to faecal contamination were of avian and canine origin. These carry comparatively lower risks to human health. This suggests that considering the origin of the contamination should be a primary factor in assessing risks of water-based recreation in Port Phillip Bay, since it can significantly impact the outcome of the risk assessment. [Reviewers note: The use of QMRA provided additional detail to support monitoring and sanitary assessment.]
Reviewer's comments and overall assessment		
Reviewer's comment (optional)	This was a large study with findings directly relevant to the primary and secondary research questions. The key findings demonstrate the broad utility of MST and QMRA approaches and are also important informing local management responses. The key findings were that the beaches: - in category 1 (swim safely) with P(ill) of ≤1% per primary contact recreational exposure about 94% of the time - in category 2 (swim at your own risk) with P(ill) between 1% and 10% only 6% of the time, and - never in category 3 (do not swim). And, the origin of the contamination should be a primary factor in assessing risks of water-based recreation, since it can significantly impact the outcome of the risk assessment. The published version of the study on the EPA Victoria website is only 59 pages and does not appear to contain all the technical detail that is likely to be available. [*Minor observation on some biomarkers used*: Uncertainty about the sources of cattle and chicken biomarkers in beach waters. It is possible that cattle faecal pollution has been transported from upstream catchments where cattle grazing is a significant land use. However, chicken biomarkers would be expected to have few sources in urban catchments in proximity to the beaches where planning controls prohibit or limit poultry ownership, whilst in upstream rural catchments poultry farming is mainly limited to intensive indoor operations which also have strict controls on management of litter. Perhaps the high chicken biomarker concentrations reported by EPA Victoria are due to the widespread land application of poultry litter, however the concentrations are surprisingly high in the Port Phillip Bay beaches included in this study].	
Overall Assessment	The Australian study contains local useful information in support of the research questions. Being both a QMRA and a grey literature document, it was possible to consider this document in the grey literature assessment and in the journal assessment "Qualitative Research" category. However, its inclusion here is consistent with the planned assessment approach described in the research protocols.	

5.2. G4: King et al. (2014)

5.2.1. Quality assessment

Criteria	Assessment	G4: King et al 2014, Review for DEFRA on bathing health risks
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	This study was a detailed review of the international recreational water health epidemiological literature published between 2003 and 2014. It reports use of formal review processes (although the processes used are not clearly referenced) and applies quality assessment criteria for selection of appropriate studies for review. As it appears to be a reasonably independent review, it can be considered to be compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	No evidence is supplied to indicate that this would be the case
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not stated, but it appears likely that Rand Corporation were commissioned (i.e. paid) by the Department for Environment, Farming and Rural Affairs (DEFRA) to carry out the study.
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	No	Last version of document cites August 2014.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	Yes	The document refers to following study: "CRD. Systematic Reviews. CRD's guidance for undertaking reviews in health care. Centre for Reviews and Dissemination, University of York 2009". This document describes detailed methodologies for review studies although the method description in the King et al study does not reflect this detail.
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	Yes	Quality assessment criteria from the CRD study cited above are used to select 21 studies for review.
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Only primary research studies were considered

Criteria	Assessment	G4: King et al 2014, Review for DEFRA on bathing health risks
Can grey literature such as government reports and policy documents be included?	No	Only primary research studies were considered
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial hazards it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	Yes	Extensive list given in Appendix B, Table 14, p.103
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	Yes	Extensive list given in Appendix B, Table 14, p.103
Is it specified what date range the literature search covers? Is there a justification?	Yes	Date range is from 2003 to 2014 (from time of publication of WHO 2003 recreational water guidelines to the date of the review.
Are search terms and/or search strings specified?	Yes	Extensive list given in Appendix B, Textbox 1, p.104
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	Yes	Quality assessment criteria are listed on pages 105 to 108. The criteria are divided by study type (randomised controlled trials (RCTs), case-control studies, cohort studies).
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	Yes	Assessment given in Appendix E, pp.117-124. However, the assessment is not clear. Questions considered were: · Were participants representative of the general population? · Were the comparator groups similar at baseline? · Were water samples taken near exposed individuals? · Were participants assigned an individual exposure? · How was exposure assessed? · How was GI assessed? .Length of follow-up (days) RCT: dropout rates Observational: Loss to follow-up
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	Yes	A formal method is not described, however the results of each study are tabulated in systematic fashion and used to support subsequent narrative text review sections.
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	Yes	Statistical findings of each study are collated and compared in order to support review conclusions e.g. Figure 2, p. 67.
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported

Criteria	Assessment	G4: King et al 2014, Review for DEFRA on bathing health risks
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	No	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	The purpose of this study was to: (i) review the literature epidemiological literature, published between the date of the WHO guidelines (2003) and the time of review preparation (2014), that examines the relationship between recreational swimming and health, including studies of microbes in water and adverse health events reported by swimmers and appropriate controls; (ii) Identify if there are differences in bathing risk for different groups of people, including, but not limited to, the general public, children/babies, surfers, competitive swimmers, anglers, canoeists, boat users, and scuba divers; (iii) Present an overview of different indicator standards (i.e. current recommendations for quantitative levels of organisms in recreational water), including the FIO classification boundaries of the 2006/7/EC Bathing Waters Directive, and to evaluate if the current literature supports these indicators; and	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*Yes*	*Include in review*

5.2.2. Data extraction

Question	Committee Guidance	G4: King et al 2014, Review for DEFRA on bathing health risks
Study summary		
Aim/objectives of study		To evaluate the epidemiological literature published between 2003 and 2014, King et al examined the relationship between recreational water use (i.e. exposure to marine water and freshwater recreational waters) and gastrointestinal illness (GI). The authors also sought to highlight any significant new research and/or evidence gaps which may help inform future bathing water quality guidelines. They focused on literature which presented water quality information based on the concentration of faecal indicator organisms (*E. coli* and enterococci) and gastrointestinal illness (GI) in order to answer the following research questions: 1. What is the post-2003 evidence for the health risks of recreational bathing in general – and to specific groups of bathers in particular? 2. What is the evidence to support the different classification standards outlined in the European Bathing Directive? King et al's research question 1 provides partial evidence for the Primary Research Question, specifically with respect to Committee guidance items (c) and (d).

Question	Committee Guidance	G4: King et al 2014, Review for DEFRA on bathing health risks
		There is also evidence in support of Secondary Research Question (i) but not for question (ii).
Author's conclusion: interpretation of results		Overall, King et al stated they found it difficult to draw any firm conclusions from the evidence because of the heterogeneity of study protocols and methodological limitations, including self-selection and misclassification biases. Thus, the various results presented by the study authors could be an artefact of the range of methods used. With the methodological limitations of all of the included studies in mind, the following general conclusions may be made: • Based on 16 studies published since 2003, there appears to be a consistent significant relationship between faecal indicator organisms (used to measure water quality) and GI in freshwater studies, but not in marine water studies. Given the apparent lack of relationship between GI and water quality levels meeting different boundaries, it is unclear whether the boundaries of the 2006/7/EC Bathing Waters Directive are supported by studies published in the post-2003 period.
Research Questions		
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	Overall, 21 papers (from 16 studies), including two randomised controlled trials and 14 observational studies, met the inclusion criteria of the review 1. What is the post 2003 evidence for the health risks of recreational bathing in general – and also to specific groups of bathers? King et al found that based on studies included in the review, there is continuing evidence that bathing in recreational water poses some increased risk of GI to bathers compared with non-bathers. Specifically: • There appears to be little or no significant difference between GI in bathers compared with non-bathers at marine beaches. • In contrast, there appears to be a consistent and significantly higher risk of GI in bathers compared with non-bathers in freshwater sites in temperate climates (up to 3.2 times higher). • There is some evidence to suggest that increased bather exposure (i.e. head immersion or swallowing water) results in a higher risk of GI, particularly for freshwater bathers. • There is evidence to suggest that an increase in time spent in water is associated with an increase in GI. Only two studies reported results separately by age group of bathers, and only one study investigated the risk of GI among other water users (e.g. in people canoeing, fishing, kayaking, motor boating, or rowing), so the data on these specific population groups remain limited. Findings were: • There is very little evidence on how the risk of GI varies with age. There is a lack of recent studies which have evaluated the risk of GI in recreational water users other than bathers (e.g. in people canoeing, fishing, kayaking, motor boating, or rowing).
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the	2. What is the evidence to support the different classification standards outlined in the European Bathing Directive? King et al's review found that: • There is little evidence for a significant dose response between faecal indicator organisms and GI in marine water. • There appears to be a significant dose response between faecal indicator organisms and GI in fresh water. • Very high levels of pollution due to heavy rainfall and urban

Question	Committee Guidance	G4: King et al 2014, Review for DEFRA on bathing health risks
	relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.	run-off or sewage contamination are associated with increased GI.
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/ implemented in settings relevant to the Australian context.	No evidence to support a response to this question.
Reviewer's comments and overall assessment		
Reviewer's comment (optional)	The methodology followed the process of a systematic review but was considered by the authors a rapid evidence assessment because the search was limited to literature published from 2003 to the review date [2014]. The detailed review methodology is described in the report and is similar to the approach used for the current narrative review. With respect to providing evidence for the current narrative review, King et al.'s review was more narrowly focused on providing information against which to evaluate the European Bathing Directive classifications. Importantly, King et al., were highly critical of the quality of the literature reviewed. They reported difficulty in drawing firm conclusions from the evidence because of the heterogeneity of study protocols and methodological limitations, including self-selection and misclassification biases. It was suggested that the various results presented by the study authors could be an artefact of the range of methods used.	
Overall Assessment	Being both a systematic review and a grey literature document, it was possible to consider this document in either category. However, its inclusion here is consistent with the planned assessment approach described in the research protocols. The review was thorough and conducted according to best practice at the time but could be more clearly reported.	

5.3. G8: NHMRC (2008)

5.3.1. Quality assessment

Criteria	Assessment	G8: NHMRC 2008, Guidelines for Managing Risks in Recreational Water
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The 2008 NHMRC Guidelines were developed by the Australian Government. They are not mandatory but rather have been developed as a tool for state and territory governments to develop legislation and standards appropriate for local conditions and circumstances.

Criteria	Assessment	G8: NHMRC 2008, Guidelines for Managing Risks in Recreational Water
Are the administrative processes documented and publicly available?	Partly	Some details of the guideline development process are reported in a Process Report
Was the work overseen by an expert advisory committee?	Yes	The work was overseen in stages by the NHMRC Working Group on Healthy Recreational Water Use and the NHMRC Guidelines for Managing Risks in Recreational Water Working Committee.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	No details are reported in the 2008 publication.
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Yes	Two rounds of public consultation were undertaken in 2004 and 2006. A summary of changes made as a result of public consultation and a list of individuals and organisations who provided submissions is detailed in a Process Report.
Is the advice peer reviewed?	Yes	The 2008 NHMRC Guidelines underwent peer-review in 2007.
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Last updated in 2008. Currently under review.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	Yes	With respect to Microbial quality, reference is made to the WHO 2003 Guidelines on Safe Recreational Water Quality, Table 5.7, p.72).
Can grey literature such as government reports and policy documents be included?	Yes	
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Not reported
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported

Criteria	Assessment	G8: NHMRC 2008, Guidelines for Managing Risks in Recreational Water
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	No	Not reported
Are the parameter value assumptions documented and explained?	No	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	No	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	No	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	No	Not reported
If expert judgement is required, is the process documented and published?	No	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	No	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	No	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	Ch. 5 of the 2008 NHMRC Guidelines deals with topics of relevance to the primary research question (i.e. monitoring, assessing and predicting risks from diffuse and point source microbial contamination in recreational waters). Although the purpose of this review is to support an update the information provided in Chapter 5, the material contained in the chapter could be considered to provide a baseline for reference against other guidance documents under examination. On that basis it can be included for further review and to identify areas for improvement in the updated Guidelines during the critical appraisal process.	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

5.3.2. Data extraction

Question	Committee Guidance	G8: NHMRC 2008, Guidelines for Managing Risks in Recreational Water
Study summary		
Aim/objectives of study		The primary aim of the 2008 NHMRC Guidelines is to protect human health. The Guidelines provide a tool for states and local agencies for use in developing legislation and standards appropriate for local conditions and circumstances and to encourage the adoption of a nationally harmonised approach to managing recreational water quality.
Author's conclusion: interpretation of results		n/a. Being a guideline document it does not contain author conclusions.
Research Questions		
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	The 2008 NHMRC Guidelines (S.5.1) implicitly recommend a classificatory approach to the management of recreational water quality. The approach involves microbial-based categorisation of the water using a combination of sanitary inspection and microbial water-quality assessment. Further combining such categorisation with prevention of exposure at times of increased risk leads to the framework for assessing recreational water quality recommended by the guidelines. This ultimately leads to the classification matrix shown in Table 5.13 of the guidelines which is based on four classes of microbial water quality (as 95th percentiles of enterococci/100 ml) by four sanitary inspection categories (rating susceptibility of the site to faecal influence). The classification matrix for faecal pollution of recreational water environments: • emphasises faecal contamination from humans, with lesser importance placed on faecal contamination from other sources. • enables local management to respond to sporadic or limited areas of pollution and thereby upgrade a recreational water body's classification, provided that appropriate and effective actions are taken to control exposure. • Provides triggers for actions to reduce risk. • provides incentives for taking action locally and reducing pollution. • Produces a generic statement of the level of risk, thereby supporting informed personal choice, and it helps to identify appropriate management and monitoring actions.
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.	n/a.
Secondary Q (ii) What are the current practices to minimise or	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on	n/a.

Question	Committee Guidance	G8: NHMRC 2008, Guidelines for Managing Risks in Recreational Water
manage this/these risk/s?	scientific evidence. (b) Provide examples/case studies of how this is achieved/ implemented in settings relevant to the Australian context.	
Reviewer's comments and overall assessment		
Reviewer's comment (optional)	Chapter 5 of the Guidelines deals with topics of relevance to the primary research question (i.e. monitoring, assessing and predicting risks from diffuse and point source microbial contamination in recreational waters). Although the purpose of this review is to support an update of the information in Chapter 5, the material contained in the chapter could be considered to provide a baseline for reference against other guidance documents under examination.	
Overall Assessment	The structure of Chapter 5 of the 2008 NHMRC Guidelines is based on a microbial-based classificatory approach, combining sanitary inspection and microbial water-quality assessment, to create a risk matrix to guide management. Although the content of the chapter needs updating, the structure still describes an effective approach for management of recreational water quality.	

5.4. G11: NSW DPIE (2020)

5.4.1. Quality assessment

Criteria	Assessment	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The Protocol for Assessment and Management of Microbial Risks in Recreational Waters was prepared by the NSW Dept of Planning, Industry and Environment and provides detailed guidance for implementing Chapter 5 of the 2008 NHMRC Guidelines.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	Not reported
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Not reported
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported

Criteria	Assessment	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	No	Not reported
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for	n/a	Not reported

Criteria	Assessment	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
feasibility of implementing the guideline values (e.g. measurement attainability)?		
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	The Protocol for Assessment and Management of Microbial Risks in Recreational Waters provides detailed guidance for implementing Chapter 5 (Microbial Quality of Recreational Water) of the 2008 NHMRC Guidelines. With respect to the primary research question, it provides a clear and detailed practical methodology for monitoring, assessing, and predicting risks from diffuse and point source microbial contamination in recreational waters. Since it augments the information in the 2008 NHMRC Guidelines with some practical detail, it can be considered to be useful for informing the response to the primary research question, although it does not provide new scientific information.	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*Partly*	*Include in review*

5.4.2. Data extraction

Question	Committee Guidance	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
Study summary		
Aim/objectives of study		The NSW DPIE Protocol for assessment and management of microbial risks in recreational waters provides guidance to support the implementation of Chapter 5 - Microbial Quality of Recreational Water for the 2008 NHMRC Guidelines. The Protocol has three stated key objectives: • Raise awareness and understanding of the risks associated with microbial contamination of recreational waters • Facilitate the adoption and consistent implementation of the 2008 NHMRC Guidelines • Increase community access to information on recreational water quality
Author's conclusion: interpretation of results		n/a. Being a guideline document it does not contain author conclusions.
Research Questions		

Question	Committee Guidance	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	The NSW DPIE Protocol is closely aligned with and builds on the 2008 NHMRC Guidelines. The Protocol describes a framework for managing microbial risks in recreational water which consists of 7 parts: (1) Understanding the microbial quality guidelines (essentially an introductory overview) (2) Selecting sites for assessment (3) Sanitary inspection (4) Microbial water quality monitoring (5) Microbial assessment and beach classification (6) Reporting (7) Management The key innovative components of the protocol are contained in Parts 2 to 6. The protocol provides much more explicit guidance for the development of recreational water microbial risk assessment and risk management than the 2008 NHMRC Guidelines. For example there are 48 pages of guidance material and 26 pages of templates vs the NHMRCs 30 pages and 9 pages respectively. The guidance is clearly laid out and of a high standard.
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.	The Protocol adopts the 2008 NHMRC Guidelines recommended approach for the use of enterococci as the indicator organism for assessing risks from microbial contamination in recreational waters.
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/implemented in settings relevant to the Australian context.	Part 7 of the 7-part management framework for managing microbial risks in recreational water lists generic management actions to reduce the microbial risks to recreational water quality. Risk management recommendations are classified as follows: .Actions to reduce likelihood - Pollution abatement sewage and stormwater controls - Use of microbial source tracking (MST) to assist in identifying sources and thus appropriate source controls .Actions to reduce consequence - Beach closures - Informed personal choice based on media advisories .Triggers for management actions - Water quality monitoring (based on enterococci) - Rapid responses to spill incidents (e.g. sewer overflows)
Reviewer's comments and overall assessment		
Reviewer's comment (optional)	Key elements of the protocol that contribute to the primary research question are: . The inclusion of an initial site prioritisation step which prioritises beaches to provide a basis for determining resource allocation. This step provides a mechanism for identifying high priority swimming locations that should attract more monitoring and reporting resources to ensure the greatest benefit is obtained. High priority beaches become the subjects of more detailed risk assessments, and programs for monitoring, reporting and microbial risk management.	

Question	Committee Guidance	G11: NSW DPIE 2020, Protocol for management of microbial risk in recreational waters
	. A detailed Sanitary Inspection process with 5 steps: 1. Define the swimming area and catchment. 2. Identify sources of faecal contamination and gather information on the frequency, duration and intensity of impact. 3. Assess likelihood for each identified source of faecal contamination. 4. Determine the Sanitary Inspection Category for the site (overall likelihood). 5. Hold a workshop or meeting with stakeholders to review pollution sources and likelihood assessment. . A microbial water quality monitoring program with specific guidance for sampling design and documentation, quality control aspects including sampling procedures, lab methods and accreditation, data management and work health and safety. . A microbial assessment and beach classification program which describes the methodology for determining beach suitability grades . Reporting of: Annual Classifications, Weekly Star Ratings, Advisories following rainfall events, daily beach pollution forecasts, communication planning and methods of communication. . Appendices with high quality templates for data collection and reporting for such items as: Sanitary inspection major attributes (e.g. pollutions sources), and water quality sample log sheets. A further noteworthy innovative aspect of the Protocol is the inclusion of methods for assessing and scoring likelihoods of contamination from a wide variety of pollutions sources including: Bather shedding, toilet facilities, wastewater treatment plant discharges (including bypass events), sewer chokes and leaks, onsite sewage treatment systems, wastewater reuse, stormwater, river discharges, lagoons, boat discharges and animals. Templates for scoring are also provided in the appendices.	
Overall Assessment	The Protocol for Assessment and Management of Microbial Risks in Recreational Waters provides detailed guidance for implementing Chapter 5 (Microbial Quality of Recreational Water) of the 2008 NHMRC Guidelines. With respect to the primary research question, it provides a clear and detailed practical methodology for monitoring, assessing and predicting risks from diffuse and point source microbial contamination in recreational waters. Since it augments the information in the 2008 NHMRC Guidelines with much practical detail, it can be considered to be very useful for informing the response to the primary research question, although it does not provide new scientific information.	

5.5. G13: US EPA (2017)

5.5.1. Quality assessment

Criteria	Assessment	G13: US EPA 2017, Review
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The US EPA's review is based on a detailed and systematic review of the scientific literature and can be considered an authoritative report on the subject. Although there is a lack of detail about the review process , the reportcontains useful, high-quality summaries of the review findings. Given that the report is informed by critical analysis of the scientific literature and follows a systematic review process , it can be considered compatible with Australian processes.
Are the administrative processes documented and publicly available?	Yes	The administrative processes for the review are described in the document on page 8. A number of review processes were undertaken including an EPA review of recreational water research, a systematic review of available peer-reviewed literature on a subset of specific topics, and a review of literature resulting from the systematic searches and from materials available from other sources such as

Criteria	Assessment	G13: US EPA 2017, Review
		technical documents from US States and the United States Geological Survey (USGS).
Was the work overseen by an expert advisory committee?	Can't Tell	Not reported
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Yes	A public consultation process is described in Section III E on p.9. It states "The EPA held a public webinar in July 2017 on the review for any interested stakeholders. Participants included stakeholders from across the spectrum of environmental, industry, local government, and public health stakeholder groups. The webinar provided an overview of the review the EPA has undertaken and enabled stakeholders to provide input on the topics included in the review. The EPA communicated some of the initial findings of the review of the science and the timeline for completing the review"
Is the advice peer reviewed?	Can't Tell	It is likely that the document and advice within was subject to peer-review but no process is described in the document or on the US EPA website (https://www.epa.gov/wqc/five-year-review-2012-recreational-water-quality-criteria).
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	No updates have been issued since the production of the 2017 report.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	The scope and methods of review are documents in section III of the report, however, there is no description of the decisions behind the scope, definitions and evidence review parameters.
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	No evidence is supplied that indicates a preference for studies that follow agreed international protocols or meet appropriate industry standards
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	Yes	The methods are documented in Section III Scope and Methods of Review on p.8 and in Appendices A and C.
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is discussed.
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	Yes	The literature search was limited to English-language, peer-reviewed citations, published between 2010 and March 2017.
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	Yes	Grey literature is cited in the document (e.g. EPA Method A, 1611, and 1609 listed in Appendix A, Table A-1, p. 83).
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	n/a	Not reported
Evidence search		
Are databases and other sources of evidence specified?	Yes	The literature databases PubMed and Web of Science are cited as information sources on p.8

Criteria	Assessment	G13: US EPA 2017, Review
		including for Appendix C, and for Appendix A on p. 84.
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	Yes	The literature databases PubMed and Web of Science are cited as information sources (e.g. p. 8).
Is it specified what date range the literature search covers? Is there a justification?	Yes	The literature search was limited to English-language, peer-reviewed citations, published between 2010 and March 2017.
Are search terms and/or search strings specified?	Yes	Search terms are specified for only for Appendix A "Advancements in Mitigating Interference in Quantitative Polymerase Chain Reaction (qPCR) Methods for Microbial Water Quality Monitoring". No search terms or search strings are provided for the other reviews.
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Aside from the exclusion criteria already listed above, no other criteria are listed.
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	Yes	Review results tabulated in Appendix C with the headings: Location, Study Type, Contamination Source, Health Effects Evaluated, Water Quality Metrics, Charges, Conclusions.
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	Yes	Extensive review of the overall body of evidence. Results described elsewhere in this review.
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		

Criteria	Assessment	G13: US EPA 2017, Review
Comments	The US EPA 2017 review addresses a range of topics relevant to both the primary and secondary research questions. It is an important reference document for the current narrative review.	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*Yes*	*Include in review*

5.5.2. Data extraction

Question	Committee Guidance	G13: US EPA 2017, Review
Study summary		
Aim/objectives of study		The US EPA "2017 Five-Year Review of the 2012 Recreational Water Quality Criteria" is a 5-year review of its 2012 Recreational Water Quality Criteria (RWQC), as required by amendments to the 1972 US Clean Water Act [section 304(a)(9)(B)]. The review objectives were: • Inventory and evaluate health study information published since 2010 on public health impacts associated with exposure to faecal contamination in recreational waters. • Review the 2012 RWQC based on internal EPA input on the science, taking into consideration feedback from the greater beach water quality community and stakeholders. • Identify additional indicators and methods, including those that have become more refined or feasible since the issuance of the 2012 criteria, and assess their applicability for predicting potential adverse human health effects from recreational exposure. • Provide information on the state of the science with respect to source tracking methods, sanitary survey design, predictive modelling for both fresh and marine waters, and other implementation tools. • Include the latest science and information pertaining to the development of other criteria, such as coliphage and cyanotoxin criteria, that have the potential to protect recreational uses. • Assess factors affecting state/authorized tribe adoption of the RWQC including perceived barriers to adoption and how states have implemented the criteria to meet their specific circumstances [Reviewers note: the last two dot points are beyond the scope of the current narrative review]
Author's conclusion: interpretation of results		The authors split the summary of review findings into two components; (i) Science Review and (ii) Implementation Review. The key elements of each component relevant to the current narrative review are presented alongside the relevant research questions below. Note that implementation review components only related to secondary question (ii).
Research Questions		
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to	Science Review • Health Studies: A growing body of evidence suggests that children can be disproportionately susceptible to health effects resulting from exposure to pathogens in recreational waters. There are opportunities for further resolution of epidemiological relationships, especially in the area of children's health protection and wider application of Enterococcus spp. qPCR. • Antimicrobial Resistance. Although of increasing interest, US EPA suggests more research is needed to better understand the

Question	Committee Guidance	G13: US EPA 2017, Review
	the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	role the environment plays in transferring antimicrobial resistant bacteria (AMRB) to primary contact recreators.
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship been demonstrated in settings relevant to Australia.	Science Review • Coliphage as an indicator: Because evidence strongly suggests most illnesses in recreational waters are due to enteric viruses, development and implementation of viral indicators, such as coliphage, may yield advances in public health protection. • Indicators and Performance of qPCR Methods. The advances in qPCR methodology since 2010 have brought greater reliability and utility to beach monitoring programs where they have been implemented, yet opportunities remain for further refinement of qPCR methodologies. Enterococcus spp. measured by qPCR is a better predictor of swimming-associated GI illness and more timely than current culturable bacterial indicators. These factors coupled with a greater distribution of qPCR-capable laboratories in the future could lead to enhanced public health protection if implemented under the current criteria. A further conclusion drawing on Dr McBrides' review and elaborated in the text (section IV, A, 4: Health Relationships and Alternative Indicators) noted that although observations show that development and use of alternative faecal indicators is a rich and evolving field, no strong case was made for changing the indicators currently. However, alternative method-indicator combinations might be supported in certain situations and warrant further study especially in specific settings, such as tropical waters.
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/implemented in settings relevant to the Australian context.	Science Review • Microbial Source Tracking. Accurate and reliable MST technologies could markedly improve future water quality management in the U.S., possibly allowing for the development of alternative site-specific criteria based on pollution sources present, strategic remediation planning based on faecal pollution levels from human sources. Implementation Review • Sanitary Surveys. Sanitary Surveys continue to serve as an important tool for informing site remediation, characterizing waters for QMRA and site-specific criteria development, and can be linked with integrated environmental modelling. • Predictive/Statistical Modelling. Predictive models offer an alternative for same-day notification and resulting public health protection with lower capital investment and unit costs than other rapid methods. • Deterministic Process Modelling for Recreational Beach Site Assessment and Enhancement/Remediation. These models provide a means of understanding physical forces influencing the movement of contaminants for problem definition and remediation and can include QMRA health-based models to develop site-specific criteria or evaluate remediation.
Reviewer's comments and overall assessment		
Reviewer's comment (optional)		

Question	Committee Guidance	G13: US EPA 2017, Review
		The review was based on 3 main review components: 1. A systematic review of available peer-reviewed literature published between 2010 and 2017 conducted for EPA by Dr Graham McBride of the NZ National Institute of Water and Atmospheric Research (NIWA). 2. A supplemental review by EPA of literature resulting from systematic searches and from other sources such as technical documents from US states and the United States Geological Survey (USGS). 3. Informal interviews with recreational water public health practitioners and members of the academic community with relevant expertise in beach monitoring. The results of the above review components informed an extensive review section of the document entitled "Findings of the Review". This section provides a general discussion of the review findings. While the review was unable to draw any concise conclusions, several suggestions for further research are provided. A summary of the findings is presented above in the responses to the primary and secondary research questions.
Overall Assessment		The review contains authoritative information on a broad range of topics and research findings from particular sources. Due to the highly heterogeneous subject matter, an effective synthesis was unable to be conducted to draw concise conclusions.

5.6. G16: WHO (2018)

5.6.1. Quality assessment

Criteria	Assessment	G16: WHO 2018, Bathing Water Review
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The WHO 2018 bathing water review is based on a detailed and systematic review of the scientific literature and can be considered an authoritative report on the subject. The review process could be more clearlyreported; however the report contains a useful, high-quality review of key themes relevant to microbial risk and recreational water use which can be considered compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	High level meeting minutes of a meeting of the WHO Expert Group on Recreational Water Quality are included in Appendix 2. However there is a lack of detail about the meeting discussion and decision-making whichdoes not contribute to transparency.
Was the work overseen by an expert advisory committee?	Yes	Although not clearly stated, based on WHO processes the work was overseen by a water quality technical advisory group and by an Expert Group on Recreational Water Quality.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Yes	It is stated on p. 10 of the document that input into the process was received through a review of a background document by the European Microbiology Expert Group (EMEG) and the Joint Research Centre (JRC), two EC meetings (an informal Bathing Water Directive expert group meeting, 5/10/17 and a Stakeholder consultation meeting, 24/11/17), a questionnaire put to all Member States

Criteria	Assessment	G16: WHO 2018, Bathing Water Review
		and feedback received on draft versions of the factsheets.
Is the advice peer reviewed?	Can't Tell	It is likely that the document and advice within was subject to peer-review, but no process is described in the document.
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	Yes	The document was published relevantly recently (June 2018).
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	Yes	Grey literature is cited in the document (e.g. Health Canada 2012 Recreational Water Guidelines cited on p. 45).
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the	No	Not reported

Criteria	Assessment	G16: WHO 2018, Bathing Water Review
information provided in the studies)? If so, provide details.		
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	This report represents the advice of the WHO, as a series of recommendations, for consideration in a potential review of the current European Commission (EC) Bathing Water Directive (BWD) – Directive 2006/7/EC3. Whilst the review process does not appear to have been undertaken in a systematic fashion, the technical content is recent and thorough and highly relevant to the primary and secondary research questions.	
Useful for answering primary research question?	*Yes*	*Include in review*
Useful for answering secondary research questions?	*Yes*	*Include in review*

5.6.2. Data extraction

Question	Committee Guidance	G16: WHO 2018, Bathing Water Review
Study summary		
Aim/objectives of study		The WHO recommendations on scientific, analytical, and epidemiological developments relevant to the parameters for bathing water quality in the Bathing Water Directive (2006/7/EC) represents the advice of the WHO, as a series of recommendations, for consideration in a potential review of the current European Commission (EC) Bathing Water Directive (BWD) – Directive 2006/7/EC3. The document summarises, in a series of fact sheets, the recent

Question	Committee Guidance	G16: WHO 2018, Bathing Water Review
		scientific literature on the existing Bathing Water Directive parameters (intestinal enterococci and *E. coli*). It also examines the feasibility of possible additional parameters (viral indicator(s) and harmful algal blooms) [not in scope of current narrative review] and considers wider/emerging issues (antimicrobial resistance, microplastics, other infectious agents) also as a series of fact sheets.
Author's conclusion: interpretation of results		The authors' conclusions are set out in the recommendations included below in the responses to primary and secondary research questions.
Research Questions		
Primary Q. How can we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?	(a) Provide examples of what is done in Australian and international jurisdictions and their reasoning (b) Determine what is done in other settings and how this relates to the Australian context (c) Determine how specific target populations such as children, immunocompromised or the elderly are impacted. (d) Determine the main factors impacting risk and its prediction (environmental, microbial, etc.).	Recommendations (with WHO no.) 1. Intestinal enterococci and *E. coli* should be retained. 2. The four levels within the current classification system (excellent, good, sufficient and poor) should be retained. 3. The classification system for each category should be based on a 95-percentile value and not a mixture of 95- and 90-percentile water quality standards. 4. The annual minimum number of samples for an EU bathing water site should be increased to 20. 5. Data from bathing water sites (with at least 80 samples) should be tested for log10 normality. Where the data are shown to be log10 normally distributed, the calculation method in Annex II of the 2006 Bathing Water Directive should be used. Where the data do not exhibit log10 normality the Hazen calculation should be used. Where there are inadequate data available, it is suggested that the Hazen calculation is used. 6. The ISO method (9308-1) for *E. coli* analysis is no longer appropriate for the measurement of bathing water quality. Sampling and sample analysis should be conducted by laboratories accredited for the methods being used. Good practice 7. Bathing water quality should be representative of the whole bathing area. This should be confirmed by occasional spatial/beach shoreline transect sampling. 8. Temporal variability in water quality should be addressed by sampling at different times to characterise the bathing day in the overall compliance data set or taking a precautionary approach and sampling when water quality is generally poorest. 9. Where predictive modelling is used to inform the public, the choice of model and methods of public information dissemination should be reported. The models should meet minimum requirements (including an explained variance of at least 50-60%) and the approach taken should be justifiable and auditable. 10. In a number of cases (such as microbial source tracking techniques and quantitative microbial risk assessment for use in bathing water profiling) it would be valuable to commission a detailed state of the art review, to provide standardised information and advice on their practical application to Member States.
Secondary Q: (i) What are the indicators/surrogates of this/these risk/s?	Committee Guidance: (a) Review the new technologies available to assess and monitor risks and determine how they could be practically applied to Australian recreational waters (b) Describe the relationship between the indicator and surrogates with adverse health outcomes. Include how this relationship	Recommendations 1. Current evidence does not support the inclusion of a viral indicator (or viral pathogen) as a regulatory parameter within the BWD. Good practice and research 2. Viruses have a valuable role to play in microbial source tracking investigations and also quantitative microbial risk assessment, and it is suggested that these tools should be considered more widely in bathing water profiling 3. Research needs to include the identification of suitable candidate viral organisms and the development of standard methods suitable for bathing water use.

Question	Committee Guidance	G16: WHO 2018, Bathing Water Review
	been demonstrated in settings relevant to Australia.	
Secondary Q (ii) What are the current practices to minimise or manage this/these risk/s?	Committee Guidance: (a) Provide examples of how mitigation strategies have been developed based on scientific evidence. (b) Provide examples/case studies of how this is achieved/ implemented in settings relevant to the Australian context.	Under the heading of "Wider/Emerging Issues", the WHO document recommends: 1. At locations where swimmer's itch is known to occur, this should be included in the bathing water profile and information provided to members of the public. 2. Where cases of wound infection (e.g. caused by Vibrio spp.) have resulted from a recreational water exposure, this information should be communicated in the bathing water profile. In addition, on-site information should be provided including advice on bather hygiene measures to minimise risk and actions to take if a wound is sustained while bathing.
Reviewer's comments and overall assessment		
Reviewer's comment (optional)	The review scope and approach (parameters and fact sheets) were determined at a WHO expert meeting in Berlin (March 2017). The parameter fact sheets are based on a focused review of the scientific literature (conducted by Dr Lorna Fewtrell during 2017) to update the relevant information in the WHO 2003 Guidelines for Safe Recreational Water Environments (Chapters 7 and 8) and the 2009 Addendum to the Guidelines (Chapter 4) and inform WHO advice to the EC.	
Overall Assessment	The review material is clearly presented and targets issues of relevance to the European Bathing Water Directive, but overall does not report on the expert analysis of the constituent research papers in detail. This may be deliberate to keep the document concise.	

6 Completed quality assessment and data extraction for the included primary studies

6.1. J2: Ahmed, Hamilton, et al., (2018)

6.1.1. Quality assessment

Q.	Criteria	J2, Ahmed, W.;, 2018, Quantitative microbial risk assessment of microbial source tracking markers in recreational water contaminated with fresh untreated and secondary treated sewage Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?	**Yes**		
1	Was there a clear statement of the aims of the research?	Yes	The main objective of this study was to undertake an exploratory QMRA analysis based on the process limit of quantification (PLOQ) of five sewage-associated MST markers targeting HF183, nifH, HAdV, HPyV and PMMoV in beach water samples seeded with fresh untreated and secondary treated sewage samples in Australia	**Definitely low risk of bias (++)**
2	Is the methodology appropriate?	Yes	The methodology is appropriate but assumes a high level of familiarity with related research by the authors where further methodological details are provided.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?	**Yes**		
3	Was the research design appropriate to address the aims of the research?	Yes	Five sewage-associated, quantitative PCR (qPCR) MST markers were evaluated to determine at what concentration these nucleic acid markers reflected a significant health risk from exposure to fresh untreated or secondary treated sewage in beach water.	**Definitely low risk of bias (++)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is adults undertaking primary contact recreation.	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Data was collected in a way that addressed the research issue, however, the relationship between the marker concentrations and the reference pathogen concentrations is not clearly defined.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of adults undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	Yes	As noted above, the relationship between the marker concentrations and the reference pathogen concentrations is not clearly defined. However it is sufficiently rigorous for concentrations of sewage markers that would pose a human health risk to be estimated.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	A clear list of conclusions is provided	**Definitely low risk of bias (++)**

Q.	Criteria	Assessment	J2, Ahmed, W.;, 2018, Quantitative microbial risk assessment of microbial source tracking markers in recreational water contaminated with fresh untreated and secondary treated sewage Comments	Risk of Bias rating
	Section C: Will the results help locally?	**Yes**		
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is valuable to inform this narrative review as it translated the concentrations of five sewage-associated molecular markers into human health risks. One major assumption however appears to be that genomic copies = viable virus (virions).	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*This QMRA has been conducted with a satisfactory level of rigour. Consequently, it is classified as having a "Probably low risk of bias".*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.1.2. Data extraction

Category	Data class	J2: Ahmed, W.; Hamilton, K. A.; Lobos, A.; Hughes, B.; Staley, C.; Sadowsky, M. J.; Harwood, V. J. 2018
Descriptive attributes	Title	Quantitative microbial risk assessment of microbial source tracking markers in recreational water contaminated with fresh untreated and secondary treated sewage
	Publication Title	Environment International
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	117 (2018) 243-249
	Publication date	2018
	Publication Source	Environment International 117 (2018) 243-249 DOI:10.1016/j.envint.2018.05.012
	Peer reviewed	Yes
	Country of origin	Australia
	Source of funding	Julius Career Award funding from CSIRO and the School of Agriculture and Food Sciences, The University of Queensland, Minnesota Agricultural Experiment Station funding to Michael J. Sadowsky
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	Norovirus (NoV) and Human Adenovirus (HAdV).

Category	Data class	J2: Ahmed, W.; Hamilton, K. A.; Lobos, A.; Hughes, B.; Staley, C.; Sadowsky, M. J.; Harwood, V. J. 2018
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m
	DOI http://dx.doi.org/	10.1016/j.envint.2018.05.012
Study characteristics	Aim/objectives of study	The stated objective of the study was to undertake an exploratory QMRA analysis based on the process limit of quantification (PLOQ) of five sewage-associated quantitative PCR (qPCR) MST markers [Bacteroides HF183 (HF183), *Methanobrevibacter smithii* nifH (nifH), human adenovirus (HAdV), human polyomavirus (HPyV) and pepper mild mottle virus (PMMoV)] in beach water samples seeded with fresh untreated and secondary treated sewage samples, to determine at what concentration these nucleic acid markers reflected a significant health risk from exposure to fresh untreated or secondary treated sewage in beach water.
	Study type/design	QMRA informed by lab analysis of sewage dosed filter-sterilized beach water samples (salinity 34‰)
	Study duration	Not stated
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Filter beach water samples used in lab.
	Exposure scenario	QMRA exposure scenario based on volume of water (in mL) ingested during swimming from a study of pool swimmers (Dufour et al., 2006, https://doi.org/10.2166/wh.2006.0026).
	Exposure pathway	Ingestion while swimming
	Source of infection/ contamination	Fresh untreated and secondary treated sewage dosed into filtered beach water samples.
	Causal organisms	NoV and HAdV 40/41 were selected as reference pathogens as these viruses are known to cause swimming-associated illnesses in recreational waters.
	Comparison group(s)	Probability of GI illness compared to US EPA 2012 guideline risk of 36 GI Illnesses/1000 exposures or 0.036.
Study methods	Water quality measurement used	Concentrations of biomarkers assessed using either data from related published study (Hughes et al 2017: https://doi.org/10.1128/AEM.00028-17), or from qPCR kits as described below.
	Method of microorganism isolation and enumeration (if applicable)	Genomic copies reported from qPCR assays.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	The water sampling protocol used in the study involved lab filtration of 300 mL of water sample to capture sewage-associated markers on the membrane, followed by nucleic acid extraction with Mo Bio Power Water DNA and RNA Isolation Kits. This allowed the authors to obtain a final volume of 100 µL of nucleic acid from 300 mL of water sample seeded with either fresh untreated sewage or secondary treated sewage. A 3 µL template of 100 µL nucleic acid was subjected to qPCR analysis. Therefore, it was possible to estimate the concentration of the sewage markers/100 mL water sample by back-calculation. Samples were prepared in triplicate.
	Limits of reporting for the organism of concern	For the biomarkers, defined criteria were established to determine the PLOQ. The PLOQ was defined as the smallest volume of sewage that could be subjected to the complete sample preparation process, including dilution, filtration and nucleic acid extraction and still be

Category	Data class	J2: Ahmed, W.; Hamilton, K. A.; Lobos, A.; Hughes, B.; Staley, C.; Sadowsky, M. J.; Harwood, V. J. 2018
		reliably quantified in 2/3 qPCR reactions. No limits of reporting were stated for NoV and HAdV 40/41.
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Limited discussion of quality assurance issues included in document. Possibly addressed in a previous study by Hughes et al 2017: https://doi.org/10.1128/AEM.00028-17). During qPCR analysis, all DNA and RNA samples were run in triplicate with three negative controls (sterile water) on 96-well plates using the CFX 96 thermocycler (Bio-Rad Laboratories, CA, USA)
Statistics	Statistical methods used	QMRA dose-response models based on log-normal probability distribution functions (pdfs) for concentrations of NoV and HAdV 40/41 in untreated sewage and secondary treated sewage.
	Details on statistical analysis (if any)	Serial ten-fold dilution series of beach water samples dosed with either fresh untreated sewage or fresh secondary treated sewage were tested to determine the PLOQ of the 5 sewage biomarkers. The corresponding probability of GI illness from NoV or HAdV 40/41 for each biomarker PLOQ was also compared with the US EPA tolerable benchmark for GI illness for recreational water (0.036).
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Among all the markers tested, HF183 concentration needed to be greater in the water sample than other markers to correspond to an exceedance of the illness benchmark (Table 2 in paper). When NoV and HAdV 40/41 were used as reference pathogens, a median concentration of 3.22×10^3 GC of the HF183 in 100 mL of water sample represented a risk above the GI illness benchmark value when beach water was contaminated with fresh untreated sewage. Similarly, 3.66×10^3 GC of HF183 in 100 mL of water sample represented a risk above the benchmark for both NoV and HAdV 40/41, when beach water was contaminated with secondary treated sewage. Table 2 in the paper lists values for the other biomarkers tested.
	How outcome was assessed	PLOQs for biomarkers assessed using serial ten-fold dilutions of sewage dosed beachwater samples.
	Method of measurement	Genomic copies reported from qPCR - measured in triplicate and reported with standard deviations.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	Results of this study provide a valuable context for water quality managers to evaluate human health risks associated with contamination from fresh sewage. The approach described here may also be useful in the future for evaluating health risks from contamination with aged or treated sewage or faeces from other animal sources as more data are made available
	Assessment of uncertainty (if any)	The authors note that the decay rates of markers especially HF183 or nifH, can be faster than HAdV. If enteric viruses persist longer in the environment and remain infective, the GI risk estimates generated by HF183 and nifH will markers need to be interpreted carefully. It was also assumed that all NoV and HAdV 40/41 quantified using qPCR are viable and infective.
Reviewer comments	Reviewer comments	The results list the concentrations in genomic copies (GC) of each of the 5 biomarkers that are equivalent to the US EPA tolerable risk benchmark for recreational water (0.036) under the assumptions that GI risks arise only from NoV and HAdV 40/41 and the only source of contamination is either fresh raw sewage or fresh secondary treated sewage.
	Results included/excluded in review (if applicable)	Table 2 in the paper lists values for each biomarker tested. It is too large to include here.
	Notes on study quality e.g. gaps, methods	As noted by the authors, it was assumed that all NoV and HAdV 40/41 quantified using qPCR are viable and infective. This is a significant source of uncertainty that does not figure in the reported biomarker values. The study makes use of the US EPA risk of GI Illness benchmark which does not take into account sequelae unlike the WHO

Category	Data class	J2: Ahmed, W.; Hamilton, K. A.; Lobos, A.; Hughes, B.; Staley, C.; Sadowsky, M. J.; Harwood, V. J. 2018
		recommended metric of DALYs. If the use of DALYs as a benchmark metric was to be considered (e.g. 1 µDALY per person per annum), instead of the US EPA benchmark, the data presented in the paper is not sufficient to allow for the calculation of the biomarker concentrations consistent with 1 µDALY.

6.2. J3: Ahmed, Payyappat, et al., (2019)

6.2.1. Quality assessment

		J3, Ahmed, W.,, 2019, Enhanced insights from human and animal host-associated molecular marker genes in a freshwater lake receiving wet weather overflows		
Q.	Criteria	Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?	**Yes**		
1	Was there a clear statement of the aims of the research?	Yes	The primary objective of the study was to determine the magnitude of sewage and animal faecal contamination in Lake Parramatta water samples collected during a dry weather period and from two storm events that coincided with wet weather overflows of sewage to the lake.	**Definitely low risk of bias (++)**
2	Is the methodology appropriate?	Yes	The methodology is appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?	**Yes**		
3	Was the research design appropriate to address the aims of the research?	Yes	Wet weather and dry weather events were sampled and compared - this is a reasonable approach as it encapsulates the likely extremes with respect to loads and concentrations.	**Definitely low risk of bias (++)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is adults undertaking primary contact recreation. Site measurements are compared with thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	As noted above, wet weather and dry weather events were sampled and compared - this is a reasonable approach.	**Definitely low risk of bias (++)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of adults undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The relationship between the marker concentrations and the reference pathogen concentrations is not well defined (similar to related studies by the same author reviewed here). It is sufficiently rigorous for estimation of concentrations of sewage markers that would pose a human health risk.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	No	There is a discussion with some conclusions at the end. The conclusions are reasonable but are not clearly stated.	**Probably high risk of bias (-)**

Q.	Criteria	J3, Ahmed, W.,, 2019, Enhanced insights from human and animal host-associated molecular marker genes in a freshwater lake receiving wet weather overflows Assessment	Comments	Risk of Bias rating
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is of some relevance to this narrative review in indicating an urban ornamental lake that is influenced by sewage and stormwater inflows is not safe for swimming after wet weather. Some more state of the art MST markers are used to confirm the point.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*This QMRA has been conducted with a satisfactory level of rigour. Consequently, it is classified as having a "Probably low risk of bias".*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.2.2. Data extraction

Category	Data class	J3: Ahmed, W., Payyappat, S., Cassidy, M., and Besley, C. 2019
Descriptive attributes	Title	Enhanced insights from human and animal host-associated molecular marker genes in a freshwater lake receiving wet weather overflows
	Publication Title	Scientific Reports
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	9 (1) 12503
	Publication date	2019
	Publication Source	Scientific Reports 9 (1) 12503 DOI:10.1038/s41598-019-48682-4
	Peer reviewed	Yes
	Country of origin	Australia
	Source of funding	Sydney Water - financial assistance
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	FIB: Escherichia coli (*E. coli*) and Enterococcus spp.
	CASP classification	Qualitative research

Category	Data class	J3: Ahmed, W., Payyappat, S., Cassidy, M., and Besley, C. 2019
	marine, estuarine or freshwater	f
	DOI http://dx.doi.org/	10.1016/j.scitotenv.2019.135390
Study characteristics	Aim/objectives of study	The primary objective of the study was to determine the magnitude of sewage and animal faecal contamination in Lake Parramatta water samples collected during a dry weather period and from two storm events that coincided with wet weather overflows of sewage to the lake.
	Study type/design	Evaluation of FIB and MST biomarkers to determine magnitude and sources of faecal contamination in a freshwater lake receiving urban stormwater runoff.
	Study duration	2 months Feb-April 2018
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/ water body	Freshwater lake receiving urban stormwater flows
	Exposure scenario	n/a. Study focuses is on identifying sources of faecal contamination
	Exposure pathway	n/a
	Source of infection/ contamination	Stormwater catchment sources
	Causal organisms	n/a. Study measured FIB and sewage-associated and animal faeces-associated marker genes.
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Concentrations of biomarkers measured in wet and dry weather samples from 5 sampling sites around Lake Paramatta, Sydney, NSW
	Method of microorganism isolation and enumeration (if applicable)	FIB enumeration via Colilert® for *E. coli* as MPN but it is noted the paper report *E. coli* results in units of CFU/100ml. Enterococcus enumerated from agar plate colonies in units of CFU/100ml. For biomarkers Genomic Copies (GC) reported from qPCR assays in units of GC/L. For DNA extraction and qPCR analysis, pH-adjusted (to 3.5) 500 ml water samples were filtered through 0.45 µm HA Millipore membranes and stored at -80°C for 1 month prior to analysis.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Water samples were collected during a dry weather period and after two storm events, and tested for a range of novel and established sewage- [Bacteroides HF183, crAssphage CPQ_056 and pepper mild mottle virus (PMMoV)] and animal faeces-associated (Bacteroides BacCan-UCD, cowM2 and Helicobacter spp. associated GFD) microbial source tracking marker genes along with the enumeration of culturable faecal indicator bacteria (FIB), namely Escherichia coli (*E. coli*) and Enterococcus spp
	Limits of reporting for the organism of concern	Limits not stated for FIB or biomarkers.
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Field and laboratory methods are described in detail in the report and were considered to be rigorous. For qPCR analyses, field and method blanks were used to ensure that no carryover contamination occurred between sampling events. In addition, a reagent blank was included for each batch of DNA samples to ensure no carryover contamination occurred from DNA extraction reagents. To minimize qPCR contamination, nucleic acid extraction and qPCR setup were performed in separate laboratories
Statistics	Statistical methods used	Box plots of FIB and MST marker genes concentrations in lake water samples categorised by sampling event and labelled for weather (wet vs dry). Pearson's correlation matrix among faecal indicator bacteria (FIB) and MST marker genes in pooled (n = 30) water samples

Category	Data class	J3: Ahmed, W., Payyappat, S., Cassidy, M., and Besley, C. 2019
	Details on statistical analysis (if any)	For statistical analysis, sewage-associated marker genes concentrations were log10 transformed. For correlation analysis, all samples collected during the study were pooled. The Pearson's product moment correlation with a two-tailed p value was used to establish the relationship between FIB and MST marker genes in Lake Parramatta water samples. Student's t-test was used to identify significant relationships of the concentrations of FIB and MST marker genes between dry and wet weather events and between sampling depths. .
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	The magnitude of general and source-specific faecal pollution was low in water samples collected during dry weather compared to storm events. The levels of HF183, crAssphage and PMMoV in water samples collected during storm events were as high as 6.39, 6.33 and 5.27 log10 GC/L of water, respectively. Moderate to strong positive correlations were observed among the quantitative occurrence of sewage-associated marker genes. The concentrations of HF183 and PMMoV in most storm water samples exceeded the risk benchmark threshold values established in the literature for primary contact recreators (see Table 3 in the paper). None of the samples tested was positive for the cowM2 (cow) marker gene, while BacCan-UCD (dog) and GFD (avian) animal-associated markers were sporadically detected in water samples collected from both dry weather and storm events.
	How outcome was assessed	Statistical analysis of wet and dry weather lake water samples as described above in statistical methods.
	Method of measurement	FIB and MST marker genes concentrations in lake water samples
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	Based on the results, the ongoing advice that swimming should be avoided for several days after storm events appears appropriate. Further research to determine the decay rates of sewage-associated marker genes in relation to each other and enteric viruses would help refine current advice. Microbial source tracking approaches employed in this study provided insights into sources of contamination over currently used FIB.
	Assessment of uncertainty (if any)	Statistical measures of uncertainty are shown in box and whisker plots of FIB and MST marker concentrations in samples, tabulated recovery efficiency (%) of MST makers given with standard deviations. Use of two-tailed p value to establish the relationship between FIB and MST marker genes.
Reviewer comments	Reviewer comments	The research is of some relevance in indicating an urban ornamental lake that is influenced by sewage and stormwater inflows is not safe for swimming after wet weather. Some more state of the art MST markers are used to confirm the point. The paper has a satisfactory level of rigour.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	A more appropriate analysis instead of the t-tests (see statistics above) would have been a 2-factor analysis of variance with treatments of depth vs wet and dry weather events. From the t-test results it was clear that there was an interaction between depth and weather event but is more difficult to understand using multiple t-tests. The study is methodologically rigorous, but clearer reporting would have assisted the reader. The most interesting component of the study is the use of previously established (published elsewhere) MST marker thresholds for GI illness risk (using the US EPA 0.036 risk threshold for water-based recreation). Given the recent publication date (2019), it would have been interesting to consider a µDALY-based risk threshold.

6.3. J4: Ahmed, Payyappat, et al., (2020)

6.3.1. Quality assessment

Q.	Criteria	J4, Ahmed, War, 2020, Sewage-associated marker genes illustrate the impact of wet weather overflows and dry weather leakage in urban estuarine waters of Sydney, Australia Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	No	The stated main aim of this study was to determine the impacts of wet weather overflows (WWOs) and dry weather overflows (DWOs) (if any) and associated sewage contamination at three estuarine sites in Sydney, NSW. It is not clearly reported what is potentially being impacted, although given the topic, it is assumed to be public health via exposure to sewage pathogens.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The methodology involved collection of water samples from 3 estuarine sites during two storm events and one weather event and at two depths (0.5 m below surface and 1 m above bottom). Samples were analysed for genetic markers of sewage bacteria and viruses and for FIB. This methodology is generally appropriate, however the DWO event is not replicated over time which weakens the statistical power of conclusions about this treatment.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Following on from the comments above, results for genetic markers and FIB were compared with US EPA criteria for GI illness and NHMRC criteria for managing risks in recreational waters. The design is appropriate for assessing the relationship between WWO and DWO and risks to public health, although this aim was not clearly stated.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is adults undertaking primary contact recreation. Site measurements are compared with thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	The research aims were not clearly stated as noted above, however, the research results are useful in support of the primary research question for this review.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of adults undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	Yes	Like the study aims, the data analysis component of the study is not entirely clear but is sufficiently rigorous to understand and support the conclusions.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	No	Similar to paper J3 included in this review, there is adiscussion with some conclusions at the end. The conclusions are reasonable but are not clearly stated.	**Probably high risk of bias (-)**

Q.	Criteria	Assessment	J4, Ahmed, War, 2020, Sewage-associated marker genes illustrate the impact of wet weather overflows and dry weather leakage in urban estuarine waters of Sydney, Australia Comments	Risk of Bias rating
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	Given the paper assesses a range of genetic markers and FIB in sewage affected WWOs and DWOs in high value recreational estuarine locations around a major metropolitan area, the research is potentially valuable in answering the primary research question of this narrative review. There are some study limitations as the aims, methods and conclusions do not clearly align, and the results and discussion sections could be reported more clearly.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*This QMRA has been conducted with a satisfactory level of rigour. Consequently, it is classified as having a "Probably low risk of bias".*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.3.2. Data extraction

Category	Data class	J4: Ahmed, Warish; Payyappat, Sudhi; Cassidy, Michele; Harrison, Nathan; Besley, Colin 2020
Descriptive attributes	Title	Sewage-associated marker genes illustrate the impact of wet weather overflows and dry weather leakage in urban estuarine waters of Sydney, Australia
	Publication Title	Science of the Total Environment
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	705 (2020) 135390
	Publication date	2020
	Publication Source	Science of the Total Environment 705 (2020) 135390 DOI:10.1016/j.scitotenv.2019.135390
	Peer reviewed	Yes
	Country of origin	Australia
	Source of funding	Sydney Water - financial assistance
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No
	immunocompromised	No
	elderly	No

Category	Data class	J4: Ahmed, Warish; Payyappat, Sudhi; Cassidy, Michele; Harrison, Nathan; Besley, Colin 2020
	indigenous	No
	Main risk associated factor?	Novel sewage-associated marker genes
	CASP classification	Qualitative research
	marine, estuarine or freshwater	e
	DOI http://dx.doi.org/	10.1016/j.watres.2018.10.088
Study characteristics	Aim/objectives of study	The stated main aim of this study was to determine the impacts of sewage network wet weather overflows (WWOs) and dry weather overflows (DWOs) and associated sewage contamination at three estuarine sites in Sydney, NSW
	Study type/design	Evaluation of FIB and MST biomarkers to determine magnitude and sources of faecal contamination in 3 estuaries receiving urban stormwater runoff.
	Study duration	7 months March-October 2018
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Three estuaries receiving urban stormwater flows
	Exposure scenario	n/a. Study focuses is on identifying sources of faecal contamination
	Exposure pathway	n/a
	Source of infection/ contamination	Stormwater catchment sources
	Causal organisms	n/a. Study measured FIB and sewage-associated and animal faeces-associated marker genes.
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Concentrations of biomarkers measured in dry weather samples and samples following storm events from 6 sampling stations at each of 3 estuaries, Sydney, NSW. At each station samples were collected at (i) 0.5 m below the water surface, and (ii) 1 m above the bottom surface to investigate whether decreased levels of MST marker genes occurred at greater depth
	Method of microorganism isolation and enumeration (if applicable)	FIB enumeration via Colilert® for *E. coli* as MPN but it is noted the paper reports *E. coli* results in units of CFU/100ml. Enterococcus enumerated from agar plate colonies in units of CFU/100ml. For biomarkers Genomic Copies (GC) reported from qPCR assays in units of GC/L. For DNA extraction and qPCR analysis, pH-adjusted (to 3.5) 500 ml water samples were filtered through 0.45 µm HA Millipore membranes and stored at -80°C for 1 month prior to analysis.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	The magnitude of sewage contamination was monitored using established and novel sewage-associated marker genes, Bacteroides HF183, pepper mild mottle virus (PMMoV), crAssphage CPQ_056, Lachnospiraceae (Lachno3) marker genes along with culturable faecal indicator bacteria (FIB) Escherichia coli (*E. coli*) and enterococci. Water samples were also analysed for four animal faeces-associated marker genes targeting avian (GFD), dog (BacCan-UCD), cow (cowM2) and horse (HoF597) species to determine the extent of animal faecal contamination.
	Limits of reporting for the organism of concern	Limits not stated for FIB or biomarkers.
	Consideration of quality assurance such as field	Field and laboratory methods are described in detail in the report and were considered to be rigorous. For qPCR analyses, Method blanks

Category	Data class	J4: Ahmed, Warish; Payyappat, Sudhi; Cassidy, Michele; Harrison, Nathan; Besley, Colin 2020
	and lab blanks, reference sites, and reporting on related physico-chemical parameters	were used to ensure that no carryover contamination had occurred between sampling events. In addition, a reagent blank was included for each batch of DNA/RNA samples to ensure no carryover contamination occurred from DNA/RNA extraction reagents. No carryover contamination was observed in method or reagent blank samples. To minimize qPCR contamination, nucleic acid extraction and qPCR setup were performed in separate laboratories
Statistics	Statistical methods used	Box plots of FIB and MST marker genes concentrations in lake water samples categorised by sampling event and labelled for weather (wet vs dry). Simple data tabulations.
	Details on statistical analysis (if any)	For statistical analysis, sewage and animal faeces-associated marker genes concentrations were log10 transformed. Pearson's correlation was used to determine the association between *E. coli* and enterococci concentration in estuarine water samples. For correlation analysis, all samples collected during the course of the study were pooled. Student's t test was performed to determine statistical significance of the concentrations of marker genes between dry and storm events as well as between two sampling depths. P values of < 0.05 were considered significant
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Analysis of sewage associated marker genes showed greater (i.e., 3–5 orders of magnitude) concentrations in water samples collected during the storm events compared to dry weather event. Among the four animal faeces-associated marker genes, cow (cowM2) and horse (HoF597) could not be detected, while the avian (GFD) marker gene was consistently present, and the dog (BacCan-UCD) marker gene was occasionally detected. Overall results suggested that after rainfall, untreated sewage from wet weather overflows (WWOs) was present at sampling locations. In addition, microbial source tracking (MST) monitoring was able to distinguish the presence of a leaking sewer impacting on the recreational area during dry weather condition. Depth profile analysis of FIB indicated overall greater concentrations at the surface compared to the bottom of the water bodies.
	How outcome was assessed	Statistical analysis of storm event and dry weather estuarine water samples as described above in statistical methods.
	Method of measurement	FIB and MST marker genes concentrations in estuarine water samples
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The results from multiple sewage-associated marker gene analysis demonstrated that the studied estuarine waters were impacted by WWOs transported by urban stormwater runoff. Ongoing advice not to swim for several days after storm events appears appropriate but the likely presence of enteric viruses and their persistence in estuarine waters needs to be considered. This study demonstrated the capability of the MST monitoring approach to understand sources (sewage or animal) of faecal contamination. This new understanding of the sources of faecal contamination should greatly enhance management decisions as to where remediation efforts of the sewerage system are required to improve estuarine bathing water quality and diminish human-health illness risk
	Assessment of uncertainty (if any)	Statistical measures of uncertainty are shown in box and whisker plots of FIB and MST marker concentrations in samples, tabulated recovery efficiency (%) of MST makers given with standard deviations. Use of two-tailed p value to establish the relationship between FIB and MST marker genes. The authors also note that sewage- associated bacterial marker genes such as HF183 has been reported to decay faster in sea or estuarine waters. However, pathogens such as enteric viruses especially in sewage contaminated water may persist longer than the bacterial targets. Currently this information is lacking, and therefore the decay

Category	Data class	J4: Ahmed, Warish; Payyappat, Sudhi; Cassidy, Michele; Harrison, Nathan; Besley, Colin 2020
		rates of sewage-associated marker genes in relation to enteric viruses need to be determined to accurately infer human health risks.
Reviewer comments	Reviewer comments	The paper assesses a range of genetic markers and FIB in sewage affected WWOs and DWOs in high value recreational estuarine locations around a major metropolitan area, thus the research is potentially valuable in demonstrating methods to monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	Like the related study included in the narrative review (Ahmed et al 2019), the discussion briefly mentions the use of the MST biomarkers for assessment of human health risk, and it would have been interesting if this topic was explored further.

6.4. J5: Ahmed, Zhang, et al., (2019)

6.4.1. Quality assessment

		J5, Ahmed, War, 2019, Comparative decay of sewage-associated marker genes in beach water and sediment in a subtropical region		
Q	Criteria	Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The primary aim of this study was to investigate the decay of four sewage-associated bacterial and viral markers (HF183, HAdV, HPyV, and crAssphage), in relation to each other and qPCR FIB, in sewage contaminated fresh and marine waters and accompanying sandy sediments	**Definitely low risk of bias (++)**
2	Is the methodology appropriate?	Yes	Decay rates of two qPCR FIB and four sewage-associated microbial source tracking (MST) marker genes (bacterial and viral) were measured in outdoor mesocosms containing fresh and marine waters and their corresponding sediments. Method descriptions are detailed and are appropriate.	**Definitely low risk of bias (++)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Seven sequential water and sediment samples were collected from mesocosms over a 40 day period. This approach generated satisfactory data to address the aims of the research.	**Definitely low risk of bias (++)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	No risk assessment was undertaken as the study sought only to determine the decay rates of sewage genetic markers.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	As noted above, the sequential sampling approach generated satisfactory data to determine marker decay rates and thus address the aims of the research.	**Definitely low risk of bias (++)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			

Q	Criteria	Assessment	J5, Ahmed, War, 2019, Comparative decay of sewage-associated marker genes in beach water and sediment in a subtropical region Comments	Risk of Bias rating
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	Data analyses considered relevant statistical issues such as management of outliers, goodness of model fits and levels of statistical significance, and thus are sufficiently rigorous	**Definitely low risk of bias (++)**
9	Is there a clear statement of findings?	Yes	As with other papers in this series by the same authors, there is adiscussion with some conclusions at the end. The conclusions are reasonable.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is valuable for informing this narrative review since addresses a component of the primary research question - this being the "main factors impacting risk and its prediction", since it quantifies the persistence of certain genetic markers of sewage in recreational water habitats.	**Definitely low risk of bias (++)**
-	**Overall risk of bias rating**	-	*The study is an observational study of sewage genetic marker decay rates in recreational freshwater and marine habitats and is sufficiently rigorous.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.4.2. Data extraction

Category	Data class	J5: Ahmed, Warish; Zhang, Qian; Kozak, Sonya; Beale, David; Gyawali, Pradip; Sadowsky, Michael J.; Simpson, Stuart 2019
Descriptive attributes	Title	Comparative decay of sewage-associated marker genes in beach water and sediment in a subtropical region
	Publication Title	Water Research
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	149 (2019) 511-521
	Publication date	2019
	Publication Source	Water Research 149 (2019) 511-521 DOI:10.1016/j.watres.2018.10.088
	Peer reviewed	Yes
	Country of origin	Australia
	Source of funding	Funding from CSIRO. Minnesota Agricultural Experiment Station funding to Michael J. Sadowsky
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No

Category	Data class	J5: Ahmed, Warish; Zhang, Qian; Kozak, Sonya; Beale, David; Gyawali, Pradip; Sadowsky, Michael J.; Simpson, Stuart 2019
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	PCR (qPCR) MST markers
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m
	DOI http://dx.doi.org/	10.2166/wh.2003.0015
Study characteristics	Aim/objectives of study	The primary aim of this study was to investigate the decay of four sewage-associated bacterial and viral markers (HF183, HAdV, HPyV, and crAssphage), in relation to each other and qPCR FIB, in sewage contaminated fresh and marine waters and accompanying sandy sediments.
	Study type/design	Outdoor mesocosms containing water and sediment were inoculated with untreated sewage, and qPCR assays were used to quantify each target over 40 days to determine their decay rates.
	Study duration	40 days
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Water samples were collected from two marine sites and one freshwater lake environment.
	Exposure scenario	n/a. Study focuses is decay rates of FIB and bacterial and viral markers
	Exposure pathway	n/a
	Source of infection/ contamination	Fresh untreated sewage dosed into outdoor mesocosms 9 x 8L plastic containers situated within a 1200 L plastic container filled with 200 L of water to provide a stable water temperature environment.
	Causal organisms	n/a. Study measured FIB and sewage-associated marker genes.
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Concentrations of qPCR FIB and sewage-associated MST markers in untreated sewage, water and sediment samples.
	Method of microorganism isolation and enumeration (if applicable)	Each 100mL water sample was filtered through 0.45 mm pore size (47mm diameter) negatively charged HA membranes (Merck Millipore). A 250 mg sediment sample was carefully drawn out from the core sampler. DNA was directly extracted from the membranes (containing targets from water) and sediment using MO-BIO Power Soil DNA kits. All DNA samples were stored at -80°C until used. The concentration of DNA in each sample was measured by using a Nano-Drop 2000 instrument (Thermo Scientific, MA, USA).
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	From each mesocosm, one water sample (100 mL) was collected on each of days 0, 1, 4, 8, 14, 24 and 40. On day 0, water in the mesocosms was sampled, using a 25mL pipette, within 30 min after sewage inoculation. Sediment core samplers, made by cutting the ends of plastic 10 mL pipettes, were used for sampling sediment from each mesocosm. One sediment sample (approximately 1 g) was collected from each mesocosm on days 0, 1, 4, 8, 14, 24 and 40. Water samples were collected prior to sediment samples to avoid sediment disturbance.
	Limits of reporting for the organism of concern	Limits for biomarkers not stated.

Category	Data class	J5: Ahmed, Warish; Zhang, Qian; Kozak, Sonya; Beale, David; Gyawali, Pradip; Sadowsky, Michael J.; Simpson, Stuart 2019
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Field and laboratory methods are described in detail in the report and were considered to be rigorous. All qPCR reactions were performed in triplicate. For each qPCR assay, positive controls (i.e., genomic or plasmid standards) and three negative controls (sterile water) were included to assess successful amplification and contamination. qPCR standards were analysed to determine the amplification efficiencies (E) and the correlation coefficient (R2). Inter-assay variability of each qPCR assay was measured using four separate qPCR runs performed on four different days using three replicates of the standard ranging from 3 to 3 x 106 GC/reaction.
Statistics	Statistical methods used	Line plots of decay of FIB and MST markers in water and sediments versus days 1 to 40 on the x-axis. Fitted decay curves.
	Details on statistical analysis (if any)	qPCR FIB and sewage associated marker data from all three mesocosms were initially evaluated by a Gaussian model using a Davies test. Data points < ALOQ were excluded from the decay rate calculation. If results of the Davies test were significant ($p < 0.05$), biphasic decay model (details cited in paper) were fitted, otherwise, a first-order decay model was used. T90 (days) and R2 regression values were reported for each combination of mesocosm (2 x marine, 1 x freshwater by sample type [sediment or water]) for each FIB/marker (Table 2 - First order decay model, Table 3 bi-phasic, where appropriate). Also shown is a correlation matrix between all qPCR FIB and sewage-associated markers in sediment and water samples for each site. Some issues with this analysis have been identified (e.g. too large to interpret, includes inappropriate comparisons like freshwater biomarker vs marine (i.e. different source waters), experiment-wise error rate for significant correlations not considered etc.)
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Decay rates of EC 23S rRNA, ENT 23S rRNA, and HF183 16S rRNA were significantly ($p < 0.05$) faster than the HAdV, HPyV and crAssphage markers in water samples from all mesocosms. In general, decay rates of bacterial targets were similar in the water columns of the studied mesocosms. Similarly, decay rates of viral targets were also alike in mesocosm water columns in relation to each other. The decay rates of FIB and sewage-associated markers were significantly faster in water samples compared to sediments in all three mesocosms.
	How outcome was assessed	Assessment of line plots and fitted decay curves
	Method of measurement	FIB and MST marker genes concentrations in mesocosm marine and fresh-water samples
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	Decay rates of bacterial targets (two FIB and HF183) were fast and similar in water samples across three mesocosms. Similarly, decay rates of viral targets (HAdV, HPyV and crAssphage) were similar in water samples, however, viral targets persisted significantly ($p < 0.05$) longer than did bacterial targets. Decay rates of FIB and sewage-associated markers in sediment mesocosm samples varied greatly across the marine and freshwater mesocosms. Decay rates of FIB and sewage-associated markers were significantly faster in water samples compared to sediment in all mesocosms. FIB (EC and/or ENT) exhibited biphasic decay rates compared to MST markers in water and sediment samples from all mesocosms. Due to the nature of decay, they may not be reliable markers to detect recent faecal pollution.
	Assessment of uncertainty (if any)	Decay rates of FIB and MST markers significantly and positively correlated with mesocosm water temperature, TOC, and turbidity, and were mostly negatively correlated with rainfall, electrical conductivity, evaporation, sunlight and pH. The authors state that further research into the introduction,

Category	Data class	J5: Ahmed, Warish; Zhang, Qian; Kozak, Sonya; Beale, David; Gyawali, Pradip; Sadowsky, Michael J.; Simpson, Stuart 2019
		distribution and persistence of pathogens and their gene markers in beach sand and sediment need to be conducted.
Reviewer comments	Reviewer comments	This is a well-designed experimental study using mesocosms to study the decay rates of qPCR FIB and sewage-associated MST markers.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	The data set collected for the study is amenable to multivariate exploratory and model-fitting analyses. For example ridge-regression or canonical correlation analysis would have been appropriate to use.

6.5. J6: Arnold, Schiff, et al., (2017)

6.5.1. Quality assessment – Cohort Study

		J6, Arnold, B., 2017, Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions		
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
	Section A1: Are the results valid?			
1	Did the study address a clearly focused issue?	Yes	The study objectives were to determine whether *exposure to seawater increased rates of incident illness* among a longitudinal cohort of surfers in San Diego, California compared with periods when they did not surf in order to determine whether exposure during or immediately after rainstorms increased rates more than did exposure during dry weather	**Definitely low risk of bias (++)**
2	Was the cohort recruited in an acceptable way?	Yes	Surfers were enrolled through in-person interviews at the 2 beaches monitored in the study and through targeted online advertising. Participants enrolled on the beach were very similar to those enrolled online. The study protocol was reviewed and approved by the institutional review board at the University of California, Berkeley, and all participants provided informed consent. Participants received a modest incentive for participation ($20 USD gift certificate per 4 weekly surveys completed).	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?		**Yes**	
3	Was the exposure accurately measured to minimise bias?	Yes	The researchers defined wet-weather exposure as exposure to seawater within 3 days of 0.25 cm or more of rainfall in a 24-hour period and all other seawater exposure as dry-weather exposure. The wet weather criterion is the same rainfall criterion used by San Diego County for posting wet-weather beach advisories	**Probably low risk of bias (+)**
4	Was the outcome accurately measured to minimise bias?	Yes	In weekly surveys, participants reported daily records of health symptoms. The researchers created composite outcomes from the symptoms and classified the 3 days after each seawater exposure as exposed periods and all other days of observation as unexposed periods. As a result of this method, there may be some subjectivity in the health measurements (i.e. participant self-reported illness classified into consistent classes by the study researchers). There may also be bias introduced since subjects and assessors were not blinded to	**Probably low risk of bias (+)**

J6, Arnold, B., 2017, Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions				
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
			exposure (although this is unavoidable given the study design).	
5	(a) Have the authors identified all important confounding factors?	Yes	A large range of study population characteristics are documented and reportedly included in the statistical modelling as covariates (see below). Note that the authors excluded from "adjusted analyses" 47 individuals (1,599 person-days of observation) who provided outcome and exposure information but failed to complete a background questionnaire and thus had missing covariate information. Statistical results are reported with and without this group ("Unadjusted" versus "Adjusted")	**Probably low risk of bias (+)**
5	(b) Have they taken into account confounding factors in the design and/or analysis?	Yes	The authors refer to supporting publications for evidence that they controlled for potential confounding from demographic exposure-related, and baseline health characteristics (Arnold B, Ercumen A. 2015 The Surfer Health Study. Open Science Framework. https://osf.io/hvn7s). The association between seawater exposure and subsequent illness using was measured using an incidence rate ratio, which was estimated using a log-linear rate model with robust standard errors to account for repeated observations within individuals. In the log-linear model potentially confounding factors (e.g. demographics) were included as covariates (equation 1, p. 15 Surfer Health Study described above). The descriptions of the statistical model are of an advanced statistical nature and are not clearly reported - hence the risk of bias rating of "probably low risk of bias"	**Probably low risk of bias (+)**
6	(a) Was the follow up of subjects complete enough?	Yes	An open cohort design was used in which participants were allowed to enter and exit the cohort over the follow-up period. Participants completed a brief enrolment questionnaire, and each Tuesday they received a text message or e-mail reminder to complete a short weekly survey	**Probably low risk of bias (+)**
6	(b) Was the follow up of subjects long enough?	Yes	Follow up was considered satisfactory given the open nature of the study and the use of the brief questionnaire.	**Probably low risk of bias (+)**
	Section B: What are the results?			
7	What are the results of this study?	Yes	**Illness associated with seawater exposure:** • Seawater exposure in the past 3 days was associated with increased incidence rates of gastrointestinal illness, diarrhea, sinus pain or infection, earache or infection, infection of open wound, skin rash, and fever, but not upper respiratory illness • With the exception of fever and skin rash, incidence rates increased from unexposed to dry-weather exposure to wet-weather exposure periods, a pattern also present on the risk scale. • Compared with unexposed periods, wet-weather exposure led to the largest relative increase in: - earaches/infections (adjusted incidence rate ratio (IRR) = 3.28, 95% confidence interval (CI): 1.95, 5.51); and - infection of open wounds (adjusted IRR: 4.96, 95% CI: 2.18, 11.29). **Illness associated with faecal indicator bacteria levels**	**Probably low risk of bias (+)**

Q.	Criteria	Assessment	J6, Arnold, B., 2017, Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions Comments	Risk of Bias rating
			• Enterococcus, total coliform, and faecal coliform levels were positively associated with increased incidence of almost all outcomes during the study. • Rainfall was a strong effect modifier of the association. • During dry weather, there was no association between Enterococcus levels and illness except for infected wounds, but Enterococcus was strongly associated with illness after wet-weather exposure (e.g. for each log10 increase, gastrointestinal illness IRR = 2.17, 95% CI: 1.16, 4.03). • There was evidence for excess risk of gastrointestinal illness at higher Enterococcus levels only during wet-weather periods: The predicted excess risk that corresponded to the current US Environmental Protection Agency regulatory guideline of 35 colony-forming units per 100 mL was 16 episodes per 1,000 (95% CI: 5, 27). • Negative control analyses showed no consistent association between faecal indicator bacteria and illness among participants during periods in which they had no recent seawater contact.	
8	How precise are the results?	Yes	The results are relatively precise as attested by the 95% confidence intervals	**Probably low risk of bias (+)**
9	Do you believe the results?	Yes	The publication summarises the outcome of a large and rigorous epidemiological study and is supported by several publications which are referenced; thus the results are compelling and consistent with expectations.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	Can the results be applied to the local population?	Yes	The magnitude of the statistical effects observed in the study are greatly dictated by the local recreational water quality environment of the study area, they should be relevant to any metropolitan surf beaches in temperate and subtropical regions of Australia, particularly in the vicinity of stormwater discharges.	**Probably low risk of bias (+)**
11	Do the results of this study fit with other available evidence?	Yes	The overall findings of the study - urban coastal seawater exposure increases the incidence rates of many acute illnesses among surfers, with higher incidence rates after rainstorms - is consistent with the general epidemiological literature on water recreational at coastal beaches.	**Probably low risk of bias (+)**
12	What are the implications of this study for practice?	Yes	The study findings support the continued use of FIB as a tool for assessing health risks to recreational water users at metropolitan surf beaches.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study is a large-scale epidemiological study of health impacts of wet weather on surfers at two major Los Angeles beaches. Although referencing a large amount of supporting literature, and dependent on local water quality conditions, the findings are satisfactorily robust and relevant in the Australian context and having probably a low risk of bias.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.5.2. Data extraction

Category	Data class	J6: Arnold, B. F., Schiff, K. C., Ercumen, A., Benjamin-Chung, J., Steele, J. A., Griffith, J. F., Steinberg, S. J., Smith, P., McGee, C. D., Wilson, R., Nelsen, C., Weisberg, S. B., and Colford, J. M., Jr. 2017
Descriptive attributes	Title	Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions
	Publication Title	American Journal of Epidemiology
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	186 (7) 866-875
	Publication date	2017
	Publication Source	American Journal of Epidemiology 186 (7) 866-875 DOI:10.1093/aje/kwx019
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	The study was funded by the city and county of San Diego, California
	Possible conflicts of interest	The authors state that the funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. Conflict of interest: none declared.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	FIB, GI Illness
	CASP classification	Cohort study
	marine, estuarine or freshwater	m
	DOI http://dx.doi.org/	10.2134/jeq2017.12.0499
Study characteristics	Aim/objectives of study	The study objectives were to determine whether exposure to seawater increased rates of incident illness among a longitudinal cohort of surfers in San Diego, California compared with periods when they did not surf in order to determine whether exposure during or immediately after rainstorms increased rates more than did exposure during dry weather
	Study type/design	Longitudinal cohort study of surfers recruited in San Diego over 2 winters, with enrolment and follow-up periods chosen to capture most rainfall events in the region.
	Study duration	6 months (January to June 2014)
Population characteristics	Population/s studied	San Diego surfers
	Selection criteria for population	Surfers were eligible if they were 18 years of age or older, could speak and read English, planned to surf in southern California during the study period, had a valid e-mail address or mobile telephone number, and could access the internet with a computer or smartphone. An open

Category	Data class	J6: Arnold, B. F., Schiff, K. C., Ercumen, A., Benjamin-Chung, J., Steele, J. A., Griffith, J. F., Steinberg, S. J., Smith, P., McGee, C. D., Wilson, R., Nelsen, C., Weisberg, S. B., and Colford, J. M., Jr. 2017
		cohort design was used in which participants were allowed to enter and exit the cohort over the follow-up period. The study protocol was reviewed and approved by the institutional review board at the University of California, Berkeley, and all participants provided informed consent. Participants received a modest incentive for participation ($20 USD gift certificate per 4 weekly surveys completed).
	Subgroups reported	n/a
	Size of study	A total of 654 individuals were enrolled who contributed on average 51 days of follow-up (range, 6–139 days).
Exposure and setting	Type of water source/water body	Beach water quality sampling locations were Ocean Beach and Tourmaline Surfing Park (also a beach). Both monitored beaches have storm-impacted drainage, attract surfers year-round, and have water quality levels similar to those of other beaches in the county
	Exposure scenario	To examine illness rates separately for dry- and wet-weather exposures, the authors created a 3-level categorical exposure that classified each participant's follow-up time into unexposed, dry-weather exposure, and wet-weather exposure periods. The researchers defined wet-weather exposure as exposure to seawater within 3 days of 0.25 cm or more of rainfall in a 24-hour period and all other seawater exposure as dry-weather exposure. The wet weather criterion is the same rainfall criterion used by San Diego County for posting wet-weather beach advisories
	Exposure pathway	Assumed exposure pathway is partial or whole-body exposure to water whilst surfing.
	Source of infection/ contamination	Urban stormwater
	Causal organisms	n/a. Study measured FIB [Enterococcus] and surfer illness rates.
	Comparison group(s)	Comparison groups were the same cohort during periods not exposed to seawater, following dry-weather exposure, and following wet weather exposure.
Study methods	Water quality measurement used	FIB (Enterococcus spp.)
	Method of microorganism isolation and enumeration (if applicable)	Water samples were tested for culturable Enterococcus (US Environmental Protection Agency method 1600), fecal coliforms (standard method 9222D), and total coliforms (standard method 9222B).
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Daily water samples were collected from January 15, 2014, to March 5, 2014, and from December 2, 2014, to March 31, 2015, at 6 sites across the 2 monitored beaches. Water samples (1L) were collected in the morning (08:30 AM ± 2 hours) just below the water surface (0.5–1.0meters) in sterilized, sample-rinsed bottles. Discharges were sampled during 6 rainstorms immediately upstream from where Tourmaline Creek and the San Diego River discharge to the sea.
	Limits of reporting for the organism of concern	Limits for FIB not stated
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	All laboratory analyses met quality-control objectives for absence of background contamination (blanks) and precision (duplicates). For surfer surveys, surfers were enrolled through in-person interviews at the 2 beaches monitored in the study and through targeted online advertising. Participants enrolled on the beach were very similar to those enrolled online. The authors refer to supporting publications for evidence that they controlled for potential confounding from demographic exposure-related, and baseline health characteristics (Arnold B, Ercumen A. 2015 The Surfer Health Study. Open Science Framework. https://osf.io/hvn7s).
Statistics	Statistical methods used	The association between seawater exposure and subsequent illness using was measured using an incidence rate ratio, which was estimated

Category	Data class	J6: Arnold, B. F., Schiff, K. C., Ercumen, A., Benjamin-Chung, J., Steele, J. A., Griffith, J. F., Steinberg, S. J., Smith, P., McGee, C. D., Wilson, R., Nelsen, C., Weisberg, S. B., and Colford, J. M., Jr. 2017
		using a log-linear rate model with robust standard errors to account for repeated observations within individuals.
	Details on statistical analysis (if any)	In the log-linear model potentially confounding factors (e.g. demographics) were included as covariates (equation 1, p. 15 Surfer Health Study described above). The descriptions of the statistical model are of an advanced statistical nature could be more concise.
	Relative risk/odds ratio, confidence interval?	Relative risk/odds ratio
Results	Outcome	Illness associated with seawater exposure: • Seawater exposure in the past 3 days was associated with increased incidence rates of gastrointestinal illness, diarrhea, sinus pain or infection, earache or infection, infection of open wound, skin rash, and fever, but not upper respiratory illness • With the exception of fever and skin rash, incidence rates increased from unexposed to dry-weather exposure to wet-weather exposure periods, a pattern also present on the risk scale. • Compared with unexposed periods, wet-weather exposure led to the largest relative increase in: - earaches/infections (adjusted incidence rate ratio (IRR) = 3.28, 95% confidence interval (CI): 1.95, 5.51); and - infection of open wounds (adjusted IRR: 4.96, 95% CI: 2.18, 11.29). Illness associated with faecal indicator bacteria levels • Enterococcus, total coliform, and faecal coliform levels were positively associated with increased incidence of almost all outcomes during the study. • Rainfall was a strong effect modifier of the association. • During dry weather, there was no association between Enterococcus levels and illness except for infected wounds, but Enterococcus was strongly associated with illness after wet-weather exposure (e.g. for each log10 increase, gastrointestinal illness IRR = 2.17, 95% CI: 1.16, 4.03). • There was evidence for excess risk of gastrointestinal illness at higher Enterococcus levels only during wet-weather periods: The predicted excess risk that corresponded to the current US Environmental Protection Agency regulatory guideline of 35 colony-forming units per 100 mL was 16 episodes per 1,000 (95% CI: 5, 27). • Negative control analyses showed no consistent association between faecal indicator bacteria and illness among participants during periods in which they had no recent seawater contact.
	How outcome was assessed	Box plots of FIB at monitored sites in wet and dry weather, illness incidence rates among surfers by type of seawater exposure, Incidence Rate Ratios (IRR) for surfer illnesses within 3 days of dry- and wet-weather seawater exposure compared with unexposed periods
	Method of measurement	Rates of surfer illnesses measured by follow up surveys.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	A total of 654 individuals were enrolled.
Author's conclusion	Interpretation of results	Surfing was associated with increased incidence of several categories of symptoms, and associations were stronger if surfing took place shortly after rainstorms. Higher levels of faecal indicator bacteria were strongly associated with fever, sinus pain/infection, wound infection, and gastrointestinal symptoms within 3 days of rainstorms. The internal consistency between water-quality measurements, patterns of illness after dry- and wet-weather exposures, and incidence profiles with time since rainstorms lead the authors to conclude that seawater exposure during or close to rainstorms at beaches impacted by urban runoff in southern California increases the incidence rates of a broad set of acute illnesses among surfers. These findings provide strong evidence to support the posting of beach warnings after rainstorms and initiatives

Category	Data class	J6: Arnold, B. F., Schiff, K. C., Ercumen, A., Benjamin-Chung, J., Steele, J. A., Griffith, J. F., Steinberg, S. J., Smith, P., McGee, C. D., Wilson, R., Nelsen, C., Weisberg, S. B., and Colford, J. M., Jr. 2017
		that would reduce pathogen sources in urban runoff that flows to coastal waters.
	Assessment of uncertainty (if any)	The statistical modelling accounted for most elements of uncertainty associated with the sample design. Sensitivity analyses that shortened the wet-weather window increased the difference between dry- and wet-weather incidence rates for most outcomes.
Reviewer comments	Reviewer comments	The magnitude of the statistical effects observed in the study are greatly dictated by the local recreational water quality environment of the study area, they should be relevant to any metropolitan surf beaches in temperate and subtropical regions of Australia, particularly in the vicinity of stormwater discharges. The overall findings of the study - urban coastal seawater exposure increases the incidence rates of many acute illnesses among surfers, with higher incidence rates after rainstorms - is consistent with the general epidemiological literature on water recreational at coastal beaches. The study findings support the continued use of FIB as a tool for assessing health risks to recreational water users at metropolitan surf beaches.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	The website version of the study contains additional tables and figures.

6.6. J15: Gitter, Mena, et al., (2020)

6.6.1. Quality assessment

Q	Criteria	J15, Gitter, A., 2020, Human health risks associated with recreational waters: Preliminary approach of integrating quantitative microbial risk assessment with microbial source tracking Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The objective of the study was to conduct a QMRA estimating the risk for GI illness using MST data describing the primary sources contributing to a bacteria impairment in a particular waterbody.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	DNA fingerprinting was used to match *E. coli* isolates from water samples to a Texas MST library. Thus the proportion of *E. coli* from 3 different sources was determined (human/unidentified, cattle/domestic animals, and wildlife). The ratio of *E. coli* in water to faeces from each source was used to determine the pathogen contribution in water from each source, and thus the dose ingested by a swimmer. Standard dose response equations were used to determine risk of illness. This is approach to QMRA rests upon a lot of assumptions (described below), but is probably reasonable to estimate relative contributions to illness risk from different sources.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research aims were fairly broad, and the method sought only to estimate GI illness risk from different sources. Consequently the design is appropriate.	**Probably low risk of bias (+)**

Q	Criteria	Assessment	J15, Gitter, A., 2020, Human health risks associated with recreational waters: Preliminary approach of integrating quantitative microbial risk assessment with microbial source tracking Comments	Risk of Bias rating
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is adults undertaking primary contact recreation. Rates of gastrointestinal illness are calculated (note that this ignores other health impacts, e.g. sequelae like G-B syndrome), and referenced to the US EPA tolerable risk guideline of 0.036 (3.6% risk of GI illness per event, US EPA 2012)	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Data was obtained from relevant literature and MST data libraries and used in the QMRA calculations. Many sources are used, but all appear to be referenced and link back to high quality publications and authors.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analyses were relatively simple yet appropriate for the research design. The main source of rigour is the ability to compare measured *E. coli* isolates to an extensive MST library local to where the study was undertaken (Texas USA). A number of minor limitations regarding the assumptions were identified and discussed (e.g. ignoring rates of FIB and pathogen decay), but these were not considered sufficient to undermine the study findings.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	There is a clear statement of findings in the study abstract, whilst the conclusions build on the findings. Ideally the conclusions should have been part of the abstract, but the authors were probably prevented from doing so by the tight word count (200) requirements of the journal for the abstract.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research findings are useful for informing this narrative review in demonstrating that specifying the sources contributing to a bacterial classification of a waterbody can assist in identifying the potential human health risk, especially when differentiating human and nonhuman sources.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study is a niche QMRA identifying a method for using E. coli measurements in a freshwater location to estimate likely reference pathogen concentrations from different sources*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.6.2. Data extraction

Category	Data class	J15: Gitter, A.; Mena, K. D.; Wagner, K. L.; Boellstorff, D. E.; Borel, K. E.; Gregory, L. F.; Gentry, T. J.; Karthikeyan, R. 2020
Descriptive attributes	Title	Human health risks associated with recreational waters: Preliminary approach of integrating quantitative microbial risk assessment with microbial source tracking
	Publication Title	Water (Switzerland)

Category	Data class	J15: Gitter, A.; Mena, K. D.; Wagner, K. L.; Boellstorff, D. E.; Borel, K. E.; Gregory, L. F.; Gentry, T. J.; Karthikeyan, R. 2020
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	12 (2) 327
	Publication date	2020
	Publication Source	Water (Switzerland) 12 (2) 327 DOI:10.3390/w12020327
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	Research partially supported by Texas State Soil and Water Conservation Board and Texas Commission on Environmental Quality
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	FIB (*E. coli*), reference pathogens (Campylobacter, Norovirus, Cryptosporidium)
	CASP classification	Qualitative research
	marine, estuarine or freshwater	f
	DOI http://dx.doi.org/	10.1021/acs.est.6b05886
Study characteristics	Aim/objectives of study	The objective of the study was to conduct a QMRA estimating the risk for GI illness using MST data describing the primary sources contributing to a bacteria impairment in a particular waterbody.
	Study type/design	QMRA of risk to primary contact recreators at an example sampling site [LEO 2 (USGS Station ID: 17379) on Walnut Creek, see next cell] with a geometric mean of *E. coli* of 163 colony forming units (cfu) 100 mL-1, and the recreational standard of *E. coli*, 126 cfu 100 mL-1. *E. coli* concentrations were used to predict reference pathogen concentrations from (a) human, (b) cattle and (c) domestic animals and wildlife, and thus the relative risk of GI illness from each source.
	Study duration	MST analyses were conducted from 2011 to 2012 in Walnut Creek, a tributary of the Leon River in the Brazos River Basin in Texas
Population characteristics	Population/s studied	Primary contact recreators
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Riverine freshwater, agricultural catchment
	Exposure scenario	Standard water ingestion by primary contact recreation as estimated by Sunger and Haas (2015, 10.2175/106143015X14212658613073) and Dufour et al, 2006, doi: 10.2166/wh.2006.017)

Category	Data class	J15: Gitter, A.; Mena, K. D.; Wagner, K. L.; Boellstorff, D. E.; Borel, K. E.; Gregory, L. F.; Gentry, T. J.; Karthikeyan, R. 2020
	Exposure pathway	Ingestion of water during primary contact recreation
	Source of infection/ contamination	Predicted concentrations of reference pathogens in river water arising from catchment sources. Sources and related reference pathogens were Cattle (Campylobacter), Human (Norovirus), and Wildlife/Domestic Animals (Cryptosporidium)
	Causal organisms	Campylobacter, Norovirus, Cryptosporidium
	Comparison group(s)	n/a
Study methods	Water quality measurement used	FIB: *E. coli* of 163 colony forming units (cfu) 100 mL-1, and the recreational standard of *E. coli*, 126 cfu 100 mL-1.
	Method of microorganism isolation and enumeration (if applicable)	Not stated. However the paper includes the following statement: "The MST data presented in this study and used for the assessment was data that had previously been published in technical documents used to inform watershed management reports. It is beyond the scope of this microbial risk assessment to extensively review the methods by which the MST samples were analysed", and "The Texas MST Library is composed of *E. coli* isolates from 12 different watersheds in Texas and includes over 8812 isolates from 2519 faecal source samples, representing humans and more than 130 different animal subclasses"
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Geometric mean *E. coli* of 8 monthly grab samples on site LEO 2 in the Leon River Watershed (12 were planned, but due to drought 4 samples could not be taken).
	Limits of reporting for the organism of concern	Limits for FIB not stated
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Not stated (but see statement above)
Statistics	Statistical methods used	QRMA dose-response modelling with use of probability distribution functions for key parameters (e.g. volume of water ingested, conc. of *E. coli* and reference pathogens in source faeces, prevalence of infection, infectious potential, etc.). Use of Monte-Carlo analysis methods to determine uncertainty.
	Details on statistical analysis (if any)	A Monte Carlo analysis of 10,000 simulations was conducted in Crystal Ball Pro® software to develop a distribution of the pathogen dose from each source, as well as to estimate the probability of illness. The probability of a GI illness based on the reference pathogen input from three faecal sources was estimated. The risk estimates (for a GI illness) were calculated with a 95% confidence level, and the median, 5th, 25th, 75th, and 95th percentile values of each risk estimate for each of three scenarios (described in outcomes below) were reviewed (using box plots).
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	The three scenarios assessed the effects of changing the contributing percentages of different sources on the overall human health risk. The simulated scenarios included: (a) each faecal source contributes 100% to the FIB concentration; (b) each faecal source contributes based upon results: 10% human (combined with unidentified), 25% cattle/domestic animals, and 65% wildlife; (c) each faecal source contributes based upon modified MST results, separating cattle and domestic animals: 7% human, 20% cattle, and 73% wildlife/domestic animals/unidentified. For each scenario, which included a mixture of faecal sources, the median risk for a GI illness was at least 0.31. The difference in total

Category	Data class	J15: Gitter, A.; Mena, K. D.; Wagner, K. L.; Boellstorff, D. E.; Borel, K. E.; Gregory, L. F.; Gentry, T. J.; Karthikeyan, R. 2020
		health risk when the human source contributed 10% as opposed to 7% was negligible. High human infectivity of norovirus and the smaller ratio of faecal indicator bacteria to norovirus than for the other pathogens, resulted in the risk being relatively similar across each scenario. These findings indicate that the proportion of cattle/domestic animals and wildlife faecal loading had a much less substantial impact on the overall risk for a GI illness.
	How outcome was assessed	Box plots and bar chart of results [Probability of GI illness] are presented in the report.
	Method of measurement	The dose of reference pathogen received was calculated from a formula (equation 1 in the paper) based on the ratio of *E. coli* in water to *E. coli* in faecal source x conc. of pathogen in same faecal source x prevalence of infection of pathogen in source x infectious potential of pathogen in humans x volume of water ingested
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	While the most frequent sources of faecal indicator bacteria at the sampling site were nonhuman, the risk of illness from norovirus, the reference pathogen representing human waste, contributed the greatest risk to human health. This study serves as a preliminary review regarding the potential for incorporating results from library-dependent MST to inform a QMRA for recreational. The simulations indicated that identifying the sources contributing to the bacterial impairment is critical to estimate the human health risk associated with recreation in a waterbody.
	Assessment of uncertainty (if any)	A sensitivity analysis of the risk of illness was conducted for each scenario to identify the assumptions that had the greatest impact on the overall risk estimate. The assumptions, prevalence of infection, and infectious potential of Campylobacter and Cryptosporidium were repeatedly identified as being the primary factors contributing to the greatest amount of uncertainty when calculating the risk of illness for each pathogen/source in each scenario. The assumptions for the volume of water ingested and density of *E. coli* in cattle/domestic animal and wildlife waste did not appear to significantly influence the sensitivity analysis.
Reviewer comments	Reviewer comments	The study is innovative and clearly reported, despite the complexity of analyses involved. The innovation of using the ratios of *E. coli* to reference pathogen concentrations in faecal sources to predict the reference pathogen concentration in the recreational water given the measured *E. coli* concentration is a clever approach. This approach does ignore the potential for *E. coli* arising from other sources (probably a low likelihood), and also ignores the likelihood of differential environmental decay rates between the *E. coli* and reference pathogens. With respect to differential decay, the ingested dose equation (equation 1 in the paper) follows the assumption that faecal pollution is fresh and directly deposited into the water, and not aged. The authors note that while these conditions may not be as realistic of actual environmental conditions, they serve as a worst-case scenario.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	This is a concise and innovative study demonstrating the use of MST data libraries, field sampling data, and QMRA methods to predict the likely risks of GI illness for primary contact recreators given annual geometric means for *E. coli*, and the contribution of different sources (cattle, domestic animals, wildlife, and humans) to that risk.

6.7. J18: Henry, Schang, et al., (2016)

6.7.1. Quality assessment

Q	Criteria	J18, Henry, R.;, 2016, Into the deep: Evaluation of SourceTracker for assessment of faecal contamination of coastal waters Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The stated aim was to use recreational water quality site microbial data in HTS and Source Tracker and to identify the main sources of contamination, and thus assist water managers with achieving better understanding of the sources of contamination at several recreational beaches in the Port Philip Bay area. The aims are stated relatively clearly.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The use of genomic sequencing of microbial communities from potential source combined with a rigorous method evaluation and statistical analysis is considered appropriate.	**Definitely low risk of bias (++)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The genomic sequencing tools were trialled in the lab using solutions spiked with known quantities of various FIB sources with the results subjected to a rigorous statistical analysis. This analysis helps underpin the conclusions from the subsequent environmental sample dataset.	**Definitely low risk of bias (++)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study was focused on demonstrating the utility of MST methods to identify microbial sources in recreational waters and thus no assessment of risks to a hypothetical population or subpopulation was undertaken.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The research aims and the study methods are closely aligned. The complexities of the study design and descriptions of analytical and statistical techniques were reported with a high level of detail.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis is set out and reported with a high level of detail.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	Clear statements of findings are located in the abstract. These are supported by the text narrative, although this is separated into sections and not summarised in the conclusions.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	This study has useful and locally relevant observations on MST methods that could be of value to this narrative review.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study is an observational study of sewage genetic marker decay rates in recreational freshwater and marine habitats and is sufficiently rigorous.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.7.2. Data extraction

Category	Data class	J18: Henry, R.; Schang, C.; Coutts, S.; Kolotelo, P.; Prosser, T.; Crosbie, N.; Grant, T.; Cottam, D.; O'Brien, P.; Deletic, A.; McCarthy, D. 2016
Descriptive attributes	Title	Into the deep: Evaluation of SourceTracker for assessment of faecal contamination of coastal waters
	Publication Title	Water Research
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	93 (2016) 242-253
	Publication date	2016
	Publication Source	Water Research 93 (2016) 242-253 DOI:10.1016/j.watres.2016.02.029
	Peer reviewed	Yes
	Country of origin	Australia
	Source of funding	Funding sources were Melbourne Water (Victoria), Environmental Protection Authority (Victoria), Mornington Peninsula Shire and the Australian Research Council Linkage program (LP120100718)
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	16S rRNA
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m,e,f
	DOI http://dx.doi.org/	10.1016/j.watres.2016.02.029
Study characteristics	Aim/objectives of study	The stated aim was to use recreational water quality site microbial data in high-throughput sequencing (HTS) and Source Tracker to identify the main sources of contamination and thus assist water managers with achieving better understanding of the sources of contamination at several recreational beaches in the Port Philip Bay (Victoria) area.
	Study type/design	The study is an observational study of sewage genetic marker decay rates in recreational freshwater and marine habitats
	Study duration	Marine water sample collection in Port Phillip Bay was between December 2014 and March 2015 (42 samples). A further 83 samples of regional riverine, estuarine, greywater, stormwater, sewage and potable source waters, plus and faecal and sand samples (as a source of MST markers) were collected between Dec 2014 and Feb 2015.
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a

Category	Data class	J18: Henry, R.; Schang, C.; Coutts, S.; Kolotelo, P.; Prosser, T.; Crosbie, N.; Grant, T.; Cottam, D.; O'Brien, P.; Deletic, A.; McCarthy, D. 2016
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Marine, estuarine.
	Exposure scenario	n/a. Study focuses is on MST
	Exposure pathway	n/a
	Source of infection/ contamination	Regional catchment sources, riverine inflows, stormwater, groundwater inflows, greywater, septic effluent, birds
	Causal organisms	Conventional (*E. coli*) and novel faecal indicator bacteria.
	Comparison group(s)	n/a
Study methods	Water quality measurement used	FIB, genomic DNA of faecal bacterial communities
	Method of microorganism isolation and enumeration (if applicable)	Colilert for *E. coli*, genomic DNA via qPCR techniques (detail of proprietary reagent described in section 2.4 of the paper).
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Water samples were collected in clean, source-water rinsed disposable bottles from each location. Triplicate beach samples were collected at each site, 30 m apart, and composited to form a single 2 L sample. Estuarine and freshwater grab samples were taken 3 m perpendicular from the bank and at an approximate depth of 0.15 m at each location.
	Limits of reporting for the organism of concern	Not stated
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Field and laboratory methods are described in detail in the report and were considered to be rigorous. PCR reactions were performed in triplicate (section 2.4).
Statistics	Statistical methods used	Spearman rank non-parametric correlations were conducted to determine the existence of relationships between operational taxonomic units (OTUs) present at each beach sampling site, the detection of investigated sources within the sink samples (i.e. the beach sites) and environmental parameters. Weighted UniFrac analysis was conducted using the QIIME beta_significance.py script to determine if samples from the same location were statistically similar based on relative abundance of identified OTUs. Principal co-ordinate analysis was conducted between the three beach sites on OTU data (presumably using the UniFrac matrix as input but this is not stated).
	Details on statistical analysis (if any)	Reviewers notes: (1) UniFrac is a distance metric used for comparing biological communities and incorporates information on the relative relatedness of community members by incorporating phylogenetic distances between observed organisms in the computation. (2) the QIIME beta_significance.py script conducts tests on each pair of samples present in an input operational taxonomic unit (otu) table, and outputs a tab delimited text file with each pair of samples and a p value representing the probability that a random sample/sequence assignment will result in more dissimilar samples than the actual pair of samples]
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	The current study applied artificial and in-laboratory derived bacterial communities to define the potential and limitations associated with the use of SourceTracker, prior to its application for faecal source tracking

Category	Data class	J18: Henry, R.; Schang, C.; Coutts, S.; Kolotelo, P.; Prosser, T.; Crosbie, N.; Grant, T.; Cottam, D.; O'Brien, P.; Deletic, A.; McCarthy, D. 2016
		at three recreational beaches near Port Phillip Bay (Victoria, Australia). The results demonstrated that at minimum multiple model runs of the SourceTracker modelling tool (i.e. technical replicates) were required to identify potential false positive predictions. The calculation of relative standard deviations (RSDs) for each attributed source improved overall predictive confidence in the results. In general, default parameter settings provided high sensitivity, specificity, accuracy, and precision. Application of SourceTracker to recreational beach samples identified treated effluent as major source of human derived faecal contamination, present in 69% of samples. Site-specific sources, such as raw sewage, stormwater and bacterial populations associated with the Yarra River estuary were also identified. Rainfall and associated sand resuspension at each location correlated with observed human faecal indicators. The results of the optimised SourceTracker analysis suggests that local sources of contamination have the greatest effect on recreational coastal water quality.
	How outcome was assessed	Principal co-ordinate analysis was conducted between the three beach sites, source waters and faecal inputs collected from Dec 14-Mar 15.
	Method of measurement	*E. coli* via Colilert and bacterial MST markers via qPCR.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The future of MST studies will be driven by the ability of researchers to identify specific source markers. Single organism approaches have distinct limitations in their ability to attribute sources in complex environmental mixes. The use of NGS* in combination with computational mixture modelling tools, such as SourceTracker for QIIME**, open new avenues for MST investigations. [Reviewer's comments: * NGS = Next Generation Sequencing **QUIIME = Quantitative Insights Into Microbial Ecology: software tools located at www.QIIME.org].
	Assessment of uncertainty (if any)	The current study demonstrated that to increase confidence in computational analysis technical replicate in SourceTracker model runs (under default conditions) and calculation of RSDs (Relative Standard Deviations) is required to better understand potential sources. Applying the method in this manner resulted in the repeatable detection of sources of human and animal contamination within coastal water sources, the introduction of which were subsequently shown to correlate with rainfall. Further site-specific evaluation is required to determine the risk posed by sand resuspension and the sources of localised beach contamination.
Reviewer comments	Reviewer comments	This study seeks to evaluate the efficacy of the SourceTracker statistical tool for assessment of faecal contamination of coastal waters. The study field, lab and statistical methods are rigorous and are presented in great detail. The reporting of results is complex and technical due to the large size of the data set and high level of detail of possible effects in the discussion. Conclusions by the authors that 24 hr rainfall was important in contributing to beach water faecal contamination, and the further sources were away from the sink (beach) sites, the less impact they had, confirms conventional wisdom about microbial contamination of beach waters.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	There were opportunities to provide further clarity on the Principal Co-ordinates analysis. This multivariate analysis has the potential to identify major underlying factors in the microbial data that were not used or reported fully in the paper. For example, the colour and shape of symbols in figure 4 are not explained in the main paper, and little is made of the clear lumping of the beach samples (sinks) a long way from the other source samples (river, estuary, wastewater, greywater, sand,

Category	Data class	J18: Henry, R.; Schang, C.; Coutts, S.; Kolotelo, P.; Prosser, T.; Crosbie, N.; Grant, T.; Cottam, D.; O'Brien, P.; Deletic, A.; McCarthy, D. 2016
		bird faeces). This implies that the measured sources have at most only minor impacts on the sinks. This compliments the SourceTracker findings but not necessarily the narrative in the text which highlights the small percentage contributions of sources identified by SourceTracker. The conclusion the reviewer draws here is that there are other significant sources of faecal contamination at the beaches that has not been adequately characterised. The authors admit to this concern with respect to Elwood Beach, where they noted that the low number of input source water samples may have limited the identification of source-specific bacterial signatures.

6.8. J20: Kelly, Feng, et al., (2018)

6.8.1. Quality assessment

		J20, Kelly, Eli, 2018, Effect of beach management policies on recreational water quality		
Q.	Criteria	Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The stated primary objective of the study was to evaluate whether beaches characterized by a set of management policies are associated with lower FIB levels	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The methodology involves use of a large data set of FIB monitoring from Florida, USA beaches (Florida Healthy Beaches Program FHBP) plus a large survey of beach management agency regional offices. Such exploratory data analyses drawing on the statistical power of a large data set are often very informative.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The exploratory data analyses of large data sets was appropriate for the research aims	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was comparison of beach management methods against FIB monitoring data and thus did not involve a hypothetical population or subpopulation	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The large datasets from the FHBP were subjected to significant processing in order for them to meet the requirements of the research issue (e.g. factor analysis etc.)	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	Preliminary statistical classifications using ANOVA and T-tests were used to select questions that demonstrated a significant effect on FIB levels for further analysis using factor analysis and multiple regression. Specifically, since factor analysis axes (of beach management categories: human use, animal	**Probably low risk of bias (+)**

Q.	Criteria	Assessment	J20, Kelly, Eli, 2018, Effect of beach management policies on recreational water quality Comments	Risk of Bias rating
			policies and control, solid waste management, grooming, beach access, and drainage) are by definition uncorrelated, they could be used as independent variables in a multiple regression equation with enterococci or faecal coliforms as the dependent variables.	
9	Is there a clear statement of findings?	Yes	There is a clear statement of findings in the abstract. These align with the text.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is useful for this narrative review in identifying the combination of natural marine beach attributes and management practices associated with better FIB monitoring results. The geographical location is restricted to Florida, but some of the information may be useful in an Australian context.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*This exploratory study of a large Florida state-wide beach management data set may provide some useful guidance in the Australian context.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.8.2. Data extraction

Category	Data class	J20: Kelly, Elizabeth A.; Feng, Zhixuan; Gidley, Maribeth L.; Sinigalliano, Christopher D.; Kumar, Naresh; Donahue, Allison G.; Reniers, Adrianus J. H. M.; Solo-Gabriele, Helena M. 2018
Descriptive attributes	Title	Effect of beach management policies on recreational water quality
	Publication Title	Journal of Environmental Management
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	212 (2018) 266-277
	Publication date	2018
	Publication Source	Journal of Environmental Management 212 (2018) 266-277 DOI:10.1016/j.jenvman.2018.02.012
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	Funded through support of the University of Miami's Leonard and Jayne Abess Center for Ecosystem Science and Policy, and the Oceans and Human Health Center. An early portion of the work was funded in part by the NSFeNIEHS Oceans and Human Health Program.
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes

Category	Data class	J20: Kelly, Elizabeth A.; Feng, Zhixuan; Gidley, Maribeth L.; Sinigalliano, Christopher D.; Kumar, Naresh; Donahue, Allison G.; Reniers, Adrianus J. H. M.; Solo-Gabriele, Helena M. 2018
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	FIB
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m
	DOI http://dx.doi.org/	10.1371/journal.pone.0174732
Study characteristics	Aim/objectives of study	The stated primary objective of the study was to evaluate whether beaches characterized by a set of management policies are associated with lower FIB levels
	Study type/design	The methodology involves use of a large data set of FIB monitoring from Florida, USA beaches (Florida Healthy Beaches Program FHBP) plus a large survey of beach management agency regional offices. Such exploratory data analyses drawing on the statistical power of a large data set are often very informative.
	Study duration	The study utilised a dataset of enterococci and faecal coliform data collected through the FHBP from July 31, 2000 to December 31, 2015.
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Marine, estuarine.
	Exposure scenario	n/a. Study focus is on beach management practices
	Exposure pathway	n/a
	Source of infection/ contamination	Specific sources are not addressed, but risk factors including beach management practices are identified that are associated with increased FIB concentrations (e.g. animals such as dogs and birds, humans, availability of amenities, beach aspect and type (open ocean vs marshy areas), and beach grooming methods (disturbance of heavy wrack can increase FIB).
	Causal organisms	FIB (enterococci and faecal coliforms)
	Comparison group(s)	n/a
Study methods	Water quality measurement used	FIB (enterococci and faecal coliforms)
	Method of microorganism isolation and enumeration (if applicable)	n/a. Historical Florida state-wide FIB beach monitoring dataset used.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what	To evaluate beach management policies, Florida Healthy Beaches Program (FHBP) state-wide FIB database was utilised. Application of inclusion criteria (minimum of 120 samples during the 15-year period of record; 2000-2015) resulted in 316 beaches for evaluation. Beach type was identified based upon the method of Donahue et al.

Category	Data class	J20: Kelly, Elizabeth A.; Feng, Zhixuan; Gidley, Maribeth L.; Sinigalliano, Christopher D.; Kumar, Naresh; Donahue, Allison G.; Reniers, Adrianus J. H. M.; Solo-Gabriele, Helena M. 2018
	steps were taken to reduce contamination?	(2017; doi.org/10.1016/j.marpolbul.2017.05.024. Beach types included open coast, bay, inlet-channel situated, manmade-structure-protected, marsh surrounded, and back-reef beaches. The FIB data for each beach were converted to a percent exceedance value to track the fraction of times that the beaches exceeded regulatory guidelines. A beach management survey was developed to collect data on management policies. The results were then compared to FIB data to determine which management condition corresponded to lower bacteria levels. The observed influence of beach morphology determined how each of the responses in the beach management survey were analysed.
	Limits of reporting for the organism of concern	Not stated
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Not stated for FIB sampling.
Statistics	Statistical methods used	To obtain a measure of the frequency with which beaches are closed due to potential health risks, the numerical measurements of colony forming units was converted to percent exceedance based on the single-sample thresholds for issuing beach advisories (104 CFU/100 ml for enterococci, 400 CFU/100 ml for faecal coliform). For analysing data on a county-by-county basis, the percent exceedance value for that entire county was aggregated using a weighted average based upon the number of samples collected at each beach within the county to compute a percent exceedance value for that county. On a beach basis, percent exceedance was computed for the entire period of record, providing one value per beach.
	Details on statistical analysis (if any)	Preliminary statistical classifications using ANOVA and T-tests were used to select questions that demonstrated a significant effect on FIB levels for further analysis using factor analysis and multiple regression. Specifically, since factor analysis axes (of beach management categories: human use, animal policies and control, solid waste management, grooming, beach access, and drainage) are by definition uncorrelated, they could be used as independent variables in a multiple regression equation with enterococci or faecal coliforms as the dependent variables.
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Analyses showed that beach geomorphology (beach type) was highly associated with exceedance of regulatory standards. Low enterococci exceedances were associated with open coast beaches (n = 211) that have sparse human densities, no homeless populations, low densities of dogs and birds, bird management policies, low densities of seaweed, beach renourishment, charge access fees, employ lifeguards, without nearby marinas, and those that manage stormwater. Factor analysis and a linear regression confirmed beach type as the predominant factor with secondary influences from grooming activities (including seaweed densities and beach renourishment) and beach access (including charging fees, employing lifeguards, and without nearby marinas).
	How outcome was assessed	The outcome was assessed through the use of large amounts of monitoring data (n > 150,000 measurements per FIB) to determine associations between the frequency of contaminant exceedances and beach management practices. The large FIB database was augmented with results from a survey designed to assess management policies for 316 beaches throughout the state of Florida

Category	Data class	J20: Kelly, Elizabeth A.; Feng, Zhixuan; Gidley, Maribeth L.; Sinigalliano, Christopher D.; Kumar, Naresh; Donahue, Allison G.; Reniers, Adrianus J. H. M.; Solo-Gabriele, Helena M. 2018
	Method of measurement	FIB exceedance rates per beach was matched against beach management practices and beach physical attributes.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The results were observable primarily because of the very large public FIB database available for analyses; similar approaches can be adopted at other beaches. The findings of this research have important policy implications because the selected beach management practices that were associated with low levels of FIB can be implemented in other parts of the US and around the world to improve recreational beach water quality.
	Assessment of uncertainty (if any)	The study supported the work of researchers who found that: -the presence of birds, humans, and dogs, cause an increase in FIB at recreational beaches. -Beach sand can provide an area in which FIBs can proliferate -Grooming in areas with heavy beach wrack that involve disturbance of the wrack may actually increase concentrations. The study also found that the availability of restrooms and showers; concession stands; solid waste management; and fees to access the beach can have an effect on FIBs. Given the associations demonstrated between beach management and FIBs, the study results support the concept of sustainable beach management. Such management would streamline or even unify the operations of different agencies that manage beach erosion, wildlife, solid waste, beach patrol and law enforcement, amenities for beach visitors, water quality monitoring, and maintenance.
Reviewer comments	Reviewer comments	The research is useful in identifying the combination of natural marine beach attributes and management practices associated with better FIB monitoring results. The geographical location is restricted to Florida, but some of the information may be useful in an Australian context.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	This was a high quality study and the large amount of data utilised was very clearly presented.

6.9. J23: Lugg, Cook, et al., (2012)

6.9.1. Quality assessment

Q.	Criteria	J23, Lugg, R.S., 2012, Estimating 95th Percentiles from Microbial Sampling: A Novel Approach to Standardising their Application to Recreational Waters Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The study seeks to facilitate the application of recreational water guidelines that use the Wyer equation (Wat. Res. 1999, 33,715) for the purpose of allocating microbial water assessment categories (MACs). The study aimscould be more clearly reported.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study describes statistical methods and a Microsoft Excel template for calculating 95th percentiles of enterococcal distributions.	**Probably low risk of bias (+)**

Q.	Criteria	J23, Lugg, R.S., 2012, Estimating 95th Percentiles from Microbial Sampling: A Novel Approach to Standardising their Application to Recreational Waters Assessment	Comments	Risk of Bias rating
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate for the aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus is on a statistical method and thus did not involve a hypothetical population or subpopulation	n/a
5	Was the data collected in a way that addressed the research issue?	n/a	The study addresses statistical methodologies - principally algorithms and a calculator - and did not involve the collection of data.	n/a
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The statistical methodology is sufficiently rigorous.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	The statement of findings could be more clearly reported but section 4.2 describes the successful application of the Excel tool.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is useful for this narrative review in providing a tool for microbial beach classifications based on enterococci and has been demonstrated to be useful in an Australian context.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study describes a useful method and tool for calculating microbial advisory criteria for beaches based on enterococci monitoring data.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.9.2. Data extraction

Category	Data class	J23: Lugg, R.S.W.; Cook, A.; Devine, B. 2012
Descriptive attributes	Title	Estimating 95th Percentiles from Microbial Sampling: A Novel Approach to Standardising their Application to Recreational Waters
	Publication Title	The Significance of Faecal Indicators in Water: A Global Perspective
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	Book Chapter
	Publication date	2012
	Publication Source	The Significance of Faecal Indicators in Water: A Global Perspective n/a (n/a) 62-71 DOI:10.1039/9781849735421-00062
	Peer reviewed	Most likely (by the book Editors Drs D Kay and C Fricker).
	Country of origin	Australia

Category	Data class	J23: Lugg, R.S.W.; Cook, A.; Devine, B. 2012
	Source of funding	Not stated
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	Yes
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	n/a
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	FIB (Enterococci)
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m
	DOI http://dx.doi.org/	10.1016/j.mimet.2020.106049
Study characteristics	Aim/objectives of study	The study seeks to facilitate the application of recreational water guidelines that use the Wyer equation (Wat. Res. 1999, 33,715) for the purpose of allocating microbial water assessment categories (MACs).
	Study type/design	The study describes statistical methods and an Microsoft Excel template (EnteroTester) for calculating 95th percentiles of enterococcal distributions and MACs
	Study duration	n/a (desktop study)
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	marine, estuarine, freshwater
	Exposure scenario	n/a. Study describes a statistical method and Excel tool for beach classifications
	Exposure pathway	n/a
	Source of infection/ contamination	n/a
	Causal organisms	n/a
	Comparison group(s)	n/a
Study methods	Water quality measurement used	FIB (enterococci)
	Method of microorganism isolation and enumeration (if applicable)	n/a
	Water sampling methods (monitoring, surrogates).	The paper describes development and application of the EnteroTester Excel tool, which facilitates the appropriate computation for 95th

Category	Data class	J23: Lugg, R.S.W.; Cook, A.; Devine, B. 2012
	Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	percentiles and corresponding classifications for beach recreational water quality categories (MACs).
	Limits of reporting for the organism of concern	n/a
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	n/a
Statistics	Statistical methods used	
	Details on statistical analysis (if any)	The paper makes use of the Wyer et al equation [Water Research 1999(33):715] to facilitate the application of recreational water quality guidelines that use the equation for the purpose of allocating microbial water quality assessment categories (MACs) A, B and C each with a defined range of infection risk.
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	The authors describe the statistical methodology and results of trialling the EnteroTester Excel Tool on coastal beaches and freshwater sites in WA, NSW and the NT.
	How outcome was assessed	The performance of the EnteroTester tool was assessed through Monte Carlo simulations and via practical application at coastal beaches and freshwater sites at several Australian jurisdictions.
	Method of measurement	Monte Carlo simulation was used to evaluate different methods for 95th percentile calculations on randomly generated datasets from the reference lognormal distribution (95th%ile = 200, log10 SD = 0.81) with simulations run from sample sizes 8 to 100 - all values below 10 were treated as censored.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The EnteroTester template is a rapid, convenient, reliable, efficient in terms of data requirements, and more accurate in estimating infection risk and in placing recreational waters in their correct MACs than other methods of calculating 95th percentiles. It should be considered for recreational water classification and management in accordance with risk-based guidelines such as those published by WHO.
	Assessment of uncertainty (if any)	The paper specifically deals with uncertainty via the Monte Carlo simulations.
Reviewer comments	Reviewer comments	The research is useful in providing a tool for microbial beach classifications based on enterococci and has been demonstrated to be useful in an Australian context.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	The study methods could be more clearly reported. It is also a relatively old paper in the context of this review and the statistical methods incorporated into the tool may need to be updated

6.10. J30: Robins, Farkas, et al., (2019)

6.10.1. Quality assessment

Q.	Criteria	J30, Robins, P., 2019, Viral dispersal in the coastal zone: A method to quantify water quality risk Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	An aim was reported as follows: to investigate the relative importance of some of the key processes influencing viral dispersal through a river-estuary-coast system by applying a hydrodynamic model to simulate fluxes at a national monitoring site (Conwy estuary, North Wales, UK).	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	Hydraulic modelling of estuarine flows for prediction of viral dispersal is an appropriate methodology for spatial assessment of viral risks to recreational waters.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Hydraulic modelling of estuarine flows for prediction of viral dispersal, with the dispersal algorithms calibrated against virus sampling and flow data is an appropriate methodology for the study aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on modelling virus dispersal in a Welsh estuary, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	Collection of water samples for viral testing and flow measurements were made at several locations along the estuary and around the estuary mouth.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The hydraulic model development and its calibration is described in detail in the methods (Section. 2.3). The descriptions are detailed and appropriate. Five scenarios are described for modelling. These address factors such as dispersal, dilution, tide and include a worst case scenario.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	The conclusions incorporate clear statements of findings in relation to the effects of storm flows on virus dispersal and survival.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The research is useful for this narrative review in highlighting factors important for viral pathogen fate in estuarine waters which are a common location for water-based recreation.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study describes useful modelling approaches to assessing pathogen risks in estuarine recreational waters.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.10.2. Data extraction

Category	Data class	J30: Robins, P. E.; Farkas, K.; Cooper, D.; Malham, S. K.; Jones, D. L. 2019
Descriptive attributes	Title	Viral dispersal in the coastal zone: A method to quantify water quality risk
	Publication Title	Environment International
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	126 (2019) 430-442
	Publication date	2019
	Publication Source	Environment International 126 (2019) 430-442 DOI:10.1016/j.envint.2019.02.042
	Peer reviewed	Yes
	Country of origin	United Kingdom
	Source of funding	The work was supported by the Natural Environment Research Council (NERC) and the Food Standards Agency (FSA) under the Environmental Microbiology and Human Health (EMHH) Programme (VIRAQUA; NE/M010996/1). Multibeam bathymetry data was collected and processed during the SEACAMS (Sustainable Expansion of the Applied Coastal and Marine Sectors; www.seacams.ac.uk, Grant Number 80366) research project at Bangor University, with funding from the Welsh Government, the Higher Education Funding Council for Wales, the Welsh European Funding Office, and the European Regional Development Fund Convergence Programme
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	Viruses
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m, e
	DOI http://dx.doi.org/	DOI:10.1016/j.envint.2019.02.042
Study characteristics	Aim/objectives of study	The study aim was to investigate the relative importance of some of the key processes influencing viral dispersal through a river-estuary-coast system by applying a hydrodynamic model to simulate fluxes at a national monitoring site (Conwy estuary, North Wales, UK).
	Study type/design	The authors developed a river-estuary-coast hydraulic model to simulate virus dispersal, driven by point source discharges and river flows in combination with tidal forcing. Viral inputs were based on measured wastewater adenovirus concentrations and the model was implemented with or without viral die-off.

Category	Data class	J30: Robins, P. E.; Farkas, K.; Cooper, D.; Malham, S. K.; Jones, D. L. 2019
		The model was applied to the Conwy river (North Wales, UK), through the estuary, to the Irish Sea coast where bathing waters and shellfisheries are known to be prone to viral contamination.
	Study duration	March 2016 to August 2017 (water sampling component)
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Marine, estuarine.
	Exposure scenario	n/a
	Exposure pathway	n/a
	Source of infection/ contamination	Catchment sources of viral pathogens including discharges from wastewater treatment plants.
	Causal organisms	Adenovirus
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Human enteric viruses including Adenovirus
	Method of microorganism isolation and enumeration (if applicable)	Not stated in the paper, but reference is made to the source data described in a related paper (Farkas et al 2018, doi.org/10.1016/j.scitotenv.2018.04.038) which describes the use of qPCR techniques for virus enumeration.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Virus sampling is described in a related paper (Farkas et al 2018, doi.org/10.1016/j.scitotenv.2018.04.038) [which was judged by the reviewer to be of satisfactory quality]. The hydraulic model development and its calibration is described in detail in the methods (Section. 2.3). The descriptions are detailed and appropriate.
	Limits of reporting for the organism of concern	Not stated
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Not stated in the paper, but reference is made to the source data described in a related paper (Farkas et al 2018, doi.org/10.1016/j.scitotenv.2018.04.038) which describes laboratory methods in detail.
Statistics	Statistical methods used	Five scenarios are described for modelling. These address factors such as dispersal, dilution, tide and include a worst case scenario. The scenarios were: Run 1: annual simulation of viral dispersal Run 2: virus dilution in space Run 3: influence of hydrology on viral dispersal Run 4: influence of the tide on viral dispersal Run 5: worst case scenario
	Details on statistical analysis (if any)	The hydraulic model for the Conwy Estuary was a vertically-averaged hydrostatic ocean model (Telemac Modelling System V7.2). For all simulations, key parameters (depth, velocity, salinity, virus concentration) were output every 15 min [creating time series of flows, depths and predicted Adenovirus concentrations in within the estuary, for each scenario]. Comprehensive validation procedures were previously conducted for hydrodynamics and salinity intrusion (citing Robins et al., 2014, doi.org/10.1016/j.ecss.2014.09.019) which tested the suitability of the model in depth-averaged mode for application to the Conwy.

Category	Data class	J30: Robins, P. E.; Farkas, K.; Cooper, D.; Malham, S. K.; Jones, D. L. 2019
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Using the suite of scenarios described above, the authors showed that river flow was the primary control of viral export to the coast. Since the Conwy catchment is short and steep, and the estuary is small and river-dominated, short-duration high intensity 'flash floods' were shown to transport viruses through the estuary and out to sea, despite dilution or die-off effects. Duplicating flow events (i.e., storm clustering) did not double the virus export since the virus re-entered the estuary on the flood tide. The tidal magnitude and timing of high water relative to peak river flow were also important drivers regulating viral dispersal. A worst case event simulation (i.e., combining high river flows with high viral loading and high spring tide) resulted in increased concentrations of virus at nearby coasts, although the spatial spread was similar to the previous scenarios.
	How outcome was assessed	Hydraulic modelling of estuarine flows for prediction of viral dispersal, with the dispersal algorithms calibrated against virus sampling and flow data, and results used for spatial assessment of viral risks to recreational waters.
	Method of measurement	Virus concentrations were measured in estuary sources based on three seasonal sets of 2-hourly measurement at 2 WWTPs and at 2 river sites over three days. Data suggested viral concentrations were stable within diurnal bihourly-samples and indicating the use of such data to calibrate the model and the model output frequency of 15-min time steps, whilst approximate, was able to provide credible scenario values.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The case study of the Conwy, highlights the importance of storm river flow as a major control delivering potentially harmful virus loads to the coast. The study applies to small, well-mixed estuaries (reviewer's note: these are common on the NSW coast). Episodes of high virus concentrations in the river did not necessarily lead to high virus concentrations offshore during periods of low river flow (i.e., Q < Q10=50m3 s−1), as the majority of simulated viruses were retained within the estuary. However, during storms (i.e., Q > Q10), the authors simulated substantial estuary-ocean exchange of viruses (between 5 and 1000 ppl), despite the virus dilution effect in the river. Viruses were exported from the estuary on the ebb tide, most of which re-entered on the following flood and continued in this back-and-forth manner in the vicinity of shellfisheries and beaches. A single high flow event flushed a greater virus load out to sea than a cluster of smaller events, or an event of lower magnitude and longer duration, amounting to the same virus flux. Risk of poor water quality near shellfisheries and beaches is therefore heightened following a single river event with peak flows greater than ~Q10, and risk is increased further following clusters of such events. Short duration, high intensity river flows heighten the coastal water quality risk. Variability within the inflowing virus concentration (e.g. due to a virus

Category	Data class	J30: Robins, P. E.; Farkas, K.; Cooper, D.; Malham, S. K.; Jones, D. L. 2019
		outbreak) was less of a control than river flow on the overall export of viruses.
	Assessment of uncertainty (if any)	The time series of model outputs for different modelling scenarios explicitly explores the spatial and temporal variability in virus concentrations in the estuary and coastal waters.
Reviewer comments	Reviewer comments	The research is useful in highlighting factors important for viral pathogen fate in estuarine waters which are a common location for water-based recreation.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	This was a good quality study which, using the Conwy Estuary as an example, highlighted a number of important factors that influence the spatial and temporal distribution of viral pathogens in small well mixed estuaries adjacent to ocean beaches. The study findings can be used to guide generic advice to recreational water managers about the types of situations and events that lead to higher risks to recreational water quality and bather health.

6.11. J34: Russo, Eftim, et al., (2020)

6.11.1. Quality assessment – Systematic Review

Q.	Criteria	J34, Russo, Gar, 2020, Evaluating health risks associated with exposure to ambient surface waters during recreational activities: A systematic review and meta-analysis Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the review address a clearly focused question?	Yes	The study consisted of a systematic review and meta-analysis to evaluate the current scientific evidence for differences in risk of illness between recreational activities typically associated with different levels of contact with water. Three clear objectives are listed: (1) assess and summarize the scientific literature on the risk of illness associated with different types of recreational activities and different levels of water contact during recreation; (2) quantitatively estimate the pooled risk of illness associated with different categories of recreational activities and levels of water contact; and (3) evaluate risk of illness across activity and water contact categories to better understand illness risk associated with different types of recreation in ambient surface waters.	**Definitely low risk of bias (++)**
2	Did the authors look for the right type of papers?	Yes	Studies of interest were those related to exposure to ambient surface water during recreational activities and any health outcomes of interest.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Do you think all the important, relevant studies were included?	Yes	The bibliographic databases searched were PubMed, Web of Science, and TOXLINE: searches were for peer reviewed articles in any language, limited to articles published during or after 1950.	**Definitely low risk of bias (++)**

Q.	Criteria	J34, Russo, Gar, 2020, Evaluating health risks associated with exposure to ambient surface waters during recreational activities: A systematic review and meta-analysis Assessment	Comments	Risk of Bias rating
4	Did the review's authors do enough to assess quality of the included studies?	Yes	It was stated that the protocol for the systematic review and meta-analysis was developed with input from a panel of external peer-reviewers and conforms to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Study quality was evaluated using a checklist of 13 questions that assess risk of bias in 7 domains. A list of questions was formulated from established guidance documents for review studies including OHAT and Cochrane handbooks. A classification system was developed to determine whether each study has either a low risk of bias or high risk of bias by focusing on 6 of the 13 risk of bias questions that reflect exposure or outcome misclassification, biased methods, and lack of adequate adjustment for potential confounders. They were: 1. Is the comparison (i.e., control or reference) group appropriate? 2. Does the study design or analysis account for important confounding and modifying variables? 3. Do researchers adjust or control for other exposures that are anticipated to bias results? 4. Are we confident in the exposure characterization? 5. Are we confident in the outcome assessment? 6. Are there any other potential threats to internal validity (e.g. inappropriate statistical methods)? Any study rated as definitely high risk of bias for any of the above 6 questions was excluded from the meta-analysis.	**Definitely low risk of bias (++)**
5	If the results of the review have been combined, was it reasonable to do so?	Yes	Descriptions of recreational activities, study participants, health outcomes, water quality, age groups, and types of water contact substantially varied among the studies meeting the inclusion criteria. To perform meta-analyses, the authors categorized each extracted effect estimate based on recreational activity, degree of water contact, health outcome, water quality, study subject age, and water type. In combining data from many studies for review, it is important to control for site specific effects. By classifying the extracted effect estimates based the various criteria described above, this requirement was recognised and accounted for.	**Definitely low risk of bias (++)**
	Section B: What are the results?			
6	**What are the overall results of the review?**	Yes	The meta-analysis confirmed a strong association between swimming and both GI and RI. Swimming approximately doubles the risk of GI and increases the risk of RI by approximately 75% compared to no-contact controls. The conclusions section states the following: "Recreational activities associated with less ambient water contact (e.g. fishing, boating, or kayaking in tranquil waters) may result in a lower risk of illness	**Probably low risk of bias (+)**

Q.	Criteria	J34, Russo, Gar, 2020, Evaluating health risks associated with exposure to ambient surface waters during recreational activities: A systematic review and meta-analysis Assessment	Comments	Risk of Bias rating
			compared to recreational activities associated with greater ambient water contact (e.g. swimming, surfing, or whitewater kayaking). This study suggests that the level of exposure with different types of recreational activities are important characteristics when assessing the risk of illness associated with recreation in ambient surface waters." This statement is stating that greater exposure to water in recreation means greater risk of illness; this is a well-established maxim in the field of recreational water quality management. The overall results are moderately informative and established with a rigorous methodology.	
7	**How precise are the results?**	Yes	Pooled risk estimates indicated: - significant elevation of gastrointestinal illness with the recreational activity categories of swimming (2.19, 95% CI: 1.82, 2.63) and sports-related contact (2.69, 95% CI: 1.04, 6.92), and - nonsignificant elevation of gastrointestinal illness with minimal contact (1.27, 95% CI: 0.74, 2.16). - significant elevation of respiratory illness with swimming (1.78, 95% CI: 1.38, 2.29) and sports-related contact (1.49, 95% CI: 1.00, 2.24), and - no elevation of respiratory illness with minimal contact (0.90, 95% CI: 0.71, 1.14) The confidence intervals for swimming and GI and RI are relatively tight indicating precise estimates, but for sports related contact the relationship is less concise.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
8	**Can the results be applied to the local population?**	Yes	. The study findings are rigorous and support the concept of use of exposure risk categories in the management of recreational water use. Since the use of such categories is already common practice in the Australia context the study findings provide affirmation of this approach.	**Probably low risk of bias (+)**
9	**Were all important outcomes considered?**	Yes	As stated, the study is rigorous and thorough and addresses most important outcomes given the available data. Information on sequelae are not included since such data would not be part of the studies reviewed, but some consideration of such health outcomes in the discussion may have been useful.	**Probably low risk of bias (+)**
10	**Are the benefits worth the harms and costs?**	Yes	This study was a generally high quality literature review and consistent with best practice for systematic reviews. The statistical analysis was complex and showed a significant level of rigour. The research question and the conclusions seek to assess and ultimately confirm what is a well-established maxim in recreational water quality management; that the risk of illness increases with the level of exposure.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study describes is a focused and clearly presented study with some possibly useful findings for the narrative review.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.11.2. Data extraction

Category	Data class	J34: Russo, Gary S.; Eftim, Sorina E.; Goldstone, Alexandra E.; Dufour, Alfred P.; Nappier, Sharon P.; Wade, Timothy J. 2020
Descriptive attributes	Title	Evaluating health risks associated with exposure to ambient surface waters during recreational activities: A systematic review and meta-analysis
	Publication Title	Water Research
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	176 (2020) 115729
	Publication date	2020
	Publication Source	Water Research 176 (2020) 115729 DOI:10.1016/j.watres.2020.115729
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	The research was funded by the United States Environmental Protection Agency Office of Science and Technology in the Office of Water
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	Yes
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	GI Illness
	CASP classification	Systematic review
	marine, estuarine or freshwater	m,e,f
	DOI http://dx.doi.org/	10.1017/S0950268818000328
Study characteristics	Aim/objectives of study	The study consisted of a systematic review and meta-analysis to evaluate the current scientific evidence for differences in risk of illness between recreational activities typically associated with different levels of contact with water. Three objectives are listed: (1) assess and summarize the scientific literature on the risk of illness associated with different types of recreational activities and different levels of water contact during recreation; (2) quantitatively estimate the pooled risk of illness associated with different categories of recreational activities and levels of water contact; and (3) evaluate risk of illness across activity and water contact categories to better understand illness risk associated with different types of recreation in ambient surface waters.

Category	Data class	J34: Russo, Gary S.; Eftim, Sorina E.; Goldstone, Alexandra E.; Dufour, Alfred P.; Nappier, Sharon P.; Wade, Timothy J. 2020
	Study type/design	Systematic review of peer-reviewed publications published during or after 1950 as listed in the bibliographic databases PubMed, Web of Science, and TOXLINE.
	Study duration	n/a (desktop study)
Population characteristics	Population/s studied	n/a (meta-analysis of many studies)
	Selection criteria for population	n/a
	Subgroups reported	Risk of GI illness associated with swimming calculated separately for children and adults
	Size of study	8,618 records identified after removing duplicates. After screening (3 levels) 92 studies with quantitative data for meta-analysis were identified.
Exposure and setting	Type of water source/water body	Marine, estuarine, freshwater
	Exposure scenario	Risk of illness associated with different types of recreational activities and different levels of water contact during recreation
	Exposure pathway	Exposure to water during recreation
	Source of infection/ contamination	Microbial pathogens
	Causal organisms	Microbial pathogens
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Most reference in the review is to FIB as indicators of the viral, bacterial and protozoan pathogens responsible for observable GI illness following water-based recreation.
	Method of microorganism isolation and enumeration (if applicable)	The review does not address laboratory methods of the constituent papers.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	As the study was a meta-analysis of quantitative data from 92 peer-reviewed studies of health risks associated with exposure to ambient surface waters during recreational activities, the authors focus was on the study results. Although not-stated, an implicit assumption is that by using peer-reviewed studies, water sampling methods utilised in the constituent studies were assumed to be of satisfactory quality. This is a reasonable assumption. With respect to appropriate management of the data used in the review, the authors state that descriptions of recreational activities, study participants, health outcomes, water quality, age groups, and types of water contact substantially varied among the studies meeting the inclusion criteria. To perform meta-analyses, it was necessary to categorise each extracted effect estimate based on recreational activity, degree of water contact, health outcome, water quality, study subject age, and water type. The authors further note that in combining data from many studies for review, it is important to control for site specific effects. By classifying the extracted effect estimates based on the various criteria described above, this requirement was recognised and accounted for.
	Limits of reporting for the organism of concern	n/a (see comments above)
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	See comments above with respect to water quality measurements. Another quality aspect for a systematic review is assessment of risk of bias for the constituent studies. The authors state that they evaluated study quality using a checklist of 13 questions that assess risk of bias in 7 domains. They formulated the list of questions from the US National Toxicology Program Office of Health Assessment and Translation (OHAT) Risk of Bias Tool, Agency for Healthcare Research and Quality, and Cochrane Handbook (references cited in paper). A relatively complex classification system based on the questions

Category	Data class	J34: Russo, Gary S.; Eftim, Sorina E.; Goldstone, Alexandra E.; Dufour, Alfred P.; Nappier, Sharon P.; Wade, Timothy J. 2020
		below (developed from the above sources) was used to assess risk of bias. 1. Is the comparison (i.e., control or reference) group appropriate? 2. Does the study design or analysis account for important confounding and modifying variables? 3. Do researchers adjust or control for other exposures that are anticipated to bias results? 4. Are we confident in the exposure characterization? 5. Are we confident in the outcome assessment? 6. Are there any other potential threats to internal validity (e.g. inappropriate statistical methods)? Any study rated as definitely high risk of bias for any of the above 6 questions was excluded from the meta-analysis.
Statistics	Statistical methods used	The risk of illness associated with different categories of recreational activities and water contact was quantitatively evaluated by combining the results of multiple studies using meta-analysis Odds ratios were considered to be reasonable estimates of relative risk because the probability of infection due to water-based recreational activities is generally low. Before performing the analyses, the authors declared any meta-analysis result derived from fewer than three studies as inconclusive.
	Details on statistical analysis (if any)	Detailed descriptions of statistical techniques testing for (i) appropriateness of pooling of data (ii) heterogeneity due to study quality, study design, activity category, water contact category, and water type. Publication bias was assessed through the use of funnel plots of pooled risk estimates from each individual study versus the log standard error of those estimates and inspecting for asymmetry. Asymmetry in the funnel plot was tested using Eggers' test, where the results were considered too indicate publication bias if $p < 0.10$ for the bias coefficient.
	Relative risk/odds ratio, confidence interval?	odds ratios and 95% CIs are listed below.
Results	Outcome	Too many OR results are present in the paper to discuss here. Key findings however were the pooled risk estimates showing: - significant elevation of gastrointestinal illness with the recreational activity categories of swimming (2.19, 95% CI: 1.82, 2.63) and sports-related contact (2.69, 95% CI: 1.04, 6.92), and - nonsignificant elevation of gastrointestinal illness with minimal contact (1.27, 95% CI: 0.74, 2.16). - significant elevation of respiratory illness with swimming (1.78, 95% CI: 1.38, 2.29) and sports-related contact (1.49, 95% CI: 1.00, 2.24), and - no elevation of respiratory illness with minimal contact (0.90, 95% CI: 0.71, 1.14) Pooled risk estimates for GI for adults and children were significantly greater than 1, whilst only estimates for adults were greater than 1 for RI. Both GI and RI risk estimates were not significantly different from each other.
	How outcome was assessed	A systematic literature review and meta-analysis was conducted to evaluate risks of illness associated with different recreational activities and different levels of contact to ambient surface waters.
	Method of measurement	A literature search located 8,618 potentially relevant studies which were then screened for quantitative measures of risk using

Category	Data class	J34: Russo, Gary S.; Eftim, Sorina E.; Goldstone, Alexandra E.; Dufour, Alfred P.; Nappier, Sharon P.; Wade, Timothy J. 2020
		inclusion/exclusion criteria established in advance. Recreational activities were categorised as swimming, sports-related contact, minimal contact, and sand contact. Relative risks were combined using a random effects meta-analysis for adverse health outcome categories that represented gastrointestinal illness, respiratory illness, skin, eye, ear, nose, throat, and cold/flu illness. There were 92 studies that met the inclusion criteria.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The meta-analysis confirmed a strong association between swimming and both gastrointestinal illness (GI) and respiratory illness (RI). Swimming approximately doubles the risk of GI and increases the risk of RI by approximately 75% compared to no-contact controls. The conclusions section states the following: "Recreational activities associated with less ambient water contact (e.g. fishing, boating, or kayaking in tranquil waters) may result in a lower risk of illness compared to recreational activities associated with greater ambient water contact (e.g. swimming, surfing, or whitewater kayaking). This study suggests that the level of exposure with different types of recreational activities are important characteristics when assessing the risk of illness associated with recreation in ambient surface waters."
	Assessment of uncertainty (if any)	The confidence intervals for swimming and GI and RI are relatively tight (see study outcome above) indicating precise estimates, but for sports related contact the relationship is less concise
Reviewer comments	Reviewer comments	Essentially the author's conclusion statement above is saying that greater exposure to water in recreation means greater risk of illness; this is a well-established maxim in the field of recreational water quality management. The overall results are moderately informative and established with a rigorous methodology. This study was a generally high quality literature review and consistent with best practice for systematic reviews (e.g. Statistical methods, risk of bias analysis). The statistical analysis was complex and showed a significant level of rigour. The research question and the conclusions seek to assess and ultimately confirm a well-established maxim in recreational water quality management; that the risk of illness increases with the level of exposure.
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	The study is rigorous and provides quantification of the general risks of GI and RI (see odds ratios above). The findings support the concept of use of exposure risk categories in the management of recreational water use. Since the use of such categories is already common practice in the Australia context the study findings provide affirmation of this approach. Information on sequelae are not included since such data would not be part of the studies reviewed, but some consideration of such health outcomes in the discussion may have been useful.

6.12. J35: Schoen, Boehm, et al., (2020)

6.12.1. Quality assessment

		J35, Schoen, Ma, 2020, Contamination Scenario Matters when Using Viral and Bacterial Human-Associated Genetic Markers as Indicators of a Health Risk in Untreated Sewage-Impacted Recreational Waters		
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The aim of the study is to extend the QMRA approach to model mixtures of sewage at different ages using genetic marker concentrations for human associated crAssphage, Bacteroides spp., and polyomavirus in sewage samples from 49 wastewater facilities across the contiguous United States.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study uses genetic marker concentrations for human associated phage, FIB and enteric viruses in US sewage samples to model the effects of sewage age on GI risk-based thresholds (RBT). This is a potentially very powerful research method.	**Definitely low risk of bias (++)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The study uses an innovative advancement of the QMRA statistical approach to model the effects of 5 different scenarios sewage ages, sources and source volumes on RBTs	**Definitely low risk of bias (++)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is people undertaking primary contact recreation. QMRA estimates are compared with US EPA acceptable thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	A curated data set described in previous publications was used.	**Definitely low risk of bias (++)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis is well laid out and relatively easy to follow whilst still being detailed and rigorous.	**Definitely low risk of bias (++)**
9	Is there a clear statement of findings?	Yes	Clear statements of findings are located in the abstract. These are supported by the text narrative, and the final section which is entitled "Implications for Water Quality Management" and describes key findings and conclusions.	**Definitely low risk of bias (++)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	This is rigorous and well-designed study with valuable and locally relevant observations for this narrative review of the use of human associated phage, FIB and human infectious virus genetic markers and QRMA methods for assessment of risks to recreational water quality.	**Definitely low risk of bias (++)**
-	**Overall risk of bias rating**	-	*The study is a high quality QMRA study of human pathogen markers and their use to assess impacts on recreational waters of sewage of different age mixtures (and subsequently different ratios of infectious pathogens).*	**Definitely low risk of bias (++)**
-	**Reviewer's conclusion**		Include in review - definitely low risk of bias	

6.12.2. Data extraction

Category	Data class	J35: Schoen, Mary E.; Boehm, Alexandria B.; Soller, Jeffrey; Shanks, Orin C. 2020
Descriptive attributes	Title	Contamination Scenario Matters when Using Viral and Bacterial Human-Associated Genetic Markers as Indicators of a Health Risk in Untreated Sewage-Impacted Recreational Waters
	Publication Title	Environmental Science & Technology
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	54 (20) 13101-13109
	Publication date	2020
	Publication Source	Environmental Science & Technology 54 (20) 13101-13109 DOI:10.1021/acs.est.0c02189
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	The research was supported by the U.S. Environmental Protection Agency Office of Research and Development
	Possible conflicts of interest	The authors declare no competing financial interest. No conflicts of interest identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	crAssphage, Bacteroides spp., polyomavirus
	CASP classification	Qualitative research
	marine, estuarine or freshwater	m,e,f
	DOI http://dx.doi.org/	10.1016/j.envint.2019.02.042
Study characteristics	Aim/objectives of study	The aim of the study is to extend the QMRA approach to model mixtures of sewage at different ages using genetic marker concentrations for human associated crAssphage, Bacteroides spp., and polyomavirus in sewage samples from 49 wastewater facilities across the contiguous United States.
	Study type/design	The study uses genetic marker concentrations for human associated phage, FIB and enteric viruses in US sewage samples to model the effects of sewage age on GI risk-based thresholds (RBT). This is a potentially very powerful research method. The study uses an innovative advancement of the QMRA statistical approach to compare RBT estimates between bacterial and viral human-associated genetic markers with different decay rate constants and to model the effects of 5 different scenarios sewage ages, sources and source volumes on RBTs
	Study duration	n/a (desktop study)

Category	Data class	J35: Schoen, Mary E.; Boehm, Alexandria B.; Soller, Jeffrey; Shanks, Orin C. 2020
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Not stated but the implication is that all classes of water body are considered (marine, estuarine, freshwater).
	Exposure scenario	Ingestion of water whilst swimming: log10-normal distribution with a mean ± SD of 1.20 ± 0.68 mL citing the study by DeFlorio-Barker et al 2018(doi.org/10.1038/jes.2017.23)
	Exposure pathway	Exposure to water during swimming
	Source of infection/ contamination	n/a
	Causal organisms	Microbial pathogens
	Comparison group(s)	n/a
Study methods	Water quality measurement used	Reference Enteric Pathogens: Salmonella enterica, Campylobacter, *E. coli* O157:H7, Cryptosporidium, Giardia, norovirus, adenovirus. Genetic markers: crAssphage (CPQ_056), human-associated Bacteroides spp. (HF183/BacR287 and HumM2) and human polyomavirus (HPyV)
	Method of microorganism isolation and enumeration (if applicable)	Probability distribution functions (PDFs) of sewage reference pathogens and related genetic markers estimated from sewage samples from 49 wastewater facilities across the contiguous United States from recently published studies cited by the authors (refs, 12, 15, 16, 17 & 18 as cited in the reference section of the paper).
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	QMRA model inputs are based on the PDFs described above.
	Limits of reporting for the organism of concern	n/a
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	n/a
Statistics	Statistical methods used	QMRA was used to estimate the respective genetic marker concentration in untreated sewage-impacted recreational water that corresponds to the United States Environmental Protection Agency (USEPA) benchmark of ~32 illnesses per 1000 swimmers, 20 referred to as an RBT in this study.
	Details on statistical analysis (if any)	Four scenarios were considered to explore the influence of sewage mixtures at different ages on the RBT. The scenarios were intended to represent simplified situations to illustrate the potential influence of varying contamination mixtures with either decreasing, equal, or increasing sewage contribution profiles (by volume) across sewage age on RBT determination. Scenario 1 seeks to estimate the RBT for sewage of a single age; this could represent a recreational water that receives a single pulse of sewage. Scenario 2 simulates a mixture of sewage of different ages with a decreasing contribution (by volume) across the sewage age range; this could represent a surface water system impacted by a continuous upstream source of sewage (e.g. a leaking pipe at an ocean beach). Scenario 3 simulates a mixture of sewage of different ages with equal

Category	Data class	J35: Schoen, Mary E.; Boehm, Alexandria B.; Soller, Jeffrey; Shanks, Orin C. 2020
		contributions (by volume) across the sewage age range and could correspond to a constant sewage pollutant source. Scenario 4 simulates a mixture with increasing contribution (by volume) across the sewage age range and could share some similarities to sporadic contamination events and/or a pollutant sewage source that decreases in flow volume over time (e.g. a storm runoff event).
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Risk-based threshold (RBT) estimates varied across different mixture and sewage age scenarios. Fresh sewage RBT estimates were not always protective when aged sewage was present, and aged sewage RBT estimates often fell below the marker lower limit of quantification. Conservative RBT estimates of 9.3×10^2 and 9.1×10^3 (copies/100 mL) for HF183/BacR287 and CPQ_056, respectively, were predicted when fresh sewage was greater (by volume) than aged at the time of measurement.
	How outcome was assessed	The QMRA results are presented in a multitude of plots in the main paper and in the supplementary paper. The plots ultimately support the conclusions in the text. However plot lines in figure 1 are inadequately labelled so that the reader cannot determine the relevance of the dashed versus solid lines.
	Method of measurement	QMRA outputs for each scenario are displayed in comparative line plots and tables in the paper (e.g. Figure 2. Cumulative distribution functions of log10 Pill for each reference pathogen when the cumulative risk is equal to the health benchmark of 32/1000).
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	Sewage contamination mixture scenario is important. This study introduced a new QMRA approach and predicted the threshold of select bacterial and viral human-associated genetic marker concentrations in untreated sewage-impacted recreational waters that correspond to a benchmark risk of gastrointestinal illness for various scenarios of diluted fresh and aged sewage contamination mixtures. Results indicate that RBT estimates for a genetic marker can vary based on sewage mixture composition. Potential Advantages of a CrAssphage Indicator The human-associated genetic markers considered in the study varied in abundance in raw sewage and exhibit a range of reported decay rate constants. Systematic QMRA analyses demonstrated the important relationship between these factors for selecting a robust human-associated genetic marker indicator for surface waters. As untreated sewage ages, differences in genetic marker abundance and decay rate constants become more pronounced, ultimately reducing indicator concentrations below typical analytical LLOQ values, thus rendering an indicator ineffective. The crAssphage genetic marker had the lowest reported decay rate constant and was one of the most abundant human-associated genetic markers considered in the study.
	Assessment of uncertainty (if any)	There is extensive discussion around uncertainty associated with QMRA model settings in section 4.4. This mostly concerns minor technical details thatare unlikely to greatly influence the results.
Reviewer comments	Reviewer comments	This is rigorous and well-designed study with valuable and locally relevant observations the use of human associated phage, FIB and human infectious virus genetic markers and QRMA methods for assessment of risks to recreational water quality. It opens the way for the use of genetic marker concentrations to assess recreational water quality by linking marker concentrations to risk of illness.

Category	Data class	J35: Schoen, Mary E.; Boehm, Alexandria B.; Soller, Jeffrey; Shanks, Orin C. 2020
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	The QMRA results are presented in a multitude of plots in the main paper and in the supplementary paper. The plots ultimately support the conclusions in the text. However, plot lines in figure 1 are inadequately labelled so that the reader cannot determine the relevance of the dashed versus solid lines.

6.13. J36: Shrestha and Dorevitch, (2019)

6.13.1. Quality assessment

		J36, Shrestha, , 2019, Evaluation of rapid qPCR method for quantification of *E. coli* at non-point source impacted Lake Michigan beaches		
Q.	Criteria	Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	A clear set of four study objectives are presented in the last paragraph of the introduction	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	Evaluation of rapid qPCR monitoring for *E. coli* in freshwater in beach water samples to assess if it can solve the 24-h delay problem, compared to culture techniques is an appropriate methodology.	**Definitely low risk of bias (++)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Sampling involved collection of 288 samples from eight high risk Chicago lakeshore beaches and tested for *E. coli* culture and qPCR four days per week between July and August 2017. This sampling plan is easy to follow and is appropriate in responding to the study aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is people undertaking primary contact recreation. QMRA estimates are compared with beach Action Values (BAV) based on US EPA acceptable thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis is detailed and rigorous.	**Definitely low risk of bias (++)**
9	Is there a clear statement of findings?	Yes	Concise statements of findings are presented in the conclusions.	**Definitely low risk of bias (++)**
	Section C: Will the results help locally?			

Q.	Criteria	J36, Shrestha, , 2019, Evaluation of rapid qPCR method for quantification of *E. coli* at non-point source impacted Lake Michigan beaches Assessment	Comments	Risk of Bias rating
10	How valuable is the research? Is the research of satisfactory value?	Yes	The study is clearly described, aligns well with the aims and reports on the effectiveness of using rapid qPCR method for *E. coli* enumeration and highlights some related issues that may be useful for informing the response to the primary research question for this narrative review.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*The study describes is a focused and clearly presented study with some potentially useful findings for the narrative review.*	**Probably low risk of bias (+)**
-	**Reviewer's conclusion**		Include in review - probable low risk of bias	

6.13.2. Data extraction

Category	Data class	J36: Shrestha, A.; Dorevitch, S. 2019
Descriptive attributes	Title	Evaluation of rapid qPCR method for quantification of *E. coli* at non-point source impacted Lake Michigan beaches
	Publication Title	Water Research
	Reference (Vol.(issue), reference no. or pages, or no. of pages)	156 (2019) 395-403
	Publication date	2019
	Publication Source	Water Research 156 (2019) 395-403 DOI:10.1016/j.watres.2019.03.034
	Peer reviewed	Yes
	Country of origin	United States
	Source of funding	The monitoring and analysis of Chicago beach water was supported by the Chicago Park District. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors
	Possible conflicts of interest	No conflicts of interest declared by authors or identified by the reviewer.
Other criteria	Does study clearly address the primary research question?	Yes
	Australian jurisdiction	No
	Does paper describe reasoning clearly	Yes
	Does overseas experience relate to Australian context	Yes
	children	No
	immunocompromised	No
	elderly	No
	indigenous	No
	Main risk associated factor?	qPCR, FIB
	CASP classification	Qualitative research

Category	Data class	J36: Shrestha, A.; Dorevitch, S. 2019
	marine, estuarine or freshwater	f
	DOI http://dx.doi.org/	10.1007/s41207-017-0035-8
Study characteristics	Aim/objectives of study	Study objectives include: 1) performance characterization of the *E. coli* qPCR draft USEPA Method based on standard curve linearity (R2), amplification efficiency (E), lower limit of quantification, and false positive rate; 2) comparison of *E. coli* qPCR measurements with two established FIB (*E. coli* culture and enterococci qPCR) results using water samples collected from eight of Chicago's Lake Michigan beaches; 3) evaluation of approaches to establish health based candidate *E. coli* qPCR Beach Action Value (BAV) criteria in the absence of an epidemiological study; and 4) to assess the degree to which beach specific BAVs differ from an optimized BAV value for the set of the eight beaches.
	Study type/design	Evaluation of rapid qPCR monitoring for *E. coli* in freshwater in beach water samples to assess if it can solve the 24-h delay problem, compared to culture techniques is an appropriate methodology.
	Study duration	Sampling conducted on Lake Michigan beaches over 2 months (July-August) 2017
Population characteristics	Population/s studied	n/a
	Selection criteria for population	n/a
	Subgroups reported	n/a
	Size of study	n/a
Exposure and setting	Type of water source/water body	Very large freshwater lake (Lake Michigan) (4,900 km^3)
	Exposure scenario	n/a. Study focus is on effectiveness of *E. coli* qPCR for determining BAVs
	Exposure pathway	n/a
	Source of infection/ contamination	n/a
	Causal organisms	Microbial pathogens
	Comparison group(s)	n/a
Study methods	Water quality measurement used	FIB: *E. coli*, enterococci
	Method of microorganism isolation and enumeration (if applicable)	*E. coli* enumeration by both Colilert® and by qPCR, enterococci by qPCR. Colilert results measured in MPN/100 ml, qPCR results measured in units of calibrator cell equivalents (CCE). The comparative cycle threshold (DDCt) method as described in US EPA Method 1609.1 was used to calculate the ratio of target sequences in the samples and calibrators to generate CCEs.
	Water sampling methods (monitoring, surrogates). Was there sufficient replication in number of samples taken, what steps were taken to reduce contamination?	Sampling involved collection of 288 samples from eight high risk Chicago lakeshore beaches and tested for *E. coli* culture and qPCR four days per week between July and August 2017.
	Limits of reporting for the organism of concern	<1 MPN/ 100mL for Colilert® , not stated for qPCR
	Consideration of quality assurance such as field and lab blanks, reference sites, and reporting on related physico-chemical parameters	Colilert® quality control procedures included analysis of duplicate samples and negative controls using sterile phosphate buffered saline (PBS) analysed once per week. Quality control for qPCR consisted of standard curves, replicate reactions for all samples, use of no template controls (NTC), method blanks (MeB), positive control calibrator samples, and SSDNA sample processing control (SPC).

Category	Data class	J36: Shrestha, A.; Dorevitch, S. 2019
Statistics	Statistical methods used	Statistical methods are described in extensive detail in section 2.6 Data Analysis of the paper. Key elements only are listed here. Graphs were produced using SAS. Descriptive statistics were summarized as medians with the interquartile ranges for both enterococci (qPCR) and *E. coli* concentrations (culture and qPCR). Frequency of BAV exceedances were calculated for enterococci qPCR and *E. coli* culture. ROC analysis (Receiver Operating Characteristics) was used to identify thresholds of *E. coli* qPCR concentrations that are predictive of exceedance of the enterococci qPCR BAV (1000 CCE/100 mL) and *E. coli* culture BAV (235 MPN/100 mL).
	Details on statistical analysis (if any)	The approach recommended by the USEPA in its Technical Support Material (TSM) (linked to the 2012 recreational water quality criteria) was used to generate candidate *E. coli* qPCR BAVs, as was receiver operating characteristic (ROC) analysis
	Relative risk/odds ratio, confidence interval?	n/a
Results	Outcome	Conventional culture-based *E. coli* methods for monitoring FIB are used at Great Lakes recreational beaches. Cultivation methods require 18 or more hours to generate results. As a consequence, public notifications about beach action value (BAV) exceedance are based on prior-day water quality. Rapid qPCR monitoring of bacteria in beach water solves the 24-h delay problem, though the USEPA-approved qPCR method targets enterococci bacteria, while Great Lakes communities are familiar with *E. coli* monitoring. For an *E. coli* qPCR method to be useful for water quality management, it was important to systematically characterize method performance, and establish BAVs for public notification purposes. Based on analyses of 288 water samples collected from eight of Chicago's Lake Michigan beaches, the *E. coli* qPCR method demonstrated acceptable performance characteristics. The method is prone to low level DNA contamination, possibly originating from assay reagents derived from *E. coli* bacteria. Both *E. coli* and enterococci BAVs were exceeded in approximately 18% of the samples. *E. coli* qPCR values were correlated with both *E. coli* culture ($r = 0.83$; $p < 0.0001$) and enterococci qPCR ($r = 0.67$; $p < 0.0001$) values. These statistical results are for same day culture results. Correlations for 1 day lag between culture and qPCR results were not significant - indicating that *E. coli* culture results available to a beach manager on a given day (from samples cultured the prior day) is not predictive of current water quality
	How outcome was assessed	Pearson's correlation coefficients between Log *E. coli* CCE, Log enterococci CCE, Log *E. coli* MPN and Log *E. coli* 1 day lag MPN (all units per 100 ml).
	Method of measurement	Evaluation of rapid qPCR monitoring for *E. coli* in freshwater in beach water samples to assess if it can solve the 24-h delay problem, compared to culture techniques.
	Number participants (exposed/non-exposed, missing/excluded) (if applicable)	n/a
Author's conclusion	Interpretation of results	The draft USEPA qPCR method targeting *E. coli* intended to be used for monitoring freshwater beaches demonstrated good technical performance. Based on the high frequencies of positive no template controls (NTC) and method blanks (MeB) in *E. coli* qPCR analysis, but not enterococci qPCR analysis, indicating that the qPCR reagent mixture for DNA amplification was likely contaminated by *E. coli* DNA. However, the degree of contamination was low, and likely would have little impact

Category	Data class	J36: Shrestha, A.; Dorevitch, S. 2019
		on beach monitoring. Using US EPA Technical Support Material (TSM), linked to the 2012 US EPA recreational water quality criteria, and ROC analyses, the authors were able to derive different candidate BAV threshold values for *E. coli* qPCR method using two US EPA recommended FIB culture and qPCR methods and corresponding health-based BAV criteria.
	Assessment of uncertainty (if any)	In reference to the above outcomes, the authors further concluded the finding that each method and reference FIB measurement yielded different *E. coli* qPCR BAV highlighted the need for further US EPA guidelines about setting site-specific alternative standards using alternative indicator and/or methods to improve clarity and refine assumptions of comparability of BAVs of different US EPA-approved methods for quantifying indicator bacteria. Given the availability of a qPCR method (enterococci) developed by US EPA, along with criteria values and BAVs calibrated directly to observed health risk in epidemiological studies, the authors stated that there was little reason to attempt developing BAV criteria for other testing methods in the absence of clear information about how results of such water testing methods predict health risk. With respect to data uncertainty, appropriate statistical methods and techniques were described in the paper to deal with such issues.
Reviewer comments	Reviewer comments	The study is clearly described, aligns well with the aims and reports on the effectiveness of using rapid qPCR method for *E. coli* enumeration. The study findings demonstrate the potential utility of using rapid qPCR for *E. coli*, either alone, or in conjunction with rapid qPCR for enterococci to determine BAVs. However, based on the issues identified by the authors, further research would be required before universal values for qPCR *E. coli* BAVs for freshwater environments could be adopted with confidence. These issues are summarised below (reviewer notes on study quality).
	Results included/excluded in review (if applicable)	n/a
	Notes on study quality e.g. gaps, methods	As noted above, the authors concluded that the finding that each method and reference FIB measurement yielded different *E. coli* qPCR BAV highlighted the need for further US EPA guidance for deriving new types of BAVs. The authors also noted that: Chicago's diversion of treated wastewater and stormwater away from Lake Michigan makes its beaches relatively unique. Thus, the study findings may not be applicable in other settings. The research took place over a single season, and the analyses were conducted in a single laboratory. It is not known whether the observed *E. coli* qPCR associations with *E. coli* culture and with enterococci qPCR results would be different in different settings or in the same setting at a different point in time. These observations indicate that a more comprehensive study design would be required to support the development of generic *E. coli* qPCR BAVs.

7 Studies excluded in final quality assessment stage

7.1. Grey literature

Following application of the quality assessment method for guidelines, ten documents were excluded (Table 7-1). These documents had satisfactory quality but on close inspection of the full text they either did not contain sufficient relevant information or were obsolete.

Note that the quality assessment focuses on the quality of evidence in the documents to contribute to responses to the primary and secondary research questions. Where the quality of such evidence is considered to be unsatisfactory, then the document is excluded from further review. Excluded documents may nevertheless be important documents in other contexts.

The completed quality assessment tables for each of the ten documents are set out in the following sections.

Table 7-1. List of grey literature excluded following quality assessment

ID	Title	Type of Study
G1: Deere et al. (2015)	Deere, D., Billington, K., McCarthy, D., McBride, G., Crosbie, N., 2015. Microbial indicators and objectives review for Victoria's State Environment Protection Policy (Waters). Melbourne Water	Discussion paper
G2: EnHealth (2012)	EnHealth, 2012. Environmental Health Risk Assessment Guidelines for Assessing Human Health Risks from Environmental Hazards. Commonwealth of Australia	Guidelines
G5: McBride et al. (2019)	McBride, G., Yalden, S., Milne, J.R., 2019. National Microbiological Water Quality Guidelines for Marine Recreational Areas: Implications from a Review of Recent Research. NIWA Client Report 2018-333HN: 93. Prepared for Envirolink. NIWA	Review
G6: McCarthy (2017)	McCarthy, D.T., 2017. Epidemiological evidence between water quality measures and illnesses in bathers of marine waters. EPA Victoria	Review
G7: Milne et al. (2017)	Recreational water quality monitoring and reporting in New Zealand: A discussion paper for Regional and Unitary Councils. NIWA Science and Technology Series Report No. 82.	Discussion paper
G9: NRMMC et al. (2006)	NRMMC, EPHC, AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Management Ministerial Council. Environment Protection and Heritage Council Australian Health Ministers' Conference, Canberra, Australia)	Guidelines
G10: NRMMC et al. (2008)	NRMMC, 2008. Australian Guidelines for Water Recycling (Phase 2): Augmentation of Drinking Water Supplies, Canberra, Australia., Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council and National Health and Medical Research Council, Canberra, Australia.	Guidelines
G12: NZMoH (2018)	NZMoH, 2018. Regional information for setting draft targets for swimmable lakes and rivers: a report on work underway to improve water quality in terms of effects on human health. New Zealand Ministry of Health.	Report
G14: US EPA (2019)	US EPA, 2019. Update for Chapter 3 of the Exposure Factors Handbook: Ingestion of Water and Other Select Liquids. Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/052F. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea/efh. U.S. Environmental Protection Agency (EPA)	Guidelines
G15: Visby and Weller-Wong (2020)	Visby, I., Weller-Wong, A., 2020. Derwent Estuary Recreational Water Quality Program. Annual Report 2019-20. Derwent Estuary Program, Tasmania.	Report

7.1.1. G1: Deere et al. (2015)

7.1.1.1. Quality assessment

Criteria	Assessment	G1: Deere et al 2015, Microbial indicators and objectives review for Victoria's SEPP
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	This study was a review of microbial indicators and objectives undertaken by a team of experienced microbial risk consultants hired by Melbourne Water. Its purpose was to inform a review of Victoria's State Environment Protection Policy, Waters of Victoria. It draws heavily on the 2008 NHMRC Guidelines as well as NZ, WHO, EU, and US EPA guidelines. Given that context it is arguable that it is compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	No evidence is supplied to indicate that this would be the case
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported, but given the nature of the report (a comment on a statutory review process), public consultation would have been highly unlikely
Is the advice peer reviewed?	No	It is likely that document was reviewed by experienced Melbourne Water staff, but no independent reviews are listed.
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	No	Last version of document cites September 2015.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Aside from listing 5 objectives, there is no discussion of decisions about scope, definitions and evidence review parameters documented and publicly available
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	The listed studies are high quality sources, but no reasons for their selection are given.
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	Yes	The review relies heavily on the 2008 NHMRC Guidelines as well as NZ, WHO, EU, and US EPA guidelines.
Can grey literature such as government reports and policy documents be included?	Yes	Such documents are listed in the reference section.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		

Criteria	Assessment	G1: Deere et al 2015, Microbial indicators and objectives review for Victoria's SEPP
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	There is some discussion of statistical approaches with respect to faecal indicator organisms, but this material is not clear.
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	Yes	There is some discussion of "acceptable risk" for endemic disease burdens from recreation on p.67.
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	With the exception of the 2012 Canadian Guidelines for Recreational Water Quality, the review covers obsolete documents that have been superseded and are out of date.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.2. G2: EnHealth (2012)

7.1.2.1. Quality assessment

Criteria	Assessment	G2: EnHealth 2012, Risk Assessment Guidelines
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The EnHealth guidelines are produced by Environmental Health Standing Committee (enHealth), which is a subcommittee of the Australian Health Protection Principal Committee (AHPPC) which is facilitated by the Commonwealth Department of Health.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	Yes	The Environmental Health Standing Committee (enHealth) oversaw the work
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported, but it is almost certain that the Commonwealth Government has funded the work.
Was there public consultation on this work? If so, provide details.	Can't Tell	It is not stated if public consultation was undertaken or not
Is the advice peer reviewed?	Yes	In the Acknowledgements section, it is stated that international peer review on the draft document was provided by Professor Steve Hrudey, University of Alberta, and ChemRisk LLC, San Francisco (Ellen Donovan and Hugh Scobie).
If so, is the peer review outcome documented and/or published?	No	No reference to publishing of the peer review is provided and it is assumed that the material has not been published.
Was the guidance/advice developed or updated recently? Provide details.	No	The document was published in 2012 and as of March 2012 no further updates are reported on the Commonwealth Health Department website https://www1.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-environ.htm
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	The EnHealth guidelines do not address individual contaminants, but rather detail risk assessment methods for chemical and microbial contaminants. No formal evidence review material is described.
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	The EnHealth guidelines clearly draw on international guidance, but this is not always referenced so the contribution of earlier methodologies is not clear.
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	The proposed methodology is enunciated as an Australian approach but reference is made to the US National Research Council publication "National Research Council (NRC) (2008). Science and decisions: Advancing risk assessment. Washington, DC: National Academy Press."
Can grey literature such as government reports and policy documents be included?	Yes	Such documents are listed in the reference section.

Criteria	Assessment	G2: EnHealth 2012, Risk Assessment Guidelines
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	Yes	The guidelines discuss the selection of toxicological endpoints and POD in detail from a methodological perspective. Values are not supplied for individual contaminants.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	The EnHealth guidelines do not address individual contaminants, but rather detail risk assessment methods for chemical and microbial contaminants. Methodological discussion and recommendations are given for the use of uncertainty and safety factors (e.g. page 72, Figure 23).
Are the parameter value assumptions documented and explained?	n/a	Discussion is limited to methodology rather than documenting values of particular parameters.
Are the mathematical workings/algorithms clearly documented and explained?	Yes	The guidelines contain detailed descriptions of algorithms and methods used for guideline derivation.
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	No	There is discussion in section 8.7 "Censored Data" on limits of reporting but no discussion on feasibility of implementation (e.g. as part of a compliance assessment).
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	Yes	Mechanistic, Mode of Action (MOA) and Key Events are discussed in detail from a methodological perspective.
If expert judgement is required, is the process documented and published?	Yes	Expert Judgement is discussed in detail from a methodological perspective.
Is dose response modelling (e.g. BMDL) routinely used?	Yes	Dose response modelling is discussed in detail from a methodological perspective.
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	Yes	Consideration of non-threshold mode of action is discussed in detail from a methodological perspective.
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	A daily intake at the threshold of toxicological concern (TTC) of 0.02 µg/kg bw corresponds to a 96 per cent probability that the lifetime risk of cancer would be less than one in a million (1 × 10–6 (p.82, citing Munro 1990, see EnHealth 2012 for reference.)

Criteria	Assessment	G2: EnHealth 2012, Risk Assessment Guidelines
Comments		
	Comments	The EnHealth guidelines are a detailed methods manual for determining risks to human health from toxins and pathogens in the environment. The assessment methodology in this table is focussed on assessing reviews of epidemiological-type studies so many of the assessment questions are either not appropriate, or only have a minor relevance. The EnHealth guidelines are useful in providing clear methodologies for risk assessment. However, they do not provide relevant information to assist in answering the primary and secondary research questions of this narrative review.
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.3. G5: McBride et al. (2019)

7.1.3.1. Quality assessment

Criteria	Assessment	G5: McBride et al 2019, NZ Marine Recreational Areas Review
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	This study sought to review literature relevant to 4 areas related to the NZ National Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. The 4 areas were: continued use of enterococci as indicators, shellfish sanitation issues (out of scope here), range of impacts of STP discharges, and appropriate indicators for brackish water bodies. These areas provide a much narrower focus than the current narrative review and address some out of scope topics. The review can be considered to be compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	No evidence is supplied to indicate that this would be the case
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported.
Is the advice peer reviewed?	No	Not reported.
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	Yes	Last version of document cites May 2019.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported

Criteria	Assessment	G5: McBride et al 2019, NZ Marine Recreational Areas Review
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	Yes	In addressing the first objective (continued use of enterococci as indicators), the study draws on the literature review that the lead author (Dr Graham McBride) undertook for the US EPA (Document G13 in this review). Given the 100% overlap with the US EPA 2017 review (Dr McBride cites it as a 2018 review), the US EPA document should take precedence for this review.
Can grey literature such as government reports and policy documents be included?	Yes	Such documents are listed in the reference section.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of	n/a	Not reported

Criteria	Assessment	G5: McBride et al 2019, NZ Marine Recreational Areas Review
implementing the guideline values (e.g. measurement attainability)?		
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	For the topics of relevance to the primary and secondary research questions, this study is largely a duplication of the review undertaken by Dr McBride for the US EPA in 2017. As such it does not contain significant relevant new material for consideration in this narrative review. Whilst there may be some material of relevance to the research questions, it will not add to the knowledge already included in the US EPA review. On that basis, this document can be excluded from further consideration.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.4. G6: McCarthy (2017)

7.1.4.1. Quality assessment

Criteria	Assessment	G6: McCarthy 2017, review marine epidemiological studies
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	No	This study is an unpublished document supplied by members of the Committee. It is self-described as a working draft and incomplete as it makes reference to accompanying tables that were not included at this stage of review. It was likely developed as a precursor document to review document G3 (EPAV 2021, QMRA for Port Phillip Bay). Given the lack of clarity over the document provenance, lack of peer review and general incompleteness the document is considered incompatible with Australian processes for guideline reviews.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	Not reported
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported

Criteria	Assessment	G6: McCarthy 2017, review marine epidemiological studies
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	No	Last version of document cites February 2017.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Cited studies appear to all be primary research studies.
Can grey literature such as government reports and policy documents be included?	No	Cited studies appear to all be primary research studies.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	Yes	Scopus is cited as the only database used
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Scopus is cited as the only database used
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported. Focus seems to have been to select only recreational water quality epidemiological studies.
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported

Criteria	Assessment	G6: McCarthy 2017, review marine epidemiological studies
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	The document was likely developed as precursor document to review document G3 (EPAV 2021, QMRA for Port Phillip Bay). As provided by the Committee the document is an incomplete working draft from early 2017. It is excluded from further consideration for this narrative review on quality grounds.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.5. G7: Milne et al. (2017)

7.1.5.1. Quality assessment

Criteria	Assessment	G7: Milne et al 2017, NZ recreational water quality monitoring discussion paper
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	No	This document is a short discussion paper with recommendations for improving current recreational water quality monitoring and reporting for NZ councils. It is largely an advocacy document for solutions to particular problems identified with NZ's approach to monitoring and managing recreational water quality risks. Consequently, it is considered not to be clearly compatible with Australian processes.
Are the administrative processes documented and publicly available?	No	Not reported

Criteria	Assessment	G7: Milne et al 2017, NZ recreational water quality monitoring discussion paper
Was the work overseen by an expert advisory committee?	No	Not reported
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	n/a	No peer review undertaken.
Was the guidance/advice developed or updated recently? Provide details.	No	Last version of document cites October 2017.
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	Yes	Such documents are listed in the reference section.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Since the study focus is on microbial risk it does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported

Criteria	Assessment	G7: Milne et al 2017, NZ recreational water quality monitoring discussion paper
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	This document is largely an advocacy document for solutions to particular problems identified with NZ's approach to monitoring and managing recreational water quality risks. It is heavily biased towards resolving those issues and does not attempt to provide an independent assessment of the literature, nor is there any evidence of peer-review. On that basis it is excluded from consideration for this narrative review on quality grounds.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.6. G9: NRMMC et al. (2006)

7.1.6.1. Quality assessment

Criteria	Assessment	G9: NHMRC et al 2006, AGWR Phase 1
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The guidelines were developed by the Australian Government. They are not mandatory but rather have been developed as an authoritative reference that can be used to support beneficial and sustainable recycling.

Criteria	Assessment	G9: NHMRC et al 2006, AGWR Phase 1
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	Yes	The work was overseen by the Joint Steering Committee of The Natural Resource Management Ministerial Council and the Environment Protection and Heritage Council as well as working groups on Risk Management, Health Risk and Environmental Risk. The names of individual persons on the committee and working groups are listed in the document.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Can't Tell	Not reported
Is the advice peer reviewed?	Can't Tell	No peer-review process is described in the document or on the related website (https://www.waterquality.gov.au/guidelines/recycled-water#managing-health-and-environmental-risks-phase-1)
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Last updated in 2006
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	Yes	With respect to pathogens, reference is made in Section 3.1.1, p.85 to the tolerable risk adopted in the guidelines being 10^{-6} DALYs per person per year, which is consistent with the latest edition of the WHO Guidelines for Drinking-water Quality (WHO 2004).
Can grey literature such as government reports and policy documents be included?	Yes	Grey literature is widely cited through the document
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	With respect to microbial risk, guideline derivation does not involve use of a toxicological endpoint for use as point of departure for health-based guideline derivation.
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported

Criteria	Assessment	G9: NHMRC et al 2006, AGWR Phase 1
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	No	Not reported
Are the parameter value assumptions documented and explained?	No	Parameter value assumptions for microbiological data are listed and referenced in Chapter 3 and in Appendix 2 (see information on Health-Based Targets)
Are the mathematical workings/algorithms clearly documented and explained?	No	From a microbial risk perspective, methods for calculating Health-Based Targets are described in Chapter 3.
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	No	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	No	A minor reference to mode of action occurs on p. 113 in reference to genotoxicity, however no clear reference to the use of mechanistic, or key events in adverse outcome pathways in deriving health-based guideline values is included.
If expert judgement is required, is the process documented and published?	No	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	No	Discussion of dose-response for pathogens is contained in section 3.2.2.
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	No	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	No	Not reported
Comments		
Comments	The AGWR Phase 1 guidelines are a detailed methods manual for determining risks to human health and environment from physical, chemical and microbiological constituents in recycled water. In some contexts, such as chemical risk assessment for recreational water, they are useful for providing information to determine impacts on water quality risks, however for microbial risk, given the richness of other sources, they provide relatively little additional information. With respect to informing responses to the primary and secondary research questions of this narrative review, they do not provide significant useful information. On that basis the guidelines are excluded from consideration for this narrative review.	

Criteria	Assessment	G9: NHMRC et al 2006, AGWR Phase 1
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.7. G10: NRMMC et al. (2008)

7.1.7.1. Quality assessment

Criteria	Assessment	G10: NMMRC et al 2008, AGWR Phase 2
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	The guidelines were developed by the Australian Government. They are not mandatory but rather have been developed as an authoritative reference that can be used to support beneficial and sustainable recycling.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	Yes	The work was overseen by the Joint Steering Committee of The Natural Resource Management Ministerial Council and the Environment Protection and Heritage Council as well as a working group. The names of individual persons on the committee and working group are listed in the document.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Can't Tell	Not reported but the reviewer recalls seeing a draft version for discussion around 2007, so it is possible there was a public consultation phase, but that it is not described in the document or on the related website at www.waterquality.gov.au
Is the advice peer reviewed?	Can't Tell	No peer-review process is described in the document or on the related website (https://www.waterquality.gov.au/guidelines/recycled-water#augmentation-of-drinking-water-supplies-phase-2)
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Last updated in 2008
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	No such studies or data is considered to the reviewer's knowledge

Criteria	Assessment	G10: NMMRC et al 2008, AGWR Phase 2
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	n/a	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	Yes	This document does not deal with microbial risk except in a passing fashion. With respect to chemicals, a detailed methodology is given in Appendix A (p. 101) "Setting guidelines for chemicals in drinking water augmented with recycled water". The methodology is based on the guidance in the Australian Drinking Water Guidelines and also makes reference to a hierarchy of other international drinking water guidelines (Box A2. p.103). No process is described for the critical assessment of the other international guidelines.
Can grey literature such as government reports and policy documents be included?	Yes	Grey literature is cited in the document (e.g. other international drinking water guidelines in Box A2. p.103).
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	Yes	As noted above, this document does not deal with microbial risk except in a passing fashion. With respect to chemicals, a detailed methodology is given in Appendix A (p. 101) "Setting guidelines for chemicals in drinking water augmented with recycled water". The methodology is based on the guidance in the Australian Drinking Water Guidelines.
Evidence search		
Are databases and other sources of evidence specified?	n/a	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	n/a	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	Yes	Described in Appendix A (p. 101) "Setting guidelines for chemicals in drinking water augmented with recycled water".
Are the parameter value assumptions documented and explained?	Yes	Parameter value assumptions for toxicological data are listed and referenced, although this is not relevant for microbial risk.
Are the mathematical workings/algorithms clearly documented and explained?	Yes	Guideline derivation algorithms for chemicals are clearly described. Microbial issues are given only passing reference.

Criteria	Assessment	G10: NMMRC et al 2008, AGWR Phase 2
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	No	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	No	A minor reference to mode of action occurs on p. 113 in reference to genotoxicity, however no clear reference to the use of mechanistic, or key events in adverse outcome pathways in deriving health-based guideline values is included.
If expert judgement is required, is the process documented and published?	No	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	No	Not reported for chemicals (although is it considered for pathogens in the context for QMRA).
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	Yes	Appendix A (p. 101) provides alternative guideline derivations algorithms for threshold and non-threshold substances.
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	2×10^{-6} (p. 15 and p.110), refers to ADWG [Although this is not relevant to the context of microbial risk which is the focus of this review.]
Comments		
Comments	The AGWR Phase 2 guidelines mainly address the gap in the phase 1 guidelines with respect to the derivation of chemical guidelines for recycled water. The phase 2 guidelines make only passing reference to microbial risk. With respect to informing responses to the primary and secondary research questions of this narrative review, they do not provide significant useful information. On that basis the guidelines are excluded from consideration for this narrative review.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.8. G12: NZMoH (2018)

7.1.8.1. Quality assessment

Criteria	Assessment	G12: NZ MoH 2018, Regional assessment
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	No	This is a regional planning document which provides State of the Environment assessments for NZ freshwater swimming environments (lakes and rivers) along with economic analyses and some landscape modelling to predict likely *E. coli* concentrations in the water bodies under different management scenarios. Similar Australian processes would be undertaken at the State and Territory Level.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	Yes	A multi-agency group is described as overseeing the report.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported

Criteria	Assessment	G12: NZ MoH 2018, Regional assessment
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Not reported
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	No	Not reported
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Not reported
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported

Criteria	Assessment	G12: NZ MoH 2018, Regional assessment
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	This NZ regional planning document is not relevant to the primary and secondary research questions of this narrative review.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.9. G14: US EPA (2019)

7.1.9.1. Quality assessment

Criteria	Assessment	G14: US EPA 2019, Algal toxins criteria
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Yes	This document deals only with the cyanotoxins Microcystins and Cylindrospermopsin, however it provides detailed methods for chemical exposure assessment during recreational water use for ingestion, inhalation and dermal exposure pathways and so could be applied to other water-associated chemical toxins. The methods are consistent with the EnHealth 2012 guidelines (and thus compatible with Australian processes) but provide more information on exposure rates. The document does not address risks associated with non-cyanobacterial microorganisms.
Are the administrative processes documented and publicly available?	No	Appendix C provides a description of literature search processes including databases and search strings for 5 different research questions. The only research question relevant to the current narrative

Criteria	Assessment	G14: US EPA 2019, Algal toxins criteria
		review was Research Question 4: "What new information, if any, is available regarding how aquatic recreational exposure ingestion rates in children differ among age groups between zero and 18 years?". The other questions were about cyanotoxin issues. Appendix F describes the results of the review of ingestion studies.
Was the work overseen by an expert advisory committee?	Can't Tell	Reference is made in the acknowledgements to some senior US EPA staff from the Office of Science and Technology and US EPA internal technical reviewers (unnamed), however there is no explicit reference to an expert committee overseeing the development of the guidelines.
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	Can't Tell	Not reported
Is the advice peer reviewed?	Yes	The document foreword states that "this document has undergone an EPA intra-agency peer-review process. The Health and Ecological Criteria Division, Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency has completed the final review and the document is approved for publication. The values were derived using the existing peer-reviewed and published science on the adverse human health effects of the toxins including previous EPA analysis, such as the EPA's Health Effects Support Document for the Cyanobacterial Toxin Microcystins and Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin (HESDs), and the EPA's Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins and Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin (Drinking Water Health Advisories) (U.S. EPA 2015a, 2015b, 2015c, 2015d). The EPA used established criteria methodologies (U.S. EPA 2000) and recreation-specific exposure parameters from the EPA's Exposure Factors Handbook (EFH) (U.S. EPA 2011) to derive these values." See documents for cited references.
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	Yes	The document was published relevantly recently (May 2019).
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported. Research questions are listed in Appendix C but there is no clear documentation of definitions and evidence review parameters.
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	Yes	Appendix C refers to Health Effects Support Documents (HESDs) which describe detailed search results and search methodology.
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	Not reported

Criteria	Assessment	G14: US EPA 2019, Algal toxins criteria
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	Yes	English only articles reviewed (e.g. p. C3, 3rd para from bottom). No justification is provided. Date ranges vary depending on question, but all cease in 2015
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	The literature assessed appears to be primary research articles from peer-reviewed literature or other US EPA studies.
Can grey literature such as government reports and policy documents be included?	Yes	Certain sections of the report make use of grey literature sources e.g. Appendix B which lists State Recreational Water Guidelines for Cyanotoxins and Cyanobacteria. Also the literature review on incidental ingestion (Appendix E) cites other US EPA documents such as the 2011 Exposure Factors Handbook.
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	n/a	With respect to recreational water contaminants, the document only deals with microcystins and cylindrospermopsins and in each case refers to other US EPA Health Effects Support Document (HESD) reports for each toxin (Section 5.2, Dose-response assessment, p. 71)
Evidence search		
Are databases and other sources of evidence specified?	Yes	PubMed and Web of Science are cited as literature search engines in Appendix C.
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	Yes	PubMed and Web of Science are cited (Appendix C.)
Is it specified what date range the literature search covers? Is there a justification?	Yes	Date ranges vary depending on question, but all cease September 2015
Are search terms and/or search strings specified?	Yes	Search strings for the research questions in Appendix C are listed.
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	English only articles reviewed (e.g. p. C3, 3rd para from bottom). This is appropriate as the bulk of the scientific literature is in English.
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	Yes	Based on available noncancer health effects information, the document recommends concentrations of microcystins and cylindrospermopsin protective of primary contact recreation. Note that neither of these toxins is in the scope of the current narrative review on microbial risks.
Derivation of health-based guideline values		
Is there justification for the choice of uncertainty and safety factors?	No	Not reported
Are the parameter value assumptions documented and explained?	Yes	Recommendations for concentrations of microcystins and cylindrospermopsins protective of primary contact recreation are given (p.17).
Are the mathematical workings/algorithms clearly documented and explained?	Yes	Guideline derivation algorithms based on reference doses of microcystins and cylindrospermopsin are clearly described (p. 52).
Does the organisation take into consideration non-health related matters to account for feasibility of	No	Not reported

Criteria	Assessment	G14: US EPA 2019, Algal toxins criteria
implementing the guideline values (e.g. measurement attainability)?		
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	Can't Tell	There is some discussion of mechanistic outcome pathways and modes of action in the document, however the documents relies on RfDs from the US EPA's Health Effects Support Document for the Cyanobacterial Toxin Microcystins and Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin (HESDs), and the EPA's Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins and Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin (Drinking Water Health Advisories) (U.S. EPA 2015a, 2015b, 2015c, 2015d). References cited within the HESD documents.
If expert judgement is required, is the process documented and published?	No	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	Can't Tell	Not reported. May be addressed in HESD documents, but since the listed toxins are out of scope of the current narrative review, this has not been ascertained.
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	Can't Tell	See above
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	Can't Tell	See above
Comments		
Comments	Due to the narrow focus on cyanotoxins which are out of scope of this review of microbial risks, the document does not assist in informing responses to the primary and secondary research questions of this narrative review. On that basis the document is excluded from further consideration for this narrative review.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.1.10. G15: Visby and Weller-Wong (2020)

7.1.10.1. Quality assessment

Criteria	Assessment	G15: Visby et al 2020, Derwent Estuary recreational water quality program
Overall guidance/advice development process		
Are the key stages of the organisation's advice development processes compatible with Australian processes?	No	This document is a short annual report summarising monitoring results for recreational sites along the Derwent River Estuary, Hobart, Tasmania. Although an Australian study, it has a narrow regional focus and contains little technical detail.
Are the administrative processes documented and publicly available?	No	Not reported
Was the work overseen by an expert advisory committee?	No	Not reported
Are potential conflicts of interest of committee members declared, managed and/or reported?	No	Not reported

Criteria	Assessment	G15: Visby et al 2020, Derwent Estuary recreational water quality program
Are funding sources declared?	No	Not reported
Was there public consultation on this work? If so, provide details.	No	Not reported
Is the advice peer reviewed?	No	Not reported
If so, is the peer review outcome documented and/or published?	No	Not reported
Was the guidance/advice developed or updated recently? Provide details.	No	Not reported
Evidence review parameters		
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	No	Not reported
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	No	Not reported
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	No	Not reported
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	No	Not reported
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	No	Not reported
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	No	Not reported
Can grey literature such as government reports and policy documents be included?	No	Not reported
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	No	Not reported
Evidence search		
Are databases and other sources of evidence specified?	No	Not reported
Does the literature search cover at least more than one scientific database as well as additional sources (which may include government reports and grey literature)?	No	Not reported
Is it specified what date range the literature search covers? Is there a justification?	No	Not reported
Are search terms and/or search strings specified?	No	Not reported
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	No	Not reported
Critical appraisal methods and tools		
Is risk of bias of individual studies taken into consideration to assess internal validity? If so, what tools are used? If not, was any method used to assess study quality?	No	Not reported
Does the organisation use a systematic or some other methodological approach to synthesise the evidence (i.e. to assess and summarise the information provided in the studies)? If so, provide details.	No	Not reported
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	No	Not reported
Derivation of health-based guideline values		

Criteria	Assessment	G15: Visby et al 2020, Derwent Estuary recreational water quality program
Is there justification for the choice of uncertainty and safety factors?	n/a	Not reported
Are the parameter value assumptions documented and explained?	n/a	Not reported
Are the mathematical workings/algorithms clearly documented and explained?	n/a	Not reported
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	n/a	Not reported
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	n/a	Not reported
If expert judgement is required, is the process documented and published?	n/a	Not reported
Is dose response modelling (e.g. BMDL) routinely used?	n/a	Not reported
Has the organisation's policy for dealing with substances for which a non-threshold mode of action may be applicable in humans been articulated and recorded?	n/a	Not reported
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	Not reported
Comments		
Comments	Although this study has some overlap with the primary research question of this narrative review, it has a narrow focus and does not provide technical detail.	
Useful for answering primary research question?	*No*	*Exclude from further review*
Useful for answering secondary research questions?	*No*	*Exclude from further review*

7.2. Primary studies

Table 7-2. List of primary studies excluded after risk of bias assessment

Study ID	Citation	CASP classification
J1: Abbott, Lugg, et al., (2011)	Abbott, B., Lugg, R., Devine, B., Cook, A., and Weinstein, P. (2011) Microbial risk classifications for recreational waters and applications to the Swan and Canning Rivers in Western Australia. Journal of Water and Health, 9(1), 70–79. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-79954561083&doi=10.2166%2fwh.2011.016&partnerID=40&md5=940b77d3cd18b4475e940be53dd50925.	Qualitative research
J7: Aslan, Anderson, et al., (2018)	Aslan, A., Anderson, K. W., and Chapman, A. (2018) The impact of tides on microbial water quality at an inland river beach. Journal of Environmental Quality, 47(5), 1123–1129. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85055417509&doi=10.2134%2fjeq2017.12.0499&partnerID=40&md5=ed0a6d15f38bf2a8b9934f885e889fcc.	Qualitative research
J8: Boehm, Graham, et al., (2018)	Boehm, A. B. (2019) Risk-based water quality thresholds for coliphages in surface waters: Effect of temperature and contamination aging. Environmental Science: Processes and Impacts, 21(12), 2031–2041. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85076384464&doi=10.1039%2fc9em00376b&partnerID=40&md5=4a42d64c38db4a3a71ee8fd56c70c699.	Systematic review
J9: Boehm, (2019)	Boehm, A. B., Graham, K. E., and Jennings, W. C. (2018) Can We Swim Yet? Systematic Review, Meta-Analysis, and Risk Assessment of Aging Sewage in Surface	Qualitative research

Study ID	Citation	CASP classification
	Waters. Environmental Science & Technology, 52(17), 9634–9645. [online] https://doi.org/10.1021/acs.est.8b01948 (Accessed September 23, 2020).	
J10: Brown, Graham, et al., (2017)	Brown, K. I., Graham, K. E., Soller, J. A., and Boehm, A. B. (2017) Estimating the probability of illness due to swimming in recreational water with a mixture of human- and gull-associated microbial source tracking markers. Environmental Science: Processes and Impacts, 19(12), 1528–1541. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85038393702&doi=10.1039%2fc7em00316a&partnerID=40&md5=f64b41f5f23632582b4ee9ef0587e58a.	Qualitative research
J11: Cazals, Stott, et al., (2020)	Cazals, M., Stott, R., Fleury, C., Proulx, F., Prévost, M., Servais, P., Dorner, S., and Burnet, J. B. (2020) Near real-time notification of water quality impairments in recreational freshwaters using rapid online detection of β-D-glucuronidase activity as a surrogate for Escherichia coli monitoring. Science of the Total Environment, 720. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85080872987&doi=10.1016%2fj.scitotenv.2020.137303&partnerID=40&md5=573e1f25aaf8ff3117b588052294d2fd.	Qualitative research
J12: Craig, Fallowfield, et al., (2003)	Craig, D. L., Fallowfield, H. J., and Croman, N. J. (2003) Effectiveness of guideline faecal indicator organism values in estimation of exposure risk at recreational coastal sites, [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-0037217776&partnerID=40&md5=c38e2164f1cdf90741dbc5f6aa73c1fb.	Qualitative research
J13: Craig, Fallowfield, et al., (2004)	Craig, D. L., Fallowfield, H. J., and Cromar, N. J. (2004) Use of microcosms to determine persistence of Escherichia coli in recreational coastal water and sediment and validation with in situ measurements. Journal of Applied Microbiology, 96(5), 922–930. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-2342544111&doi=10.1111%2fj.1365-2672.2004.02243.x&partnerID=40&md5=5ff8b1a97d2929c9d4163161f292f835.	Qualitative research
J14: Federigi, Verani, et al., (2019)	Federigi, I., Verani, M., Donzelli, G., Cioni, L., and Carducci, A. (2019) The application of quantitative microbial risk assessment to natural recreational waters: A review. Marine Pollution Bulletin, 144, 334–350. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85066123450&doi=10.1016%2fj.marpolbul.2019.04.073&partnerID=40&md5=eab1546e9f4303ab4395029800ded0fa.	Systematic review
J16: Goodwin, Schriewer, et al., (2017)	Goodwin, K. D., Schriewer, A., Jirik, A., Curtis, K., and Crumpacker, A. (2017) Consideration of Natural Sources in a Bacteria TMDL-Lines of Evidence, Including Beach Microbial Source Tracking. Environmental Science & Technology, 51(14), 7775–7784. [online] http://www.ncbi.nlm.nih.gov/pubmed/28633521.	Qualitative research
J17: Hart, Blackwood, et al., (2020)	Hart, J. D., Blackwood, A. D., and Noble, R. T. (2020) Examining coastal dynamics and recreational water quality by quantifying multiple sewage specific markers in a North Carolina estuary. Science of the Total Environment, 747. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85089280225&doi=10.1016%2fj.scitotenv.2020.141124&partnerID=40&md5=66fdc341ee08c819fdd954ebc226ab0e.	Qualitative research
J19: Hughes, Beale, et al., (2017)	Hughes, B., Beale, D. J., Dennis, P. G., Cook, S., and Ahmed, W. (2017) Cross-comparison of human wastewater-associated molecular markers in relation to fecal indicator bacteria and enteric viruses in recreational beach waters. Applied and Environmental Microbiology, 83(8). [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85016586897&doi=10.1128%2fAEM.00028-17&partnerID=40&md5=c51efa06547a0446f801eaccdc2b827b.	Qualitative research
J21: Kinzelman, Byappanahalli, et al., (2020)	Kinzelman, J., Byappanahalli, M. N., Nevers, M. B., Shively, D., Kurdas, S., and Nakatsu, C. (2020) Utilization of multiple microbial tools to evaluate efficacy of restoration strategies to improve recreational water quality at a Lake Michigan Beach (Racine, WI). Journal of Microbiological Methods, 106049. [online] http://www.ncbi.nlm.nih.gov/pubmed/32891633.	Qualitative research
J22: Korajkic, McMinn, et al., (2018)	Korajkic, A., McMinn, B. R., and Harwood, V. J. (2018) Relationships between microbial indicators and pathogens in recreational water settings. International Journal of Environmental Research and Public Health, 15(12). [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-	Systematic review

Study ID	Citation	CASP classification
	85058755142&doi=10.3390%2fijerph15122842&partnerID=40&md5=ac292c33b6db0847218031ab094ded80.	
J24: McKee, Molina, et al., (2020)	McKee, B. A., Molina, M., Cyterski, M., and Couch, A. (2020) Microbial source tracking (MST) in Chattahoochee River National Recreation Area: Seasonal and precipitation trends in MST marker concentrations, and associations with *E. coli* levels, pathogenic marker presence, and land use. Water Research, 171. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85077660807&doi=10.1016%2fj.watres.2019.115435&partnerID=40&md5=3b24f5a20267bf39edbc02c2cd35ac76.	Qualitative research
J25: Mulder, Franz, et al., (2020)	Mulder, A. C., Franz, E., de Rijk, S., Versluis, M. A. J., Coipan, C., Buij, R., Müskens, G., Koene, M., Pijnacker, R., Duim, B., Bloois, L. van der G., Veldman, K., Wagenaar, J. A., Zomer, A. L., Schets, F. M., Blaak, H., and Mughini-Gras, L. (2020) Tracing the animal sources of surface water contamination with Campylobacter jejuni and Campylobacter coli. Water Research, 187, 116421. [online] https://linkinghub.elsevier.com/retrieve/pii/S0043135420309568 (Accessed December 7, 2020).	Qualitative research
J26: Napier, Haugland, et al., (2017)	Napier, M. D., Haugland, R., Poole, C., Dufour, A. P., Stewart, J. R., Weber, D. J., Varma, M., Lavender, J. S., and Wade, T. J. (2017) Exposure to human-associated fecal indicators and self-reported illness among swimmers at recreational beaches: a cohort study. Environmental Health: A Global Access Science Source, 16(1), 103.	Cohort study
J27: Napier, Poole, et al., (2018)	Napier, M. D., Poole, C., Stewart, J. R., Weber, D. J., Glassmeyer, S. T., Kolpin, D. W., Furlong, E. T., Dufour, A. P., and Wade, T. J. (2018) Exposure to Human-Associated Chemical Markers of Fecal Contamination and Self-Reported Illness among Swimmers at Recreational Beaches. Environmental Science and Technology, 52(13), 7513–7523. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049595798&doi=10.1021%2facs.est.8b00639&partnerID=40&md5=2effa6656c6b1612f24f248871d0c6c0.	Cohort study
J28: Oun, Yin, et al., (2017)	Oun, A., Yin, Z., Munir, M., and Xagoraraki, I. (2017) Microbial pollution characterization of water and sediment at two beaches in Saginaw Bay, Michigan. Journal of Great Lakes Research, 43(3), 64–72. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85011601680&doi=10.1016%2fj.jglr.2017.01.014&partnerID=40&md5=7d0a7d006cffa5eaae9ae423c88177e1.	Qualitative research
J29: Polkowska, Räsänen, et al., (2018)	Polkowska, A., Räsänen, S., Al-Hello, H., Bojang, M., Lyytikäinen, O., Nuorti, J. P., and Jalava, K. (2018) An outbreak of Norovirus infections associated with recreational lake water in Western Finland, 2014. Epidemiology and Infection, 146(5), 544–550. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042537706&doi=10.1017%2fS0950268818000328&partnerID=40&md5=1f5e49d2400315f68de34a82e1b29caa.	Cohort study
J31: Rodrigues and Cunha, (2017)	Rodrigues, C. and Cunha, M. Â. (2017) Assessment of the microbiological quality of recreational waters: indicators and methods. Euro-Mediterranean Journal for Environmental Integration, 2(1), 25.	Systematic review
J32: Roser, Davies, et al., (2006)	Roser, D., Davies, C. M., Ashbolt, N. J., and Morison, P. (2006) Microbial exposure assessment of an urban recreational lake: A case study of the application of new risk-based guidelines. Water science and technology : a journal of the International Association on Water Pollution Research, 54, 245–52.	Qualitative research
J33: Rosiles-González, Ávila-Torres, et al., (2019)	Rosiles-González, G., Ávila-Torres, G., Moreno-Valenzuela, O. A., Cháidez-Quiroz, C., Hernández-Flores, C. I., Acosta-González, G., Brown, J. K., Betancourt, W. Q., Gerba, C. P., and Hernández-Zepeda, C. (2019) Norovirus and human adenovirus occurrence and diversity in recreational water in a karst aquifer in the Yucatan Peninsula, Mexico. Journal of Applied Microbiology, 127(4), 1255–1269. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85072234282&doi=10.1111%2fjam.14385&partnerID=40&md5=fa03bb4c4ca6e28555f4fed47d8178e2.	Qualitative research
J37: Shrestha, Kelty, et al., (2020)	Shrestha, A., Kelty, C. A., Sivaganesan, M., Shanks, O. C., and Dorevitch, S. (2020) Fecal pollution source characterization at non-point source impacted beaches under dry and wet weather conditions. Water Research, 182. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-	Qualitative research

Study ID	Citation	CASP classification
	85087112406&doi=10.1016%2fj.watres.2020.116014&partnerID=40&md5=c2de5f75e67f48ff73c13154bb0f1200.	
J38: Shrestha, Midwinter, et al., (2019)	Shrestha, R. D., Midwinter, A. C., Marshall, J. C., Collins-Emerson, J. M., Pleydell, E. J., and French, N. P. (2019) Campylobacter jejuni strains associated with wild birds and those causing human disease in six high-use recreational waterways in New Zealand. Applied and Environmental Microbiology, 85(24). [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85075485714&doi=10.1128%2fAEM.01228-19&partnerID=40&md5=c16bb475c4bf7b0a1880b7855d5a06bc.	Qualitative research
J39: Steele, Blackwood, et al., (2018)	Steele, J. A., Blackwood, A. D., Griffith, J. F., Noble, R. T., and Schiff, K. C. (2018) Quantification of pathogens and markers of fecal contamination during storm events along popular surfing beaches in San Diego, California. Water Research, 136, 137–149. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042706261&doi=10.1016%2fj.watres.2018.01.056&partnerID=40&md5=c3c51ff9b1a82a3abf6034a23a689a85.	Qualitative research
J40: Xue, Feng, et al., (2018)	Xue, J., Feng, Y., Wijesinghe, R. U., and Wood, C. W. (2018) Using Bacteroidales genetic markers to assess fecal pollution sources in coastal waters. Water and Environment Journal, 32(1), 84–93. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85030169371&doi=10.1111%2fwej.12302&partnerID=40&md5=8c0304f66842c016ad7eacb03e160497.	Qualitative research
J41: Xue, Lin, et al., (2018)	Xue, J., Lin, S., Lamar, F. G., Lamori, J. G., and Sherchan, S. (2018) Assessment of fecal pollution in Lake Pontchartrain, Louisiana. Marine Pollution Bulletin, 129(2), 655–663.	Qualitative research
J42: Zimmer-Faust, Steele, et al., (2020)	Zimmer-Faust, A. G., Steele, J. A., Griffith, J. F., and Schiff, K. (2020) The challenges of microbial source tracking at urban beaches for Quantitative Microbial Risk Assessment (QMRA). Marine Pollution Bulletin, 160. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85090223929&doi=10.1016%2fj.marpolbul.2020.111546&partnerID=40&md5=5875300aec04c5c37c35f07920c8f8a4.	Qualitative research

7.2.1. J1: Abbott, Lugg, et al., (2011)

7.2.1.1. Quality assessment

		J1, Abbott, B., 2011, Microbial risk classifications for recreational waters and applications to the Swan and Canning Rivers in Western Australia		
Q.	Criteria	Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?	**Can't tell**		
1	Was there a clear statement of the aims of the research?	No	This is a simple descriptive study that seeks to "review the process to assess risk" in recreational waters of Perth's Swan and Canning River system. The specific study aims could be more clearly reported.	**Probably high risk of bias (-)**
2	Is the methodology appropriate?	Yes	Unable to fully determine the appropriateness of the methodology based on the aims as described.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?	**Yes**		
3	Was the research design appropriate to address the aims of the research?	Can't tell	The study aims could be described more clearly to determine if the research design was appropriate for the aims.	**Probably high risk of bias (-)**
4	Was the chosen hypothetical population or subpopulation	Yes	The hypothetical population is adults undertaking primary contact recreation and site risk	**Probably low risk of bias (+)**

Q.	Criteria	J1, Abbott, B., 2011, Microbial risk classifications for recreational waters and applications to the Swan and Canning Rivers in Western Australia Assessment	Comments	Risk of Bias rating
	appropriate for addressing the study research aims?		classifications indicate if retrospective follow-ups should occur.	
5	Was the data collected in a way that addressed the research issue?	Yes	The study presents a compilation of results of local recreational water risk assessments consistent with the 2008 NHMRC Guidelines and provide some commentary on the results	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of adults undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	No	The data analysis is limited to a simple collation of local recreational water use sites on the Swan-Canning River System and is not particularly rigorous.	**Probably high risk of bias (-)**
9	Is there a clear statement of findings?	No	There is some general commentary as to why particular locations received their sanitary risk classifications and some conclusions with respect to items that could improve the 2008 NHMRC Guidelines, but there is no clear statement of research findings.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	Yes	The paper contains some commentary and conclusions on the limitations of the current 2008 NHMRC Guidelines which may be useful for support of the guideline updates.	**Probably low risk of bias (+)**
-	**Overall risk of bias rating**	-	*This simple descriptive study has limitations including a lack of clearly defined goals and analytical rigour. Consequently, it is classified as having a "Probably high risk of bias".*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias	

7.2.2. J7: Aslan, Anderson, et al., (2018)

7.2.2.1. Quality assessment

Q.	Criteria	J7, Aslan, Asl, 2018, The Impact of Tides on Microbial Water Quality at an Inland River Beach Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The aim of the study was to assess the effect of flood and ebb tide conditions on microbial water quality in a tidal river used for recreational activities	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	Bacterial genetic markers and FIB (enterococci) were sampled in flood and ebb tides in a single estuary was analysed. The methodology is appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	This is a simple observational study of genetic markers in a single estuary. The implication of the aims is that the results are transferable to all estuarine recreational	**Probably high risk of bias (-)**

Q.	Criteria	J7, Aslan, Asl, 2018, The Impact of Tides on Microbial Water Quality at an Inland River Beach Assessment	Comments	Risk of Bias rating
			water. The study design is inadequate to support this this broader application.	
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	No risk assessment was undertaken as the study only described variability in genetic markers due to tidal movements.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The study only sought to determine the effects of tidal flows on genetic markers of faecal contamination, yet the impact of tidal variation was only examined at one site. It stands to reason that the flow environment at different sites would differ, and this may affect the variance of microbial markers.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis was relatively simple but sufficient for the study aims.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	No	The chief conclusions is that "Tidal flow can significantly impact the water quality in the short term" (conclusion, last paragraph) which is a well established and well understood phenomenon.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The research is of low relevanceto the research questions in this narrative review as it seeks to verify a well-established fact, i.e., that there is a tidal influence on water quality including the microbial aspects.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The study is of low relevance for answering the research questions of this narrative review.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.3. J8: Boehm, Graham, et al., (2018)

7.2.3.1. Quality assessment

Q.	Criteria	J8, Boehm, A., 2018, Can We Swim Yet? Systematic Review, Meta-Analysis, and Risk Assessment of Aging Sewage in Surface Waters Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the review address a clearly focused question?	Yes	The research question is not clearly described. The assumed objective was: to use decay rate constants compiled from a review of the literature in a QMRA to investigate how exposure to fecal contamination from untreated sewage of different ages during swimming affects the resultant gastrointestinal illness risk.	**Probably low risk of bias (+)**
2	Did the authors look for the right type of papers?	Yes	Two reviewers assessed papers against a series of 6 criteria: 1) the paper contains quantitative data on the decay of the pathogen or indicator of interest in raw (unaltered) surface water, (2) the article is in English, (3) the paper is not a review, presents primary data, and is peer reviewed, (4) the paper does not contain data solely on disinfection treatments (5) the temperature of the decay experiments is greater than 4°C and	**Probably low risk of bias (+)**

J8, Boehm, A., 2018, Can We Swim Yet? Systematic Review, Meta-Analysis, and Risk Assessment of Aging Sewage in Surface Waters				
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
			less than 30°C, and (6) the methods used to enumerate the target are logical, justifiable, and described in the paper.	
	Section A2: Is it worth continuing?			
3	Do you think all the important, relevant studies were included?	Yes	Leading biological bibliographic databases were used. These were Web of Science core collection (search field = topic), Scopus (search field = article title, abstract, keyword), and PubMed (search field = all fields) were searched	**Definitely low risk of bias (++)**
4	Did the review's authors do enough to assess quality of the included studies?	No	With the exception of the criteria for selection described above, no information is supplied with respect to how the reviewers assessed the quality of the studies (neither in the main paper, nor the supplementary material).	**Definitely high risk of bias (--)**
5	If the results of the review have been combined, was it reasonable to do so?	Can't tell	Decay rate constants were extracted from papers by a single reviewer and since the nature of the data varied considerably, it was subjected to considerable manipulation (conversions, model revisions, etc.) to permit the subsequent meta-analysis. Whilst such data manipulation would be necessary, the methods are described only briefly in the paper and could be more clearly reported.	**Probably high risk of bias (-)**
	Section B: What are the results?			
6	What are the overall results of the review?	Yes	Based on a systematic review 333 first order decay rate constants (k) were compiled for human norovirus and its surrogates feline calicivirus and murine norovirus, Salmonella, Campylobacter, Escherichia coli O157:H7, Giardia, and Cryptosporidium, and human-associated indicators in surface water. A meta-analysis investigated effects of sunlight, temperature, and water matrix on k. Average k ranked: Campylobacter > human-associated markers > Salmonella> *E. coli* O157:H7 > norovirus and its surrogates > Giardia > Cryptosporidium. Compiled k values were used in a QMRA to simulate gastrointestinal illness risk associated with swimming in water with aged sewage contamination. The QMRA used human-associated faecal indicator HF183 as an index for the amount of sewage present and thereby provided insight into how risk relates to HF183 concentrations in surface water. A risk-based water quality threshold for HF183 in surface waters that takes into account uncertainty in contamination age is derived to be 4100 copies/100 mL.	**Probably low risk of bias (+)**
7	How precise are the results?	No	The statistical analysis of the compiled dataset is described in detail and provides a list of study limitations t in the discussion. Overall the study is ambitious in seeking to derive a reliable relationship between sewage age and a median of the human genetic marker HF183 using meta-analysis. A review of box plots (figure S5, supplement) of simulated GI risk vs log10 HF183 copies per 100 ml shows the 25th and 75th percentiles of log10 HF183 to encapsulate 2 log (i.e. 2 orders of magnitude). Thus even for a single hypothetical scenario, the confidence intervals are large. In a real world application, uncertainty would likely be even greater.	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			
8	Can the results be applied to the local population?	No	The tolerable risk threshold used in the modelling is the US EPA 30 cases of GI illness per 1000 for a single swimming event. This threshold ignores sequelae which would likely be considered in the Australian context. Use of a 1µDALY per person per annum threshold or equivalent may require a different interpretation of the data and results of this study. It is also unclear if the results of this study can be used locally, since recreational water quality is typically influenced by more	**Probably high risk of bias (-)**

J8, Boehm, A., 2018, Can We Swim Yet? Systematic Review, Meta-Analysis, and Risk Assessment of Aging Sewage in Surface Waters				
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
			than one contaminant source and is not limited to the hypothetical situation of WWTP effluent simulated in the current study.	
9	Were all important outcomes considered?	No	Sequelae were excluded from the QRMA as noted above.	**Probably high risk of bias (-)**
10	Are the benefits worth the harms and costs?	No	The description of the literature review and data compilation was not consistent with best practice for systematic reviews. The statistical analysis was complex, however, significant study limitations were noted, the hypothetical scenario for the QMRA is unrealistic for the Australian context and the simulated results show wide confidence intervals. These observations all serve to undermine confidence in the study findings.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to methodological and statistical limitations, the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.4. J9: Boehm, (2019)

7.2.4.1. Quality assessment

Q.	Criteria	Assessment	J9, Boehm, Ale, 2019, Risk-based water quality thresholds for coliphages in surface waters: effect of temperature and contamination aging Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The goal of the study was to derive risk-based water quality thresholds for coliphages in surface waters using a modelling approach.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study uses a QMRA framework to derive risk-based surface water quality thresholds (consistent with US EPA criteria) for somatic and F+ or male-specific coliphages.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	While the use of QMRA is appropriate to answer the research goal, the use raw sewage data as the single source of contamination would lead to unrealistic estimates of predicted illness rates, since other sources are ignored. This may be acceptable in a hypothetical study of risk but does not seem appropriate for informing the primary research question. A validated risk assessment framework is not cited.	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is people undertaking primary contact recreation. QMRA estimates are compared with US EPA acceptable thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	The data sourced for the QMRA was from published estimates of GI pathogens and indicators in raw sewage. Sources were diverse and used to construct PDFs for Monte-Carlo analysis. The diversity of data sources is a potential study limitation but is probably unavoidable.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of people undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	Yes	Data analyses are described in detail and are sufficiently rigorous	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	No	There is a discussion that does not include clear conclusions at the end. Whilst there is some discussion of findings, there is no clear statement of findings.	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The research is interesting in a general, academic sense, but is biased towards sewage sources and thus will not be valuable in informing the primary research question of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*This study makes use of QMRA approach which are reasonably rigorous and is of interest in an academic sense, particularly in the USA, but is based on biased assumptions of pathogen sources.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.5. J10: Brown, Graham, et al., (2017)

7.2.5.1. Quality assessment

Q.	Criteria	J10, Brown, K. , 2017, Estimating the probability of illness due to swimming in recreational water with a mixture of human- and gull-associated microbial source tracking markers Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The study seeks to establish thresholds for MST markers at which the US EPA illness benchmark (~3 illnesses per 100 swimmers) is exceeded using QMRA	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	QMRA with Monte-Carlo simulations is used to predict the probability of illness (Pill) associated with swimming in water with varying concentrations of MST markers. The methodology is appropriate	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Use of QMRA is appropriate to address the research question. A validated risk assessment framework is not cited, but the QMRA is described in great detail and is satisfactory.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is people undertaking primary contact recreation. QMRA estimates are compared with US EPA acceptable thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	The data sourced for the QMRA was from diverse sources including estimates of GI pathogens and indicators in sewage, treated effluent and gull faeces as well as measurement of genetic markers in effluent. Source data was used to construct PDFs for Monte-Carlo analysis. The diversity of data sources is a potential study limitation, but is probably unavoidable.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question 6 is not applicable since there is no real population of study participants. Rather, the population assessed is a hypothetical population of people undertaking primary contact recreation.	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	There are no ethical issues since the study does not make use of real participants. Instead health risks of a hypothetical population of adults undertaking primary contact recreation is assessed.	n/a
8	Was the data analysis sufficiently rigorous?	Yes	Data analyses are described in detail and are sufficiently rigorous. Source data is diverse, coming from a range of publications. The authors seek to account for this issue through increased complexity of the Monte-Carlo analyses. This could be reported more clearly.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	There is a discussion of study limitations with some conclusions at the end. The conclusions are reasonable.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The research is interesting in a general, academic sense. However, there a number of significant limitations of the data and method described in section 4.4 that raise concerns about the appropriateness of extrapolating the study findings to other situations. For example, the study does not consider aging of the contamination, the varied data sources meaning that pathogen concentrations could deviate from actual values at specific beaches and	**Definitely high risk of bias (--)**

Q.	Criteria	J10, Brown, K. , 2017, Estimating the probability of illness due to swimming in recreational water with a mixture of human- and gull-associated microbial source tracking markers Assessment	Comments	Risk of Bias rating
			the MST markers used are not 100% specific to the nominated animal hosts.	
-	**Overall risk of bias rating**	-	*This study makes use of QMRA approach which is reasonably rigorous and is no doubt of interest in an academic sense, particularly in the USA, but is based on biased assumptions of pathogen sources.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.6. J11: Cazals, Stott, et al., (2020)

7.2.6.1. Quality assessment

Q.	Criteria	J11, Cazals, M., 2020, Near real-time notification of water quality impairments in recreational freshwaters using rapid online detection of β-D-glucuronidase activity as a surrogate for Escherichia coli monitoring Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The main objective of this study was to investigate the usefulness of rapid online monitoring of ß-D-glucuronidase (GLUC) activity (a marker for *E. coli*) for timely and safe recreational water quality assessment and management	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The methodology involves comparison GLUC activity to culturable *E. coli* determinations at 3 riverine beaches in Quebec, Canada and one riverine beach in New Zealand (all freshwater) and comparison of management responses based on the measurements to determine the differences (e.g. rates of false alarms etc.). This methodology is appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Standard observational study of genetic markers at 4 riverine sites across 2 countries. The design is appropriate to address the aims of the research. A larger data set across more sites would have strengthened the design.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	No risk assessment was undertaken. The study describes the difference in management responses based on GLUC monitoring versus culturable *E. coli* monitoring.	n/a
5	Was the data collected in a way that addressed the research issue?	No	Sites differed in *E. coli* sample collection methods and enumeration methods which could introduce bias in results. GLUC activity measurements were the same across all sites.	**Probably high risk of bias (-)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a

Q.	Criteria	J11, Cazals, M., 2020, Near real-time notification of water quality impairments in recreational freshwaters using rapid online detection of β-D-glucuronidase activity as a surrogate for Escherichia coli monitoring Assessment	Comments	Risk of Bias rating
8	Was the data analysis sufficiently rigorous?	Yes	Data analyses are described in detail and are sufficiently rigorous.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	There is a discussion with some conclusions at the end. The conclusions provide an adequate description of the findings.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	Rates of false alarms varied between 0 to 32% and failures to act between 3 and 10% which suggests the technology provides a weak substitute for regular *E. coli* monitoring, which itself does not adequately cover risks from many waterborne pathogens.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The study is an observational study of the use an E. coli enzymatic marker as a more rapid substitute for standard E. coli monitoring. The research results have a probable high risk of bias due to variation in E. coli sample collection methods and enumeration methods, the high rates of false alarms, the limited size of the data set and the narrow focus on E. coli as an appropriate indicator for waterborne pathogens since its limitations as a sole indicator are widely understood.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.7. J12: Craig, Fallowfield, et al., (2003)

7.2.7.1. Quality assessment

Q.	Criteria	J12, Craig, D., 2003, Effectiveness of guideline faecal indicator organism values in estimation of exposure risk at recreational coastal sites Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	No	The statement of aims is not clear: "The primary aim of this research was to attempt to more accurately identify a potential environmental exposure from contaminated waters in the first stage of a health risk assessment for recreational coastal waters".	**Definitely high risk of bias (--)**
2	Is the methodology appropriate?	No	Using laboratory-based microcosms, the study sought to compare decay rates of two species of Salmonella in estuarine waters to that of "a number of faecal indicators" - later established to be *E. coli* and Enterococcus faecium. It is arguable that lab microcosms do not adequately represent the real estuarine environment. An appropriate approach would be to link the research to a field study to assess basis for extrapolation of microcosm results to the real world. Therefore, the methodology does not seem appropriate.	**Definitely high risk of bias (--)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Can't tell	Unable to determine the appropriateness of the design based on the aims as described.	**Probably high risk of bias (-)**

Q.	Criteria	J12, Craig, D., 2003, Effectiveness of guideline faecal indicator organism values in estimation of exposure risk at recreational coastal sites Assessment	Comments	Risk of Bias rating
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is adults undertaking primary contact recreation. Rates of gastrointestinal illness are calculated (note that this ignores other health impacts, e.g. sequelae like G-B syndrome), but not referenced to any tolerable risk guideline.	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	No	Lab microcosms were established to provide an environment for determining decay rates	**Probably high risk of bias (-)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	Data analyses are described in detail and are sufficiently rigorous in the statistical sense, but limitations noted in the paper include a lack of available data on the occurrence of Salmonella spp. in recreational coastal water; the dose-response did not consider previous exposure or immunity, and Salmonella spp. infectivity may differ from that assumed after exposure to low-nutrient conditions such as coastal waters	**Probably high risk of bias (-)**
9	Is there a clear statement of findings?	Yes	It is stated that the research highlights the limited effectiveness of using prescribed faecal coliform concentrations in the water column alone to estimate the risk of exposure to pathogenic microorganisms during recreational activity at coastal areas. It demonstrates that coastal sediments act as a reservoir for both indicator and pathogenic organisms released into the coastal environment. This statement is relatively clear although does not align with the stated aims and sediments were already (even in 2003) a well understood source of pathogens.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	It is acknowledged in the paper that the estimations determined by the QRMA model are exclusive to the risk of infection of Salmonella spp. and do not take into account exposure to other bacterial, protozoan or viral pathogens. In the context of research in support of protection of recreational water quality, the research is of low relevance for answering the research questions of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*This study has a number of limitations including the research question and the results are of low relevance to this narrative review. The paper self-identifies many limitations of the research.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.8. J13: Craig, Fallowfield, et al., (2004)

7.2.8.1. Quality assessment

Q.	Criteria	J13, Craig, D. , 2004, Use of microcosms to determine persistence of Escherichia coli in recreational coastal water and sediment and validation with in situ measurements Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The study aims are clearly stated but there are two different aims are stated in separate sections: (i) To determine the persistence of the faecal indicator organism *Escherichia coli* in recreational coastal water and sediment using laboratory-based microcosms and validation with in situ measurements, and (ii) to more accurately describe environmental exposure in the first stage of a health risk assessment for recreational coastal waters	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	No	The study sought to compare decay rates of *E. coli* in estuarine waters between laboratory-based microcosms and in-situ measurements. The lab microcosms were apparently indoors and thus the perspex columns used were not exposed to sunlight unlike the in-situ environmental samples and thus do not appropriately represent the marine environment. Therefore, the methodology does not seem appropriate.	**Definitely high risk of bias (--)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	Comparison of decay rates of *E. coli* dosed into indoor lab microcosms (70mm diameter x 310 mm length perspex tubes) in the absence of the bactericidal effects of UV light to *E. coli* in-situ samples subjected to such light and also to varying tidal current and dilutions in order to better understand decay rates *E. coli* following a contamination event (e.g. stormflow) will lead to false conclusions based on confounded experimental data. A better approach would have been to apply sunlight to the microcosms to replicate the real world effect and to use a conservative tracer for the in-situ samples (perhaps matching with a hydraulic model). Such measures would enable a more appropriate comparison. A further issue that was not addressed was the possibility of resuspension of *E. coli* from sediments in in-situ samples - a possible affect that was not addressed in the study.	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	No risk assessment was undertaken. The study describes the difference in culturable *E. coli* decay rates between lab microcosms and in-situ samples.	n/a
5	Was the data collected in a way that addressed the research issue?	No	The experiment design is confounded with respect to UV light and water movement as described above and thus the data cannot be considered to have been appropriate for addressing the research issue.	**Definitely high risk of bias (--)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	The data analyses were relatively simplistic but otherwise appropriate for the type of data. However due to the confounding issues with the experimental design	**Definitely high risk of bias (--)**

Q.	Criteria	J13, Craig, D. , 2004, Use of microcosms to determine persistence of Escherichia coli in recreational coastal water and sediment and validation with in situ measurements Assessment	Comments	Risk of Bias rating
			described above, there is uncertainty regarding the results which could be misleading.	
9	Is there a clear statement of findings?	No	There is a concise statement of findings given in the study abstract but given the limitations identified regardinga confounding andexperimental design there is uncertainty around the findings which could be misleading. The statement of findings cannot be considered clear given the study limitations.	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The research results are of low relevance for answering the research questions of this narrative review due to the confounding of the study design and other limitations described above.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to the confounding of the study design and other limitations the study has a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.9. J14: Federigi, Verani, et al., (2019)

7.2.9.1. Quality assessment

Q.	Criteria	J14, Federigi, , 2019, The application of quantitative microbial risk assessment to natural recreational waters: A review Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the review address a clearly focused question?	No	There is no clear statement of study aims or research questions.	**Definitely high risk of bias (--)**
2	Did the authors look for the right type of papers?	Yes	Publication selection followed four main criteria, based on papers: (1) focusing on recreational exposure to natural waters including both coastal (marine or estuarine) and inland waters (i.e. lakes, rivers, canals); (2) in English, (3) performing QMRA based on pathogens, (4) original research article and peer reviewed.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Do you think all the important, relevant studies were included?	Yes	A broad search of four electronic databases: PubMed, Scopus, ScienceDirect, and Web of Science core collection was performed using the following search terms in the query: (QMRA OR “quantitative microbial risk assessment”) AND (“bathing waters” OR “recreational waters” OR recreation OR bathing). The search method also made use of PRISMA guidelines (Moher et al. 2009)>	**Definitely low risk of bias (++)**
4	Did the review’s authors do enough to assess quality of the included studies?	No	With the exception of the criteria for selection described above, no information is supplied with respect to how the reviewers assessed the quality of the studies.	**Definitely high risk of bias (--)**
5	If the results of the review have been combined, was it reasonable to do so?	n/a	The review was focused on qualitative aspects of the studies and did not involve the combination of data to create a database for meta-analysis	n/a
	Section B: What are the results?			

Q.	Criteria	Assessment	Comments	Risk of Bias rating
		J14, Federigi, , 2019, The application of quantitative microbial risk assessment to natural recreational waters: A review		
6	What are the overall results of the review?	No	The review results consist of collections of observations on the attributes of the 54 included studies stratified by 23 subheadings under the broad groupings of (i) Time trend of QRMA studies, geographical location, and types of water, (ii) Aims of the QRMA in the study design, and (iii) Different approaches to QMRA steps and related issues. The discussion section seeks to tie the observations together but there are limitations given that there is no clear statement of study aims or research questions. A conclusions sections lists 6 research gaps which may be considered as the overall findings of the review. 1. A lack of epidemiological data on the main pathogens of concern in specific geographical areas; 2. A lack of site-specific water quality data for many pathogens; 3. Little consideration of the recovery efficiency of the detection methods during dose-calculation; 4. A lack of dynamic QMRA models for adults with regular exposure to recreational waters, such as surfers who may have acquired a higher immune status than the general adult population; 5. A lack of human challenge trials specifically for recreational exposure and for different population groups; 6. A lack of studies aimed at reconciling dose-response curves with epidemiological studies.	**Probably high risk of bias (-)**
7	How precise are the results?	n/a	The review results are of a qualitative nature and consist of commentary on the findings in the shortlisted research papers.	n/a
	Section C: Will the results help locally?			
8	Can the results be applied to the local population?	No	This paper consists of a general review of the recreational water QMRA literature and draws some conclusions about future research objectives. It provides little information of relevance to the current narrative review.	**Definitely high risk of bias (--)**
9	Were all important outcomes considered?	Can't tell	It is not possible to state if all important outcomes have been considered as the study objectives were not clearly stated.	**Probably high risk of bias (-)**
10	Are the benefits worth the harms and costs?	No	This review had a number of limitations regarding clear aims and critical analysis of the findings.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to limitations regarding review aims and critical analysis the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.10. J16: Goodwin, Schriewer, et al., (2017)

7.2.10.1. Quality assessment

Q.	Criteria	J16, Goodwin, K, 2017, Consideration of Natural Sources in a Bacteria TMDL-Lines of Evidence, Including Beach Microbial Source Tracking Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	No	There is no statement of aims or objectives of the research. The paper simply describes what was done to establish source of FIB and assess the success of bird exclusion measures.	**Definitely high risk of bias (--)**
2	Is the methodology appropriate?	Yes	MST methods and qPCR analysis was used to identify sources of FIB. A separate study on gull marker persistence was also carried out. The methods are described in detail and are sufficiently rigorous.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?	**No**		
3	Was the research design appropriate to address the aims of the research?	No	Since there were no research aims described, the design cannot be assessed against them.	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	FIB concentrations were compared against US EPA and Californian criteria. These criteria are based on protection of adults (hypothetical) undertaking primary contact recreation.	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Data was obtained from field measurements and lab FIB and qPCR data analyses and used in the MST analyses. Methods are described in detail and are of appropriate quality, although research question was not clearly defined as noted above.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analyses were clear, detailed and appropriate for supporting the findings	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	There is a clear statement of findings in the study abstract, however the study lacks a clear set of conclusions.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This is a complex study to determine the source of continued FIB exceedances, despite improvement works, at a high value metropolitan beach in LA. Since no gull control had been undertaken previously yet the site was "frequented by hundreds of birds daily", the findings that gull were a significant source and the water quality improvements post gull control measures served to confirm a well-known risk pathway. The findings are also site-specific so the overall value of the research is low in regards to answering the research questions of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the research aims and findings that are of low relevance to this narrative review, the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.11. J17: Hart, Blackwood, et al., (2020)

7.2.11.1. Quality assessment

Q.	Criteria	Assessment	J17, Hart, Just, 2020, Examining coastal dynamics and recreational water quality by quantifying multiple sewage specific markers in a North Carolina estuary Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	Three objectives are listed: (1) to quantify the dynamics and magnitude of faecal contamination in the stormwater discharge to highly-used receiving waters of a coastal town in North Carolina (2) to use quantitative approaches to discern the sources of fecal contamination and to determine whether human sources could be responsible for observed FIB concentrations (3) to identify the potential for simple predictive models to be developed that may assist in the ability to adequately manage such a high-profile estuarine resource. The objectives are clearly identified, although each objective is broad and could be clarified further.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	MST methods and qPCR analysis of samples from two stormwater outfalls was used to identify sources of FIB. Such a methodology is appropriate, but the description of the methods could be reported more clearly.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	Enterococci and 12-hour cumulative antecedent rainfall were plotted against the qPCR marker HF183 concentrations to assess their potential predictive capability (HF183 is marker for Bacteroides FIB).	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	Enterococci (FIB) concentrations were compared against North Carolina Department of Environmental Quality (NCDEQ) criteria Tier 1 standard of 104 MPN/100 mL. The criteria are not explained, but a web search indicated that this criteria is for immediate (24hr) notice to the public. (https://deq.nc.gov/about/divisions/water-resources/drinking-water/compliance-services/public-notification-rule-tier). The conclusion to be drawn is that the criteria are protective of the general public (with no further specification). Compliance with a regulatory criterion is not a goal, but was included to provide context with respect to recreational water quality management, thus it is probably appropriate for addressing the study aims.	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Detailed descriptions of sample collection and analytical methods are presented. The methods are appropriate, although they could be reported more clearly.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	The data analyses in this paper have some limitations. For example several correlation coefficient matrices are used to identify relationships between measured variables (Figure 5). However it is not clear how to use these images to discern important relationships. Principal component analysis (PCA), or multiple regression would have been much more powerful and	**Definitely high risk of bias (--)**

Q.	Criteria	J17, Hart, Just, 2020, Examining coastal dynamics and recreational water quality by quantifying multiple sewage specific markers in a North Carolina estuary Assessment	Comments	Risk of Bias rating
			easier to interpret statistical tools to use here. Similarly figure 6 shows linear fits between FIB and qPCR markers but does not provide statistical metrics for the lines in order to judge their quality. Since these data analyses are used to derive the conclusions this introduces uncertainty in the study findings.	
9	Is there a clear statement of findings?	No	There are some concise statements of findings in the abstract, but they don't clearly link to the aims which could be more clearly reported. Furthermore, given the limitations with the statistical analysis, the abstract findings may be misleading.	Probably high risk of bias (-)
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This study has limitations regarding the aims, methodology, inappropriate statistical analysis, and a focus on a local stormwater drainage issue that would be difficult to extrapolate to other circumstances as required for this narrative review.	Definitely high risk of bias (--)
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the aims, methodological rigour and statistical analysis and findings that are of low relevance for this review, the study is considered to have a high risk of bias.*	Definitely high risk of bias (--)
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.12. J19: Hughes, Beale, et al., (2017)

7.2.12.1. Quality assessment

Q.	Criteria	J19, Hughes, B., 2017, Cross-Comparison of Human Wastewater-Associated Molecular Markers in Relation to Fecal Indicator Bacteria and Enteric Viruses in Recreational Beach Waters Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Can't tell	There is no clear statement of aims, but instead, there is a description of the methods undertaken followed by a statement of why that method was used (see last paragraph of introduction). The latter statements could be considered aims, however this is not clear. The aims are to (i) identify suitable marker(s) of human faecal pollution and their occurrence in relation to FIB and enteric viruses in a scenario where beach water samples are amended with various amount of fresh raw and secondary-treated wastewater. and (ii) determine to what extent these FIB, MST markers, and enteric viruses are present in ambient recreational beach water and sand samples from South East Queensland (SEQ), Australia, to understand the health risks associated with human faecal pollution.	Probably high risk of bias (-)
2	Is the methodology appropriate?	Yes	MST markers in beach water samples spiked with raw and secondary treated wastewater were assessed using qPCR assays. The results were compared to local (SEQ) beach water samples.	Probably low risk of bias (+)

Q.	Criteria	J19, Hughes, B., 2017, Cross-Comparison of Human Wastewater-Associated Molecular Markers in Relation to Fecal Indicator Bacteria and Enteric Viruses in Recreational Beach Waters Assessment	Comments	Risk of Bias rating
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Can't tell	Unable to accurately determine if the study design is appropriate based on the aims as described. Comparison of spiked lab samples versus environmental samples seems reasonable to help explain the results, however this does not align well with the stated aims (as noted above).	**Probably high risk of bias (-)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study was focused on demonstrating the utility of MST methods to identify microbial sources in recreational waters and thus no assessment of risks to a hypothetical population or subpopulation was undertaken.	n/a
5	Was the data collected in a way that addressed the research issue?	No	Unable to determine if the data collection methods were appropriate based on the aims as described.	**Probably high risk of bias (-)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	The statistical analyses in the paper have limitations that could impact certainty in the findings. For example, the correlation matrices between dependent variables (qPCR markers) does not provide useful information, only indicating some similar behaviour amongst the markers (which would be expected in sewage spiked samples). Canonical correlation analysis (CCA), or multiple regression would have been much more powerful and easier to interpret statistical tools to use here. Table 1 also uses non-standard units of concentration per 3 uL of DNA/RNA extracted from beach water - such data needs to be linked to some sort of standards so their utility can be gauged.	**Definitely high risk of bias (--)**
9	Is there a clear statement of findings?	No	There are a couple of statements of findings in the abstract, but they don't clearly link to the aims and discussion which could be reported more clearly.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This study has limitations regarding the aims, methodological rigour and inappropriate statistical analyses.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the aims, methodological rigour and statistical analyses , the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.13. J21: Kinzelman, Byappanahalli, et al., (2020)

7.2.13.1. Quality assessment

Q.	Criteria	J21, Kinzelman,, 2020, Utilization of multiple microbial tools to evaluate efficacy of restoration strategies to improve recreational water quality at a Lake Michigan Beach (Racine, WI) Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Can't tell	The stated purpose of this study (to demonstrate the utility of traditional and 21st Century methods of microbiological analysis in ascertaining the influence of previously identified pollution sources on the receiving waters of Lake Michigan) could be reported more clearly.	**Probably high risk of bias (-)**
2	Is the methodology appropriate?	Yes	The study is a descriptive study of impacts of beach management at a great lakes site on FIB and MST 16S rRNA Gene Sequences, this is probably appropriate, although the method could be reported more clearly. Uncertain if these methods could be applied in other settings.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?	**No**		
3	Was the research design appropriate to address the aims of the research?	Can't tell	Unable to determine if the research aims are appropriate based on the reported aims as described.	**Probably high risk of bias (-)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was comparison of beach management methods against FIB monitoring data and thus did not involve a hypothetical population or subpopulation	n/a
5	Was the data collected in a way that addressed the research issue?	No	Unable to determine this based on the aims as described.	**Probably high risk of bias (-)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The statistical methods described in the paper are appropriate, but there is a lack of synthesis of the results, that could be more clearly reported.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	No	There are a couple of statements of findings in the abstract, but they don't clearly link to the text which could be more clearly reported.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This study has limitations regarding the aims, and an inadequate synthesis of the results to help inform management of recreational beaches elsewhere.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the aims, methodological rigour and findings that are of low relevance for this narrative review, the study is considered to have a high risk of bias.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.14. J22: Korajkic, McMinn, et al., (2018)

7.2.14.1. Quality assessment

Q.	Criteria	J22, Korajkic, , 2018, Relationships between microbial indicators and pathogens in recreational water settings Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the review address a clearly focused question?	No	The review cites 2 stated goals: (1) to examine reported relationships between various indicators and pathogen species to determine the feasibility of indicators as pathogen sentinels in recreational waters; and (2) to identify factors that affect this relationship (or lack thereof). The research questions that underpin these goals could be more clearly described	**Probably high risk of bias (-)**
2	Did the authors look for the right type of papers?	No	The search terms (described below) were very narrow and are likely to have excluded some key papers that were relevant to the study objectives.	**Probably high risk of bias (-)**
	Section A2: Is it worth continuing?			
3	Do you think all the important, relevant studies were included?	No	Bibliographic databases queried were PubMed and Google Scholar. The databases were searched using the following keywords: "Recreational water and 'x' pathogens", and "swimming pools 'x' pathogens" where x = viral, bacterial, protozoan, and fungal, regardless of the year published. Yet only 73 papers were identified which based on the current narrative review indicates that many papers must have been overlooked. Google Scholar has a particularly weak retrieval result since the searching method offers little opportunity for nuanced search terms to capture appropriate literature.	**Probably high risk of bias (-)**
4	Did the review's authors do enough to assess quality of the included studies?	No	No information is supplied with respect to how the reviewers assessed the quality of the studies.	**Definitely high risk of bias (--)**
5	If the results of the review have been combined, was it reasonable to do so?	No	The data analyses conducted for the study are severely compromised by the lumping together of heterogeneous data sets. For example, data from a subset (33) of included studies (those that reported in sufficient detail) are presented and analysed for mean concentrations of FIB, alternative indicators, MST markers, bacterial, viral and protozoan pathogens in fresh and marine water (figs 3 & 4) - yet these data are used out of context from the reporting study and all information on the environmental conditions that they represent has not been reported. For example do they represent stormflow or baseline conditions or both? have different catchment contaminant sources have been combined in a systematic way, so that certain sources are not over-represented in the database? etc.	**Definitely high risk of bias (--)**
	Section B: What are the results?			
6	What are the overall results of the review?	No	The overall results cited are: - Significant relationships were more commonly reported between FIB and pathogenic bacteria or protozoa, compared to pathogenic viruses (p: 0.0022–0.0005), and this was more pronounced in freshwater compared to marine. - Statistically significant relationships were typically noted following wet weather events and at sites known to be impacted by recent faecal pollution. - While FIB, alternative indicators, and MST markers continue to be suitable indicators of faecal pollution, their relationship with waterborne pathogens, particularly viruses, is tenuous at best and influenced by	**Probably high risk of bias (-)**

Q.	Criteria	Assessment	J22, Korajkic, , 2018, Relationships between microbial indicators and pathogens in recreational water settings Comments	Risk of Bias rating
			many different factors such as frequency of detection, variable shedding rates, differential fate and transport characteristics, as well as a broad range of site-specific factors such as the potential for the presence of a complex mixture of multiple sources of faecal contamination and pathogens. The above findings could benefit from more critical analysis and are reflective of the likely heterogeneous nature of the included studies. It is possible that a focus on the results from high quality studies alone could have led to a different interpretation.	
7	How precise are the results?	No	The results of the study, where quantitative, are imprecise. For example, due to the inappropriate combining of data for the meta-analysis described above, the error bars shown in figures 3 & 4 display wide margins of uncertainty - frequently 3 to 4 log. Interestingly, standard deviations are used to display errors which can give the impression of a somewhat smaller error range than 95% confidence intervals or even box plots.	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			
8	Can the results be applied to the local population?	No	The aims of this review could be more clearly defined. There are limitations based on combining heterogeneous data sets in order to draw some generalisations. The impact of important local contributing factors is lost. The reviewers arrive at the conclusion that local factors are important because of the wide margins of uncertainty that they observed in their meta-analysis.	**Definitely high risk of bias (--)**
9	Were all important outcomes considered?	Can't tell	It is possible a more critical review of data quality and evaluation of the findings of better quality individual studies may have led to identification of more insightful findings.	**Probably high risk of bias (-)**
10	Are the benefits worth the harms and costs?	No	This study had a number of limitations including broad study aims, a lack of quality assessment of included papers and a meta-analysis that combined heterogeneous data sets.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the aims and methodological rigour, the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.15. J24: McKee, Molina, et al., (2020)

7.2.15.1. Quality assessment

Q.	Criteria	Assessment	J24, McKee, By , 2020, Microbial source tracking (MST) in Chattahoochee River National Recreation Area: Seasonal and precipitation trends in MST marker concentrations, and associations with *E. coli* levels, pathogenic marker presence, and land use Comments	Risk of Bias rating
	Section A1: Are the results valid?			

		J24, McKee, By , 2020, Microbial source tracking (MST) in Chattahoochee River National Recreation Area: Seasonal and precipitation trends in MST marker concentrations, and associations with *E. coli* levels, pathogenic marker presence, and land use		
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
1	Was there a clear statement of the aims of the research?	Yes	A clear and ambitious set of four objectives is set out in the penultimate paragraph of the introduction related to determining sources and MST marker levels associated with exceedances of the Beach Action Values (BAV) for *E. coli* and presence of a pathogenic markers.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study uses field sampling in wet and dry conditions at a number of sites with enterococci and MST marker qPCR testing	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate for the aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was comparison of beach management methods against FIB monitoring data and thus did not involve a hypothetical population or subpopulation	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The data collection from a range of sites with different potential sources of microbial contamination plus the mix of FIB and qPCR MST markers is considered appropriate	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Can't tell	The statistical methodology is sufficiently rigorous, but the graph labels could be improved to aid interpretation. Furthermore the results as displayed demonstrate weak correlations. For example Fig.4 R2 values are low and there is an obvious outlier on each graph that would inflate the already weak relationship, yet the accompanying narrative does not account for this.	**Probably high risk of bias (-)**
9	Is there a clear statement of findings?	No	There is a list of detailed minor findings which lack a clear synthesis, as well as some concluding comments, which although clear, do not clearly align with the objectives as stated earlier in the paper.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This study had broad objectives that sought to identify clear relationships between Beach Action Values (based on FIB) and many potential diffuse sources over a large area. Only weak relationships were observed and the statistical interpretation leading to these is unclear (see above). Consequently, the value of this research in a wider context is not satisfactory for the purposes of this current narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the methodological and statistical analysis and findings that have low relevance for this narrative review, the study is considered to have a high risk of bias.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.16. J25: Mulder, Franz, et al., (2020)

7.2.16.1. Quality assessment

Q.	Criteria	J25, Mulder, An, 2020, Tracing the animal sources of surface water contamination with Campylobacter jejuni and Campylobacter coli Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	This study was relatively clear: the study aimed to quantify Campylobacter prevalence and genotype diversity in surface water, as well as the relative contributions of several putative animal sources to surface water contamination with C. jejuni and C. coli in the Netherlands using high-throughput genomic data derived from whole-genome sequencing (WGS).	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	No	Water samples were collected in areas which largely varied in densities of specific livestock groups in the Netherlands. Specifically, six landuse areas were selected, with either a high or a low density of poultry, pigs, or ruminants (i.e. cattle, sheep and goats combined). Within each of these six landuse areas, 3 different types of freshwater (recreational, agricultural, and WWTP influenced) were sampled. The study seeks to attribute the influence of the different landuses on the Campylobacter genotypes using analysis of molecular variance methods (AMOVA) as an extension of analysis of variance (ANOVA). However the different treatments (e.g. high ruminants density vs low ruminants density) within the landuse factor are not replicated meaning that effects other than, say ruminant density, could be the cause of any observed differences or other assumptions here.	**Probably high risk of bias (-)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	The research design is essentially a complex conventional three-factor analysis of covariance with the factors being (i) livestock land use (poultry, pigs, ruminants) (with a covariate of density as high or low), (ii) surface water location type (recreational, agricultural, and WWTP influenced) and season (summer, autumn, winter, spring). However this structure is not clearly recognised by the authors and thus leads to limitations within the study design including likely lack of statistical power due to inadequate replication within landuse factors and confounding expressed landscape treatments with other unknown/unmeasured landscape factors.	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on identification of Campylobacter sources in surface waters in the Netherlands and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	No	Source attribution analysis based on whole-genome sequencing (WGS) is satisfactorily robust, but the assessment of effects of livestock density, water type and season has limitations due to the confounding issue described above.	**Probably high risk of bias (-)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a

Q.	Criteria	J25, Mulder, An, 2020, Tracing the animal sources of surface water contamination with Campylobacter jejuni and Campylobacter coli Assessment	Comments	Risk of Bias rating
8	Was the data analysis sufficiently rigorous?	Yes	Aside from the methodological limitations identified above, the data analysis is for the most part rigorous. An exception here is the canonical correlation plots (fig.5) could be more clearly presented.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	Clear statements of findings are listed in the conclusions. It is unclear if these findings can beinterpreted in a wider context. For example, wild birds and meat-producing poultry are identified as the main contributors to Campylobacter contamination of surface water, but the effect depends on water type, season, and local livestock density (i.e. highly variable in space and time and hardly a useful observation).	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This study has an ambitious statistical sampling design which has some limitations in its application which has lead to potentially misleading conclusions on treatment effects. The major findings are highly location specific and although informative, it is unclear if they would be useful for informing the current narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the methodological and statistical analysis and findings that are of low relevance to this narrative review, the study is considered to have a high risk of bias.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.17. J26: Napier, Haugland, et al., (2017)

7.2.17.1. Quality assessment

Q.	Criteria	J26, Napier, M., 2017, Exposure to human-associated fecal indicators and self-reported illness among swimmers at recreational beaches: A cohort study Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the study address a clearly focused issue?	Yes	The primary objective of this study was to estimate the association between four human-associated *Bacteroides* markers and self-reported gastrointestinal (GI), diarrheal, and respiratory illness among swimmers at six U.S. marine and freshwater beaches enrolled in the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) study from 2003 to 2007. A secondary objective was to determine whether these *Bacteroides* markers modify the association between a general *Enterococcus* indicator and GI and respiratory illnesses	**Definitely low risk of bias (++)**
2	Was the cohort recruited in an acceptable way?	Yes	The study makes use of the NEEAR historical data set and archived water samples which were accessed to test for the *Bacteroides* markers. For the original NEEAR study, procedures, questionnaires, protocols and consent process were reviewed and approved by the Institutional Review Board (IRB) of the Centers for Disease Control and Prevention. The NEEAR study was a prospective cohort study: participants were adults enrolled at beaches on weekends and holidays in summer. Participants completed	**Probably low risk of bias (+)**

Q.	Criteria	Assessment	Comments	Risk of Bias rating
	J26, Napier, M., 2017, Exposure to human-associated fecal indicators and self-reported illness among swimmers at recreational beaches: A cohort study			
			surveys on site and received follow-up telephone interviews 10-12-days later to determine incident symptoms of gastrointestinal illness, diarrhea and respiratory illness.	
	Section A2: Is it worth continuing?		**Yes**	
3	Was the exposure accurately measured to minimise bias?	Can't tell	Some measures are described to determine exposure bias, but the descriptions lack detail, so the true extent of such measures is somewhat unclear. An example of measures taken include participants reporting water contact, but not "body immersion" being excluded from analysis because they comprise a group with heterogeneous water exposure.	**Probably high risk of bias (-)**
4	Was the outcome accurately measured to minimise bias?	Yes	Health outcomes were classified by the researchers into consistent categories - this is considered an important step to protect against classification errors in the dataset. For example, "GI illness" referred to any of the following: (1) diarrhea (≥3 loose stools in a 24-h period); (2) vomiting; (3) nausea with stomach ache; or (4) nausea or stomach ache and interference with regular activities (missed time from work/regular activities due to illness). Diarrhea alone was also assessed as a separate outcome. "Respiratory illness" referred to any two of the following: sore throat, cough, runny nose, cold, or fever.	**Probably low risk of bias (+)**
5	(a) Have the authors identified all important confounding factors?	Can't tell	The authors state that they used directed acyclic graphs to evaluate potential confounding factors plausibly associated with poor water quality and illness, however there is no further discussion of the graphs in the results, discussion or 31-page supplementary file.	**Probably high risk of bias (-)**
5	(b) Have they taken account of the confounding factors in the design and/or analysis?	Can't tell	The description of the statistical methods could be reported more clearly. No discussion of confounding factors was identified apart from the brief material cited above. This could be because the author's terminology distinguished between covariables as potential confounders vs study limitations due to factors such as relative persistence of *Bacteroides* markers vs general *Enterococcus* markers, the long term freezer storage of samples (several years) prior to testing for genetic markers etc.	**Probably high risk of bias (-)**
6	(a) Was the follow up of subjects complete enough?	Yes	As noted above, participants completed surveys on site and received follow-up telephone interviews 10-12-days later to determine incident symptoms of gastrointestinal illness, diarrhea and respiratory illness. Given the nature of the study, this approach is complete enough.	**Probably low risk of bias (+)**
6	(b) Was the follow up of subjects long enough?	Yes	Follow up was considered satisfactory given the large scale of the study and the use of the information that was gathered.	**Probably low risk of bias (+)**
	Section B: What are the results?			
7	What are the results of this study?	Can't tell	This was a large study with a very large dataset and there are many very large data tables to interpret including 26 pages of tables in the supplementary report. Consequently the review here focuses on the authors conclusions. The authors sought to determine whether human-associated *Bacteroides* markers could be useful indicators of faecal contamination at recreational beaches by testing for associations between such markers and self-reported GI, diarrheal, and respiratory illness among swimmers. The results showed inconsistent associations between the presence of human-associated *Bacteroides* markers and illness, though positive patterns with GI, diarrhea, and respiratory illnesses associated with detection of one marker, BsteriF1, were observed.	**Probably high risk of bias (-)**

Q.	Criteria	J26, Napier, M., 2017, Exposure to human-associated fecal indicators and self-reported illness among swimmers at recreational beaches: A cohort study Assessment	Comments	Risk of Bias rating
			No evidence was detected that Bacteroides markers modified the association between the non-source-specific general indicator *Enterococcus* and illness; however in marine waters there was a pattern of an increased GI illness risk in the presence of HF183, BsteriF1 and BuniF2 when *Enterococcus* was measured by qPCR. Quantitative measures, rather than a presence-absence categorization, may more accurately characterize the associations between human markers of faecal contamination and swimming associated illness risk. These interpretations of the results would seem acceptable assuming that the experiment-wise error rate (EER) is accounted for (see below). However, it is not clear if this has been done so the validity of the results is unclear.	
8	How precise are the results?	Can't tell	The results are relatively imprecise as can be seen in Figure 3 of the paper which shows the generally large 95% confidence intervals. This uncertainty is recognised by the authors and their discussion of the few clearly positive results is limited to the markers with 95% confidence intervals that did not, or only minimally overlapped the 0% risk difference (centre line of figure 3 in the paper). However, it is not clear if these multiple individual comparisons account for experiment-wise error rate. When a series of significance tests is conducted on the same data set, the experiment-wise error rate (EER) is the probability that one or more of the significance tests results in a Type I error. Reference is made to a statistical paper by Greenland (2004, https://doi.org/10.1093/aje/kwh221) however, the actual approach taken by the authors is unclear.	**Probably high risk of bias (-)**
9	Do you believe the results?	No	Overall, the authors observed weaker and more inconsistent associations between illness and Bacteroides markers than expected. Possible reasons given for the weak relationships were; - that human-associated *Bacteroides* markers may be less persistent than general *Enterococcus* markers in the environment. - that the densities of the human markers may have been impacted by the long-term freezer storage of the samples at −40 °C - that the human associated *Bacteroides* markers in this study were often undetected. These factors prompted the use of the presence-absence approach for data analysis, which may have limited the author's ability to estimate associations. - that the level of non-specific faecal contamination may have been so high that the addition of a human marker did not add any additional information to the estimation of illness risk. Given the above limitations, the study findings areseverely limited by the uncontrolled effect of sample freezing and storage for several years and the lack of clarity about the EER. Consequently the results are compromised by these limitations.	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			
10	Can the results be applied to the local population?	No	Given the compromised results, it is not considered appropriate to apply the findings elsewhere.	**Definitely high risk of bias (--)**

Q.	Criteria	J26, Napier, M., 2017, Exposure to human-associated fecal indicators and self-reported illness among swimmers at recreational beaches: A cohort study Assessment	Comments	Risk of Bias rating
11	Do the results of this study fit with other available evidence?	Can't tell	Correspondence with other evidence is weak, as noted by the authors who were surprised by the study results.	**Probably high risk of bias (-)**
12	What are the implications of this study for practice?	No	Due to the serious limitations in the study design with respect to the aged/thawed samples and EER, it does not seem appropriate to draw any significant conclusions from this study given the uncertainty over the reliability of the testing of genetic markers from 2 to 6 years old frozen samples. The authors state, "We were unable to calculate an average daily concentration for each *Bacteroides* marker due to limited detectable values and prolonged storage of samples, both of which had an unknown effect on the accuracy of the quantified amount". Hence the authors switched to classifying exposure as present (detected in ≥2 samples/day) or absent (detected in 0–1 sample/day), which is likely to have weakened the expected relationships.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to methodological and statistical limitations, the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.18. J27: Napier, Poole, et al., (2018)

7.2.18.1. Quality assessment

Q.	Criteria	J27, Napier, Me, 2018, Exposure to Human-Associated Chemical Markers of Fecal Contamination and Self-Reported Illness among Swimmers at Recreational Beaches Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the study address a clearly focused issue?	Yes	The study sought to determine if there is a link between chemical markers of faecal contamination and negative health impacts associated with exposure to waterborne pathogens, using data from a large, multi-site cohort study. The primary objectives were to: (1) estimate the association between chemical markers of human-derived faecal pollution and self-reported illness among recreational swimmers, and (2) determine whether chemical markers were able to identify human source when used in combination with conventional faecal indicator *Enterococcus* spp. that were detected by qPCR.	**Definitely low risk of bias (++)**
2	Was the cohort recruited in an acceptable way?	Yes	The study makes use of the NEEAR historical data set. For the original NEEAR study, procedures, questionnaires, protocols and consent process were reviewed and approved by the Institutional Review Board (IRB) of the Centers for Disease Control and Prevention. The NEEAR study was a prospective cohort study: participants were adults enrolled at beaches on weekends and holidays in summer. Participants completed surveys on site and received follow-up telephone interviews 10-12-days later to determine incident symptoms of gastrointestinal illness, diarrhea and respiratory illness.	**Probably low risk of bias (+)**

Q.	Criteria	J27, Napier, Me, 2018, Exposure to Human-Associated Chemical Markers of Fecal Contamination and Self-Reported Illness among Swimmers at Recreational Beaches Assessment	Comments	Risk of Bias rating
	Section A2: Is it worth continuing?			
3	Was the exposure accurately measured to minimise bias?	Can't tell	Some measures are described to control exposure bias, but the descriptions lack detail (e.g. exclusion of non-swimmers, etc.), so the true extent of such measures is somewhat unclear.	**Probably high risk of bias (-)**
4	Was the outcome accurately measured to minimise bias?	Yes	The paper makes reference to previous studies here, but it seems that it is the same data set as described in the related paper reviewed here (i.e. Napier et al 2017), so the same classifications apply	**Probably low risk of bias (+)**
5	(a) Have the authors identified all important confounding factors?	Can't tell	The author's ability to make inferences was limited by the fact that a high proportion of chemical samples was left-censored (i.e. below the limit of detection) and could not be analysed quantitatively. The authors arranged the data as presence/absence (dichotomisation) but noted that this affected estimation of risk difference by reducing the proportion of cases with chemical exposure. Other confounding factors are not identified or discussed.	**Probably high risk of bias (-)**
5	(b) Have they taken account of the confounding factors in the design and/or analysis?	Can't tell	As with the related study reviewed here (Napier 2017) the description of the statistical methods could be more clearly reported. No discussion of confounding factors was located apart from the brief material cited above.	**Probably high risk of bias (-)**
6	(a) Was the follow up of subjects complete enough?	Yes	As noted above, the paper makes reference to previous studies here, but it seems that it is the same data set as described in the related paper reviewed here (i.e. Napier et al 2017), so the same classifications apply.	**Probably low risk of bias (+)**
6	(b) Was the follow up of subjects long enough?	Yes	As above	**Probably low risk of bias (+)**
	Section B: What are the results?			
7	What are the results of this study?	Can't tell	The authors conclusions were: Sixty-two chemical markers were analysed from daily water samples at freshwater and marine beaches. Of those, 20 were found consistently. With the possible exception of bisphenol A and cholesterol, no chemicals were consistently associated with increased risks of illness. These two chemicals were suggestively associated with 2% and 1% increased risks of GI illness and diarrhea in both freshwater and marine beaches. This interpretation of the results is acceptable assuming that the experiment-wise error rate (EER) is accounted for (see below). However, it is not clear if this has been done so the validity of the results is unclear.	**Probably high risk of bias (-)**
8	How precise are the results?	Can't tell	Similar to the findings in the Napier et al 2017 study, the results are relatively imprecise as can be seen in Figure 2 of the paper which shows the generally large 95% confidence intervals. It is also not clear if these multiple individual comparisons account for experiment-wise error rate. When a series of significance tests is conducted on the same data set, the experiment-wise error rate (EER) is the probability that one or more of the significance tests results in a Type I error. Reference is made to a statistical paper by Greenland (2004, https://doi.org/10.1093/aje/kwh221) however, the actual approach taken by the authors is unclear	**Probably high risk of bias (-)**
9	Do you believe the results?	No	The effect sizes are generally weak and it is not clear if the EER has been controlled	**Definitely high risk of bias (--)**
	Section C: Will the results help locally?			

Q.	Criteria	J27, Napier, Me, 2018, Exposure to Human-Associated Chemical Markers of Fecal Contamination and Self-Reported Illness among Swimmers at Recreational Beaches Assessment	Comments	Risk of Bias rating
10	Can the results be applied to the local population?	No	Given the compromised results, it is not appropriate to apply the findings elsewhere.	**Definitely high risk of bias (--)**
11	Do the results of this study fit with other available evidence?	Can't tell	There is limited research on this topic, thus it is unclear if the study fits any such evidence.	**Probably high risk of bias (-)**
12	What are the implications of this study for practice?	No	Due to weak and limited effect sizes noted and the possible serious limitation in the study design with respect to the EER, it does not seem appropriate to draw any significant conclusions from this study.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to methodological and statistical limitations, the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.19. J28: Oun, Yin, et al., (2017)

7.2.19.1. Quality assessment

Q.	Criteria	J28, Oun, A.; Y, 2017, Microbial pollution characterization of water and sediment at two beaches in Saginaw Bay, Michigan Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The study aims are clear. They are: 1) determine the faecal pollution level of two recreational beaches at Saginaw Bay using faecal indicators and virus infectivity measurements; 2) identify the probable source of contamination in the two recreation al beaches using host specific human and bovine markers; 3) characterise the microbial pollution load of sediments; 4) determine the relationship of faecal indicators (*E. coli* and enterococci) with Bacteroides markers; and 5) evaluate the use of viruses as microbial source tracking tools.	**Definitely low risk of bias (++)**
2	Is the methodology appropriate?	Yes	Water and sediment were sampled at two beaches weekly over 13 weeks in swimming season and tested for *E. coli*, enterococci, and Bacteroides qPCR assays. This simple sampling plan is easy to follow and is appropriate in responding to the study aims.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate for the aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on *E. coli*, enterococci, and Bacteroides qPCR assays in Saginaw Bay, Lake Michigan, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The data collection from two of sites with historically poor water quality and undefined sources of pollution plus the mix of FIB and qPCR MST markers is considered appropriate	**Probably low risk of bias (+)**
6	Has the relationship between researcher and	n/a	Question not applicable, since there were no human study participants	n/a

Q.	Criteria	J28, Oun, A.; Y, 2017, Microbial pollution characterization of water and sediment at two beaches in Saginaw Bay, Michigan Assessment	Comments	Risk of Bias rating
	participants been adequately considered?			
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	The data analysis involved checks for normality, log transformations to reduce skewness, and use of standard parametric tests (e.g. Pearsons correlation, T-tests etc.), which is appropriate. However, the discussion of the results in relation to the clearly laid out project aims could be more clearly reported.	**Probably high risk of bias (-)**
9	Is there a clear statement of findings?	No	A number of potentially interesting findings supporting null hypotheses or of only weak significance discussed in the text are not included in the study conclusions nor abstract. This could possibly be due to publication bias because of pressure to highlight only strongly statistically significant results. For example neither of the following key observations are included in the conclusions and abstract: (i) use of HAdV and BAdV (human and bovine adenovirus) as a microbial source tracking methods in the studied beaches failed to identify the source of faecal contamination, and (ii) weak correlations were observed between the concentration of FIB and Bacteroides markers in grab water samples.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	Overall the study findings are probably strongly influenced by local conditions of the study area which does not support extrapolation of the findings to other contexts such as in this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the methodological rigour and statistical analysis and findings that are of low relevance to this narrative review, the study is considered to have a high risk of bias.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.20. J29: Polkowska, Räsänen, et al., (2018)

7.2.20.1. Quality assessment

Q.	Criteria	J29, Polkowska,, 2018, An outbreak of Norovirus infections associated with recreational lake water in Western Finland, 2014 Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the study address a clearly focused issue?	No	There is no clear statement of aims.	**Definitely high risk of bias (--)**
2	Was the cohort recruited in an acceptable way?	Can't tell	The study was a retrospective cohort study. As noted by the authors, the recruitment of study subjects was based on press releases and participation in the study was voluntary, which may introduce volunteer bias.	**Probably high risk of bias (-)**
	Section A2: Is it worth continuing?		**No**	

J29, Polkowska,, 2018, An outbreak of Norovirus infections associated with recreational lake water in Western Finland, 2014				
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
3	Was the exposure accurately measured to minimise bias?	Yes	Exposure was based on responses to a web questionnaire seeking information on common risk factors that could contribute to recreational water-derived gastroenteritis. The risk factors included getting water in mouth while swimming, submersing head under water, swallowing water while swimming, playing on wet sand, eating own food, using change room, using toilet, using carpet wash place (this last item is apparently a cultural practice in Finland, where special piers for washing carpets are common in lakes and coastal areas). Also information on the illness rates including, date and time of onset of gastrointestinal symptoms, number of persons who fell ill in the household and general hygienic conditions at the beaches. The risk factors are appropriate and would be expected to be relatively straight forward to answer in a survey.	**Probably low risk of bias (+)**
4	Was the outcome accurately measured to minimise bias?	Yes	The outcomes were based on questionnaire responses completed by the participants which may introduce some minor levels of error compared to other approaches such as direct interviews.	**Probably low risk of bias (+)**
5	(a) Have the authors identified all important confounding factors?	Yes	The authors identify a number of possible confounding factors that remained uncontrolled these include: the recruitment of study subjects was based on press releases and participation in the study was voluntary, which may introduce volunteer bias, some people could respond to both the initial web-based survey and cohort study, people with more severe symptoms or parents of young children may tend to participate more often and some bias may be related to self-reporting of symptoms, which were not validated by medical examination. It is not possible to judge the net effects of such factors but it seems reasonable to conclude that their effects would be small.	**Probably low risk of bias (+)**
5	(b) Have they taken account of the confounding factors in the design and/or analysis?	No	The factors described above were addressed in the study design and may have a minor influence on the results.	**Probably high risk of bias (-)**
6	(a) Was the follow up of subjects complete enough?	n/a	Being a retrospective study there was no follow up required.	n/a
6	(b) Was the follow up of subjects long enough?	n/a	Being a retrospective study there was no follow up required.	n/a
	Section B: What are the results?			
7	What are the results of this study?	Yes	Of 1453 persons enrolled in the study, 244 met the case definition (attack rate, 17%). Risk factors for gastroenteritis included getting water in the mouth while swimming (Risk ratio (RR) 3.32; 95% CI 2.36–4.68) and playing on the wet sand at the beach (RR 1.90; 95% CI 1.50–2.41). In a multivariable analysis (logistic regression), the source of the infection was likely at two lakes (lake A Odds ratio (OR) 1.66; 95% CI 1.15–2.39 and lake B, OR 2.35; 95% CI 1.49–3.72). Norovirus (NoV) was found in 19 stool samples. All water samples from implicated beaches had acceptable values of faecal indicator bacteria and were negative for NoV. The likely source of the outbreak was lake-water contaminated with NoV at two popular lakes. Closure of swimming beaches, advice on hygienic precautions and rapid outbreak alerts were efficient in controlling the outbreak	**Probably low risk of bias (+)**
8	How precise are the results?	Can't tell	Statistical effect sizes were moderate, and the statistical model fitted could have been explained a bit more clearly to enable a more accuratel assessment of the overall precision.	**Probably high risk of bias (-)**

Q.	Criteria	J29, Polkowska,, 2018, An outbreak of Norovirus infections associated with recreational lake water in Western Finland, 2014 Assessment	Comments	Risk of Bias rating
9	Do you believe the results?	Yes	The overall results are consistent with a lake norovirus contamination event. This is supported by the public health statistics following beach closures which showed a drop in gastroenteritis rates among lake visitors.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	Can the results be applied to the local population?	Yes	The findings could be applied in an Australian context, but the fact that NoV was not detected in the lakes and that FIB levels were within acceptable levels is not surprising due to the low infectious dose of NoV. Overall the results conform with well-established risk pathways.	**Probably low risk of bias (+)**
11	Do the results of this study fit with other available evidence?	Yes	The study results are consistent with well-established public health knowledge.	**Probably low risk of bias (+)**
12	What are the implications of this study for practice?	No	Although not clearly stated in the study, bather shedding was implied as the main causal pathway for GI illness. The study results reinforce already well-established knowledge that NoV is a significant cause of gastroenteritis in crowded unhygienic beach recreation areas.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The findings are of low relevance for the Australian context and this narrative review.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.21. J31: Rodrigues and Cunha, (2017)

7.2.21.1. Quality assessment

Q.	Criteria	J31, Rodrigues,, 2017, Assessment of the microbiological quality of recreational waters: indicators and methods Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Did the review address a clearly focused question?	No	No clearly focused question is stated, but it can reasonably be inferred that the authors sought to "present an overview of several pathogen indicators and quantification methods to ensure the microbiological quality of RW", Although this is itself a reasonable objective, for the purposes of this narrative review it could be more clearly reported.	**Probably high risk of bias (-)**
2	Did the authors look for the right type of papers?	No	No information is supplied with respect to how the reviewers selected studies for review.	**Definitely high risk of bias (--)**
	Section A2: Is it worth continuing?			
3	Do you think all the important, relevant studies were included?	No	No information is supplied with respect to bibliographic databases, follow up reference lists, inclusion/exclusion criteria, etc., to source studies for review so it is possible that some important papers were overlooked	**Probably high risk of bias (-)**
4	Did the review's authors do enough to assess quality of the included studies?	No	No information is supplied with respect to how the reviewers assessed the quality of the studies.	**Definitely high risk of bias (--)**
5	If the results of the review have been combined, was it reasonable to do so?	n/a	The review was focused on qualitative aspects of the studies and did not involve the combination of data to create a database for meta-analysis	n/a

Q.	Criteria	Assessment	J31, Rodrigues,, 2017, Assessment of the microbiological quality of recreational waters: indicators and methods Comments	Risk of Bias rating
	Section B: What are the results?			
6	What are the overall results of the review?	n/a	Some general commentary is made about the limitations of conventional FIB monitoring of recreational waters and the need for new technologies, particularly new biosensing methods that permit field use and use in early warning systems. Given the highly qualitative nature of the commentary this review question is considered to be not applicable.	n/a
7	How precise are the results?	n/a	The review results are of a qualitative nature and consist of commentary on the findings in the shortlisted research papers.	n/a
	Section C: Will the results help locally?			
8	Can the results be applied to the local population?	No	The review findings are highly qualitative and high level and although conceivably widely applicable, there are limitations in methodological rigour such as the selection of review papers, critical appraisal of their quality and critical synthesis of the content. Consequently it is concluded that there is probably a risk of bias with respect to this criterion.	**Probably high risk of bias (-)**
9	Were all important outcomes considered?	No	The review could benefit from more critical analysis. The review is more appropriate as an introduction to the general topic of recreational water quality monitoring rather than a critical review of the state of the science.	**Probably high risk of bias (-)**
10	Are the benefits worth the harms and costs?	No	This study had a number of limitations including lack of clear study aims and the high level and broad nature of the commentary. The study could benefit from a more critical analysis and data synthesis.	**Definitely high risk of bias (--)**
-	**Overall risk of bias rating**	-	*Due to limitations regarding the methodological rigour (e.g. selection and quality assessment of the included literature, critical analysis) the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.22. J32: Roser, Davies, et al., (2006)

7.2.22.1. Quality assessment

Q.	Criteria	Assessment	J32, Roser, Dav, 2006, Microbial exposure assessment of an urban recreational lake: A case study of the application of new risk-based guidelines Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	No	There is no clear statement of aims.	**Definitely high risk of bias (--)**
2	Is the methodology appropriate?	No	The paper is clearly reported but the methodology has some serious limitations. For example, the paper presents a case study as an example of the development of a water safety plan for protection of recreational water quality in a 10 ha urban lake. Three stages are listed but it is acknowledged that the 3rd stage was still in progress at the time of writing, so the assessment is incomplete. Furthermore it was noted that the lake was potentially contaminated by sewage sources, yet no consideration of viral risk as evidenced	**Definitely high risk of bias (--)**

Q.	Criteria	J32, Roser, Dav, 2006, Microbial exposure assessment of an urban recreational lake: A case study of the application of new risk-based guidelines Assessment	Comments	Risk of Bias rating
			by monitoring of viral pathogens or markers, or consideration of times when sewage flows may occur is included (apparently due to lack of funds).	
	Section A2: Is it worth continuing?	**No**		
3	Was the research design appropriate to address the aims of the research?			
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?			
5	Was the data collected in a way that addressed the research issue?			
6	Has the relationship between researcher and participants been adequately considered?			
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?			
8	Was the data analysis sufficiently rigorous?			
9	Is there a clear statement of findings?			
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?			
-	**Overall risk of bias rating**	**-**	*Due to the lack of aims, and methodological and statistical limitations the study is considered to have a high risk of bias.*	**Definitely high risk of bias (--)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias.	

7.2.23. J33: Rosiles-González, Ávila-Torres, et al., (2019)

7.2.23.1. Quality assessment

Q.	Criteria	J33, Rosiles-Go, 2019, Norovirus and human adenovirus occurrence and diversity in recreational water in a karst aquifer in the Yucatan Peninsula, Mexico Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The stated aim was to determine the seasonal occurrence and diversity of norovirus (NoV) and human adenovirus (HAdV) in groundwater from sinkholes, and brackish water used for recreational activities in the karst aquifer of the Yucatan Peninsula, Mexico	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study is largely descriptive and describes sampling of waters from sinkholes (using ultrafiltration) used for	**Probably low risk of bias (+)**

Q.	Criteria	J33, Rosiles-Go, 2019, Norovirus and human adenovirus occurrence and diversity in recreational water in a karst aquifer in the Yucatan Peninsula, Mexico Assessment	Comments	Risk of Bias rating
			primary contact recreation for viral pathogens (Norovirus and Adenovirus).	
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	In principle, sampling of a range of karst aquifer sinkholes would be an appropriate approach, however the description of the sampling sites, their localities and their relationship to the aquifer, the aquifer attributes and potential sources of viral pathogens described in the paper could be more clearly reported. The emphasis is mostly on diversity of norovirus (NoV) and human adenovirus (HAdV).	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing viral diversity in Mexican sinkholes used for water recreation, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	The stated aim was to determine the seasonal occurrence and diversity of norovirus (NoV) and human adenovirus (HAdV) in groundwater from sinkholes, and brackish water used for recreational activities in the karst aquifer of the Yucatan Peninsula, Mexico and the data collection method enabled such an assessment, although the context could have been strengthened with more details on site description.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The statistical analyses of viral diversity are rigorous, but the spatial analysis of site responses and assessment of viral sources is limited.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Can't tell	There is a short statement in the abstract, but it does not address the aims.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The assessment of norovirus (NoV) and human adenovirus (HAdV) diversity has low relevance in relation to the main elements of the primary research question (how do we monitor, assess and predict risks from diffuse and point source microbial contamination in recreational waters?).The research in the context of this narrative review is not of satisfactory value to answer the research questions.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*Due to study limitations regarding the methodological rigour and findings that are of low relevance to this narrative review, the study is considered to have a high risk of bias.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.24. J37: Shrestha, Kelty, et al., (2020)

7.2.24.1. Quality assessment

		J37, Shrestha, 2020, Fecal pollution source characterization at non-point source impacted beaches under dry and wet weather conditions		
Q.	**Criteria**	**Assessment**	**Comments**	**Risk of Bias rating**
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	A clear set of four study objectives are presented in the last paragraph of the introduction	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study authors investigated the role of microbial source tracking (MST) as a complement to routine beach monitoring at Chicago beaches. In summer 2016, water samples from nine Chicago beaches were analyzed for *E. coli* by culture and enterococci by qPCR. The methodology is exploratory but is appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate to address the aims of the research since nearly 200 samples are assessed. Given the exploratory design, such a large number is necessary.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Yes	The hypothetical population is people undertaking primary contact recreation. The study authors examined associations between FIB Beach Action Values (BAV) exceedance and MST marker detection. BAVs are based on US EPA acceptable thresholds for gastrointestinal illness (note that this ignores other health impacts, e.g. sequelae like G-B syndrome).	**Probably low risk of bias (+)**
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis could be more clearly reported to minimise use of acronyms for MST markers, sample sites and regulatory thresholds and statistical metrics, but is of satisfactory rigour.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	Statements of findings are presented in the conclusions.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	Although the study is well conducted the study aims and findings are mainly of relevance to the Chicago lakeshore beaches which are not influenced by stormwater drains due to deliberate engineering practices. Australian metro beaches by comparison are not freshwater and highly likely to receive stormwater runoff.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The findings are of low relevance for the Australian context and this narrative review.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.25. J38: Shrestha, Midwinter, et al., (2019)

7.2.25.1. Quality assessment

Q.	Criteria	J38, Shrestha, , 2019, Campylobacter jejuni strains associated with wild birds and those causing human disease in six high-use recreational waterways in New Zealand Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The primary objectives of this study were (i) to assess the proportions of Campylobacter- and C. jejuni-positive water samples from each of six riverine study sites in the NZ north island and (ii) to determine the potential associations between the presence of both Campylobacter spp. and ruminant associated C. jejuni and explanatory variables such as month, site of sample collection, and river flow rates.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	Water samples were collected between 2005 and 2009 from six high-use recreational waterways in the Manawatu-Wanganui region of the North Island. Relationships between Campylobacter spp and potentially predictive environmental variables was examined as was Campylobacter genetic diversity and potential sources via multilocus sequence typing (MLST). The methodology is considered appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate to address the aims of the research.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing Campylobacter presence and sources in NZ riverine recreational waters, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The data analysis is detailed and rigorous.	**Definitely low risk of bias (++)**
9	Is there a clear statement of findings?	Yes	A summary of findings is presented in the abstract, however the discussion could be more clearly reported.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	Although the study is well conducted the study aims and findings are mainly of relevance to NZ riverine recreational waters and are highly dependent on the nature of the source catchments. The findings that Campylobacter spp are more prevalent in high flows in rivers with avian wildlife and ruminants confirms current knowledge. Whilst the MLST component of the	**Probably high risk of bias (-)**

Q.	Criteria	J38, Shrestha, , 2019, Campylobacter jejuni strains associated with wild birds and those causing human disease in six high-use recreational waterways in New Zealand Assessment	Comments	Risk of Bias rating
			paper is more interesting, it is not useful for informing the primary research question of this narrative review.	
-	**Overall risk of bias rating**	-	*The findings are of low relevance for the Australian context and this narrative review.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.26. J39: Steele, Blackwood, et al., (2018)

7.2.26.1. Quality assessment

Q.	Criteria	J39, Steele, Jo, 2018, Quantification of pathogens and markers of fecal contamination during storm events along popular surfing beaches in San Diego, California Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	Two objectives are embedded in the last paragraph of the introduction: (i) to investigate viral and bacterial pathogen dynamics in the stormwater of two urban watersheds that discharge to high-use swimming/surfing beaches in southern California, (ii) to utilize principal component analysis and other relational statistical approaches to assess relationships across MST markers and pathogen types, yielding potentially valuable information for subsequent mitigation efforts.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	Using a mix of techniques to quantify microbial communities in relation to stormwater flows is an appropriate methodology	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	No	The use of digital qPCR methods in microbial source tracking (MST) is appropriate, however, the application of PCA to microbiological data has limitations. PCA assumes linear relationships between all variables whereas microbial taxa have unimodal relationships with environmental variables. Thus samples at either end of an environmental gradient may both have low values for a microbial taxon and thus would be classified as similar by the analysis; any correlations with environmental variables on PCA axes based on such data would be misleading. This problem is well known in the ecological statistical literature and ecologists have developed a range of techniques to overcome the issue including use of robust dissimilarity coefficients, and ordination techniques like non-metric multidimensional scaling and canonical correlation analysis.	**Definitely high risk of bias (--)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing relationships between FIB and qPCR markers and stormwater sources and flow variability on ocean beach	n/a

Q.	Criteria	J39, Steele, Jo, 2018, Quantification of pathogens and markers of fecal contamination during storm events along popular surfing beaches in San Diego, California Assessment	Comments	Risk of Bias rating
			recreational waters, and thus did not involve a hypothetical population or subpopulation.	
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	Probably low risk of bias (+)
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	No	Analysis and discussion of the qPCR data was sufficiently rigorous, although inhibition problems introduced uncertainty into some of the results. However, the PCA analysis was seriously limited as noted above.	Definitely high risk of bias (--)
9	Is there a clear statement of findings?	Can't tell	The abstract contains some concise statements on findings, but these are interspersed with method descriptions. The conclusions provide a broad overview and could be more clearly reported.	Probably high risk of bias (-)
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The study aims could have been reported more clearly and were only marginally rated as having a low risk of bias. It would also have been helpful for the reader to have a clearer description of the benefits of the novel digital qPCR technology . The PCA component is statistically limited as discussed, whilst the overall findings are heavily determined by local catchment sources. Consequently, the research does not provide much material in support of the primary research question.	Probably high risk of bias (-)
-	**Overall risk of bias rating**	-	*Due to statistical limitations, and findings that are strongly determined by local catchment factors the study is considered to have a high risk of bias.*	Probably high risk of bias (-)
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.27. J40: Xue, Feng, et al., (2018)

7.2.27.1. Quality assessment

Q.	Criteria	J40, Xue, J.; F, 2018, Using Bacteroidales genetic markers to assess fecal pollution sources in coastal waters Assessment	*Comments*	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The objectives are described in the last paragraph of the introduction: to determine if human and bovine faeces were responsible for poor microbial water quality in the study area (eastern shore of Mobile Bay in southern Alabama, USA) and the relationship between FIB and Bacteroidales genetic marker concentrations	Probably low risk of bias (+)

Q.	Criteria	J40, Xue, J.; F, 2018, Using Bacteroidales genetic markers to assess fecal pollution sources in coastal waters Assessment	*Comments*	Risk of Bias rating
2	Is the methodology appropriate?	Yes	Use of FIB and qPCR markers as part of an MST study to distinguish between sources of faecal contamination along the beach front and within tributaries to the bay is appropriate.	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate to address the aims of the research as total of 101 water samples were collected from 9 sites in the bay and analysed for enterococci FIB and qPCR markers targeting general (AllBac), human-associated (HF183), and cattle-associated (CowM3) Bacteroidales	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing relationships between FIB and qPCR markers of faecal contamination sources in source tributaries and beach front recreational waters, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The statistical analyses of FIB and qPCR Bacteroidales-based MST markers is satisfactory although the overall analysis was mainly descriptive and site-specific in keeping with the limited ambitions of the study aims.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Can't tell	Some clear statements are contained in the abstract, but these do not address the depth of the findings. The conclusions provide only some general overview statements and don't specifically address the study findings.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This is simple study of only local relevance to the Mobile Bay recreational beaches. The research aims are limited and although the study clearly reported, it is of low relevance to answer the primary research question of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The study is considered to have a high risk of bias due to its focus on local, site-specific attributes of the study area.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.28. J41: Xue, Lin, et al., (2018)

7.2.28.1. Quality assessment

Q.	Criteria	J41, Xue, J.; L, 2018, Assessment of fecal pollution in Lake Pontchartrain, Louisiana Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The objectives were to determine if human and bovine faeces were responsible for poor microbial water quality in Lake Pontchartrain, a large semi-enclosed estuary adjacent to New Orleans, Louisiana, USA and to determine if the presence of such faecal sources is dependent upon specific environmental conditions.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study made use of FIB and qPCR MST markers to identify sources around Lake Pontchartrain which is considered an appropriate methodology	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The research design is appropriate to address the aims of the research - 160 water samples were collected from 10 sites along Lake Pontchartrain and analysed for FIB (*E. coli*, Enterococcus) and qPCR markers targeting *E. coli*, Enterococcus spp., human-associated (HF183F/265R), and cattle-associated (CowM3F/M3R) Bacteroidales	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing relationships between faecal FIB and qPCR markers of contamination sources at recreational sites around Lake Pontchartrain, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection was appropriate to address the research issue.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Yes	The statistical analyses of FIB and qPCR Bacteroidales-based MST markers is satisfactory although the data graphs (fig.2, fig.3) could be more clearly reported, and the overall analysis was mainly descriptive and site-specific in keeping with the limited study aims.	**Probably low risk of bias (+)**
9	Is there a clear statement of findings?	Yes	Statements of findings are presented in the conclusions.	**Probably low risk of bias (+)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	This is a simple study of only local relevance to the Lake Pontchartrain recreational beaches. The research aims are limited and although the study is clearly reported, it is of low relevance to support the primary research question of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The study is considered to have a high risk of bias due to its focus on local, site-specific attributes of the study area.*	**Probably high risk of bias (-)**
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

7.2.29. J42: Zimmer-Faust, Steele, et al., (2020)

7.2.29.1. Quality assessment

Q.	Criteria	J42, Zimmer-Fau, 2020, The challenges of microbial source tracking at urban beaches for Quantitative Microbial Risk Assessment (QMRA) Assessment	Comments	Risk of Bias rating
	Section A1: Are the results valid?			
1	Was there a clear statement of the aims of the research?	Yes	The objectives were to identify the primary sources of faecal contamination to Inner Cabrillo Beach (ICB), Los Angeles, California during dry weather in order to guide the characterization of representative pathogens for risk assessment.	**Probably low risk of bias (+)**
2	Is the methodology appropriate?	Yes	The study made use of FIB and qPCR MST markers to identify sources along Inner Cabrillo Beach (ICB), Los Angeles, which is considered an appropriate methodology	**Probably low risk of bias (+)**
	Section A2: Is it worth continuing?			
3	Was the research design appropriate to address the aims of the research?	Yes	The study design had three stated elements: 1) daily water samples collected during dry weather along ICB and processed for FIB and MST markers; 2) a high-resolution temporal study was conducted, targeting the influence of the tidal cycle on variability in FIB and MST marker levels at ICB; and 3) a spatial survey of human marker levels in the harbor comparing HF183 levels at ICB and at various offshore, harbor locations. These elements are appropriate for addressing the study aims.	**Probably low risk of bias (+)**
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	n/a	The study focus was on assessing relationships between faecal FIB and qPCR markers of contamination sources at recreational sites around ICB, and thus did not involve a hypothetical population or subpopulation.	n/a
5	Was the data collected in a way that addressed the research issue?	Yes	Data collection ultimately proved inadequate to inform the stated study aim of characterization of representative pathogens for risk assessment, since the pathogen loadings from potential human sources could not confidently be qualified. This is recognised by the author, clearly stated, and a key finding of the study.	**Probably low risk of bias (+)**
6	Has the relationship between researcher and participants been adequately considered?	n/a	Question not applicable, since there were no human study participants	n/a
	Section B: What are the results?			
7	Have ethical issues been taken into consideration?	n/a	Question not applicable, since there were no human study participants	n/a
8	Was the data analysis sufficiently rigorous?	Can't tell	The statistical analysis is missing the fitting of some sort of linear model (e.g. multiple regression) or an explanation of why this was not done. The result is that the data analysis could be more clearly synthesised and reported.	**Probably high risk of bias (-)**
9	Is there a clear statement of findings?	Can't tell	The abstract contains a couple of statements that may considered part of the study findings, but overall there is no clear statement of findings.	**Probably high risk of bias (-)**
	Section C: Will the results help locally?			
10	How valuable is the research? Is the research of satisfactory value?	No	The findings of this study could be more clearly reported, and the general results are heavily determined by the local catchment sources. Consequently, the research findings are of low relevanceto support the primary research question of this narrative review.	**Probably high risk of bias (-)**
-	**Overall risk of bias rating**	-	*The study is considered to have a high risk of bias due to its focus on local, site-specific attributes of the study area.*	**Probably high risk of bias (-)**

Q.	Criteria	J42, Zimmer-Fau, 2020, The challenges of microbial source tracking at urban beaches for Quantitative Microbial Risk Assessment (QMRA) Assessment	Comments	Risk of Bias rating
-	**Reviewer's conclusion**		Exclude from further review due to high risk of bias and relevance.	

8 Studies excluded in screening

8.1. Grey literature excluded in full-text screening

The following list of grey literature citations were scanned against inclusion/exclusion criteria and for relevance to the primary and secondary research questions and deemed not to be relevant. Scanning involved accessing the full text document and checking through the document sections checking for any sections that may have some content relevant to the primary and secondary research questions.

8.1.1. Screened on relevance

The following studies were screened on relevance with reasons given in brackets "[ ]".

Deere, D., Rooney, G., 2013. QMRA of the Yarra River: Phase 3, upper Yarra, Warrandyte to Warburton. Water Futures P/L. [Not a peer-reviewed document]

ECDC, 2020. Final joint report in respect of a one health country visit to Ireland from 07 October 2019 to 11 October 2019 to discuss policies relating to antimicrobial resistance (No. Ref. Ares (2020)2047456, DG(SANTE) 2019-6622). European Centre for Disease Prevention and Control (ECDC) and European Commission Directorate-General for Health and Food Safety. [Document makes only minor passing reference to recreational waters]

Hawaii DoH, 2014. Water Quality Standards, Hawaii Administrative Rules (HAR), Chapter 11-54, State of Hawaii, Department of Health. [Simple water quality criteria, no contextual information supplied]

Health Canada, 2020. Guidelines for Canadian Recreational Water Quality: Cyanobacteria and their Toxins. Guideline Technical Document for Public Consultation. Health Canada, Ontario, Canada. [Out of scope]

Health Protection Branch, B., 2018. Decision Protocol for Cyanobacterial Toxins in B.C. Drinking Water and Recreational Water. Health Protection Branch, British Columbia, Canada. [Out of scope]

Health Protection NSW, 2013. Public Swimming Pool and Spa Pool Advisory Document. Health Protection NSW, Sydney. [Out of Scope: applies to public swimming pools and spas that receive chemical disinfection]

Health Protection Service, 2014. ACT Guidelines for Recreational Water Quality (No. HPS-00-0434). Health Protection Service, ACT Government, ACT. [Simple 12-page pamphlet based on NHMRC 2008]

Ontario MHLTC, 2018. Recreational Water Protocol, 2018. Ministry of health and Long-Term Care, Ontario, Canada. [Out of Scope: high level regulatory document, does not deal specifically with microbial risks]

Queensland Health, 2019. Water quality guidelines for public aquatic facilities. Queensland Health, Queensland. [Applies to out-of-scope waterbodies]

State of Connecticut, 2016. State of Connecticut Guidelines for Monitoring Swimming Water and Closure Protocol. Connecticut Department of Public Health, Connecticut Department of Energy & Environmental Protection, State of Connecticut, United States. [Out of Scope: contains regional compliance monitoring information and makes only passing reference to microbial risks]

8.1.2. Screened on other criteria

The following studies were screened out because they were non-Australian studies published prior to 2017 (i.e. the cut-off date agreed with the Committee to manage the quantity of literature to review. See Section 2.4.4 for justification).

Health Canada, 2012. Guidelines for Canadian recreational water quality. Third Edition. Health Canada, Ottawa.

NZMoE, 2003. Microbiological water quality guidelines for marine and freshwater recreational areas. New Zealand Ministry of the Environment.

US EPA, 2012. Recreational Water Quality Criteria (No. Office of Water 820-F-12-058). US Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC, United States.

US EPA, 2010. Quantitative Microbial Risk Assessment to Estimate Illness in Freshwater Impacted by Agricultural Animal Sources of Fecal Contamination (No. Office of Water EPA 822-R-10-005). US Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC, United States.

US EPA, 2014. Microbiological Risk Assessment (MRA) Tools, Methods, and Approaches for Water Media (No. Office of Water EPA-820-R-14-009). US Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC, United States.

US EPA, 2015. Review of Coliphages as Possible Indicators of Fecal Contamination for Ambient Water Quality. (No. 820- R-15- 098.). US EPA Office of Water, Washington, DC, USA.

US EPA, 2016. 2016 Coliphage Experts Workshop: Discussion Topics and Findings (No. No. EPA 823-F-16-001). US EPA Office of Water, Washington D.C.

WHO, 2016. Quantitative microbial risk assessment: Application for water safety management. World Health Organization.

WHO, 2016. Protecting surface water for health: Identifying, assessing and managing drinking-water quality risks in surface-water catchments. World Health Organization.

WHO, 2014. Briefing Note. Antimicrobial Resistance: An Emerging Water, Sanitation and Hygiene Issue (No. WHO/FWC/WSH/14.7). World Health Organization, Switzerland.

WHO, 2009. Guidelines for safe recreational water environments. Addendum to Volume 1 - List of agreed updates. WHO Reference Number: WHO/HSE/WSH/10.04. World Health Organization.

Wymer, L., Brenner, K., Martinson, J., Stutts, W.R., Schaub, S.A., Dufour, A., Hamel, D., Wilde, K., Brown, S., Siefring, S.C., 2006. The EMPACT Beaches Project Results from a Study on Microbiological Monitoring in Recreational Waters (No. EPA 600/R-04/023). US Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Cincinnati, Ohio, USA.

8.2. Primary studies excluded in full-text screening

8.2.1. Addressed in existing review [+ detail] (85 studies)

Aragonés, L.; López, I.; Palazón, A.; López-Úbeda, R.; García, C. (2016). Evaluation of the quality of coastal bathing waters in Spain through fecal bacteria Escherichia coli and Enterococcus. The Science of the Total Environment 566-567: 288-297, DOI:10.1016/j.scitotenv.2016.05.106, [Addressed in existing review - RCIT Predictive/Deterministic Modelling].

Ashbolt, N. J.; Schoen, M. E.; Soller, J. A.; Roser, D. J. (2010). Predicting pathogen risks to aid beach management: The real value of quantitative microbial risk assessment (QMRA). Water Research 44 (16)4692-4703. DOI:10.1016/j.watres.2010.06.048 [Addressed in existing review - QMRA].

Benedict, R. T.; Neumann, C. M. (2004). Evaluating Oregon's beach sites for application to United States Environmental Protection Agency's BEACH Act criteria. Marine Pollution Bulletin 49 (7-8) 630-636, DOI:10.1016/j.marpolbul.2004.04.006, [Addressed in existing review - RCIT Predictive/Deterministic Modelling].

Brownell, M. J.; Harwood, V. J.; Kurz, R. C.; McQuaig, S. M.; Lukasik, J.; Scott, T. M. (2007). Confirmation of putative stormwater impact on water quality at a Florida beach by microbial source tracking methods and structure of indicator organism populations. Water Research 41 (16) 3747-3757, DOI:10.1016/j.watres.2007.04.001, [Addressed in existing review - MST methods].

Byappanahalli, Muruleedhara N.; Nevers, Meredith B.; Whitman, Richard L.; Ge, Zhongfu; Shively, Dawn; Spoljaric, Ashley; Przybyla-Kelly, Katarzyna (2015). Wildlife, urban inputs, and landscape configuration are responsible for degraded swimming water quality at an embayed beach. Journal of Great Lakes Research 41 (1) 156-163, DOI:10.1016/j.jglr.2014.11.027, [Addressed in existing review - MST methods, qPCR Methods for FIB].

Choi, S.; Chu, W. P.; Brown, J.; Becker, S. J.; Harwood, V. J.; Jiang, S. C. (2003). Application of enterococci antibiotic resistance patterns for contamination source identification at Huntington Beach, California. Marine Pollution Bulletin 46 (6) 748-755, DOI:10.1016/S0025-326X(03)00046-8, [Addressed in existing review - Emerging/wider issue - antimicrobial resistance (AMR)].

Coffey, Rory; Benham, Brian; Kline, Karen; Wolfe, Mary Leigh; Cummins, Enda (2015). Potential Microbial Load Reductions Required to Meet Existing Freshwater Recreational Water Quality Standards for a Selection of Mid-century Environmental Change Scenarios. Environmental Processes-an International Journal 2 (4) 609-629, DOI:10.1007/s40710-015-0114-2, [Addressed in existing review - RCIT Predictive/Deterministic Modelling].

Converse, R. R.; Kinzelman, J. L.; Sams, E. A.; Hudgens, E.; Dufour, A. P.; Ryu, H.; Santo-Domingo, J. W.; Kelty, C. A.; Shanks, O. C.; Siefring, S. D.; Haugland, R. A.; Wade, T. J. (2012). Dramatic improvements in beach water quality following gull removal. Environmental Science and Technology 46 (18) 10206-10213, DOI:10.1021/es302306b, [Addressed in existing review - MST methods, qPCR Methods for FIB].

Dickerson, J. W.; Hayedorn, C.; Hassall, A. (2007). Detection and remediation of human-origin pollution at two public beaches in Virginia using multiple source tracking methods. Water Research 41 (16) 3758-3770, DOI:10.1016/j.watres.2007.02.055, [Addressed in existing review - MST methods].

Duris, J. W.; Haack, S. K.; Fogarty, L. R. (2009). Gene and antigen markers of Shiga-toxin producing *E. coli* from Michigan and Indiana river water: Occurrence and relation to recreational water quality criteria. Journal of Environmental Quality 38 (5) 1878-1886, DOI:10.2134/jeq2008.0225, [Addressed in existing review - qPCR methods].

Edge, T. A.; Hill, S.; Seto, P.; Marsalek, J. (2010). Library-dependent and library-independent microbial source tracking to identify spatial variation in faecal contamination sources along a Lake Ontario beach (Ontario, Canada). Water Science and Technology 62 (3) 719-727, DOI:10.2166/wst.2010.335, [Addressed in existing review - MST methods, qPCR Methods for FIB].

Edge, T. A.; Hill, S.; Stinson, G.; Seto, P.; Marsalek, J. (2007). Experience with the antibiotic resistance analysis and DNA fingerprinting in tracking faecal pollution at two lake beaches. Water Science and Technology 56 (11) 51-58, DOI:10.2166/wst.2007.757, [Addressed in existing review - MST methods].

Edge, Thomas A.; Hill, Stephen (2007). Multiple lines of evidence to identify the sources of fecal pollution at a freshwater beach in Hamilton Harbour, Lake Ontario. Water Research 41 (16) 3585-3594, DOI:10.1016/j.watres.2007.05.012, [Addressed in existing review - MST methods].

Esseili, M. A.; Kassem, I. I.; Lis, J.; Sigler, V. (2014). Application of denaturing gradient gel electrophoresis (DGGE) for assessing fecal pollution sources at a recreational beach. Journal of Water and Health 12 (4) 846-857, DOI:10.2166/wh.2014.034, [Addressed in existing review - MST].

Fewtrell, L.; Kay, D. (2015). Recreational Water and Infection: A Review of Recent Findings. Current environmental health reports 2(1):85-94, DOI:10.1007/s40572-014-0036-6 [Addressed in existing review - FIO enterococci].

Fiello, M.; Mikell, A. T.; Moore, M. T.; Cooper, C. M. (2014). Variability in the characterization of total coliforms, fecal coliforms and Escherichia coli in recreational water supplies of North Mississippi, USA. Bulletin of Environmental Contamination and Toxicology 93 (2) 133-137, DOI:10.1007/s00128-014-1299-1, [Addressed in existing review - RCIT Predictive/Deterministic Modelling].

Furukawa, T.; Yoshida, T.; Suzuki, Y. (2011). Application of PFGE to source tracking of faecal pollution in coastal recreation area: a case study in Aoshima Beach, Japan. Journal of Applied Microbiology 110 (3) 688-696, DOI:10.1111/j.1365-2672.2010.04918.x, [Addressed in existing review - MST methods].

Furukawa, Takashi; Suzuki, Yoshihiro (2013). A Proposal for Source Tracking of Fecal Pollution in Recreational Waters by Pulsed-Field Gel Electrophoresis. Microbes and Environments 28 (4) 444-449, DOI:10.1264/jsme2.ME13075, [Addressed in existing review - MST methods].

Gourmelon, M.; Caprais, M.P.; Mieszkin, S.; Marti, R.; Wéry, N.; Jardé, E.; Derrien, M.; Jadas-Hécart, A.; Communal, P.Y.; Jaffrezic, A.; Pourcher, A.M. (2010). Development of microbial and chemical MST tools to identify the origin of the faecal pollution in bathing and shellfish harvesting waters in France. Shifting paradigms in the assessment of recreational water quality 44 (16) 4812-4824, DOI:10.1016/j.watres.2010.07.061, [Addressed in existing review - MST methods].

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8.2.2. Basic sanitary survey (6 studies)

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8.2.3. Comment on another paper (3 studies)

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8.2.4. Non-Australian study cited in key review (94 studies)

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8.2.7. Not relevant to primary research question (40 studies)

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Yoder, Jonathan S; Craun, Gunther F; Calderon, Rebecca L (2008). Surveillance for waterborne disease and outbreaks associated with recreational water use and other aquatic facility-associated health events--United States, 2005-2006. [Report] Centers for Disease Control and Prevention (CDC), US Department of Health [PMID: 18784642] 57:, DOI:, [Not relevant to primary research question - National outbreak summary].

8.2.8. Obsolete [+ reason] (16 studies)

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Noble, Rachel T.; Weisberg, Stephen B. (2005). A review of technologies for rapid detection of bacteria in recreational waters. Journal of Water and Health 3 (4):381-392, DOI:10.2166/wh.2005.051, [Obsolete - Literature review].

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Santo Domingo, JORGE W; Hansel, JOEL (2008). Waterborne diseases and microbial quality monitoring for recreational water bodies using regulatory methods. Oceans and Human Health: Risks and Remedies from the Sea :337-357 [Obsolete - Literature review].

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Weisberg, Stephen B; Noble, Rachel T; Griffith, John F (2007). Microbial indicators of marine recreational water quality. Manual of Environmental Microbiology, Third Edition :280-289 [Obsolete - Literature review].

Yoder, J. S.; Blackburn, B. G.; Craun, G. F.; Hill, V.; Levy, D. A.; Chen, N.; Lee, S. H.; Calderon, R. L.; Beach, M. J. (2004). Surveillance for waterborne-disease outbreaks associated with recreational water--United States, 2001-2002. MMWR. Surveillance summaries : Morbidity and mortality weekly report. Surveillance summaries / CDC 53 (8):1-22 [Obsolete - Literature review].

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8.2.9. Out of scope [+ reason] (52 studies)

Brown, Kendra I.; Boehm, Alexandria B. (2015). Comparative decay of Catellicoccus marimmalium and enterococci in beach sand and seawater. Water Research 83:377-384, DOI:10.1016/j.watres.2015.06.055, [Out of scope - Beach sand focus].

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Halliday, E.; Gast, R. J. (2011). Bacteria in beach sands: An emerging challenge in protecting coastal water quality and bather health. Environmental Science and Technology 45 (2):370-379, DOI:10.1021/es102747s, [Out of scope - Beach sand focus].

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sands. Limnology and Oceanography-Methods 8:146-154, DOI:10.4319/lom.2010.8.146, [Out of scope - Beach sand focus].

Halliday, Elizabeth; McLellan, Sandra L.; Amaral-Zettler, Linda A.; Sogin, Mitchell L.; Gast, Rebecca J. (2014). Comparison of Bacterial Communities in Sands and Water at Beaches with Bacterial Water Quality Violations. Plos One 9 (3):e90815, DOI:10.1371/journal.pone.0090815, [Out of scope - Beach sand focus].

Heaney, C. D.; Exum, N. G.; Dufour, A. P.; Brenner, K. P.; Haugland, R. A.; Chern, E.; Schwab, K. J.; Love, D. C.; Serre, M. L.; Noble, R.; Wade, T. J. (2014). Water quality, weather and environmental factors associated with fecal indicator organism density in beach sand at two recreational marine beaches. Science of the Total Environment 497-498:440-447, DOI:10.1016/j.scitotenv.2014.07.113, [Out of scope - Beach sand focus].

Manjarrez-Paba, Ganiveth; Blanco Herrera, Jorge Ivan; Gonzalez Arrunategui, Betsy Paola (2018). Environmental and Health Risk by the Presence of Parasites in the Sand of Cartagena Beaches. Beach Management Tools - Concepts, Methodologies and Case Studies 24:831-844 [Out of scope - Beach sand focus].

Sabino, R.; Rodrigues, R.; Costa, I.; Carneiro, C.; Cunha, M.; Duarte, A.; Faria, N.; Ferreira, F. C.; Gargaté, M. J.; Júlio, C.; Martins, M. L.; Nevers, M. B.; Oleastro, M.; Solo-Gabriele, H.; Veríssimo, C.; Viegas, C.; Whitman, R. L.; Brandão, J. (2014). Routine screening of harmful microorganisms in beach sands: Implications to public health. Science of the Total Environment 472:1062-1069, DOI:10.1016/j.scitotenv.2013.11.091, [Out of scope - Beach sand focus].

Shibata, T.; Solo-Gabriele, H. M. (2012). Quantitative microbial risk assessment of human illness from exposure to marine beach sand. Environmental Science and Technology 46 (5):2799-2805, DOI:10.1021/es203638x, [Out of scope - Beach sand focus].

Skórczewski, Piotr; Mudryk, Zbigniew; Gackowska, Joanna; Perlinski, Piotr (2012). Abundance and distribution of fecal indicator bacteria in recreational beach sand in the southern Baltic Sea. Revista de Biología Marina y Oceanografía 47 (3):503-512 [Out of scope - Beach sand focus].

Solo-Gabriele, Helena M; Harwood, Valerie J; Kay, David; Fujioka, Roger S; Sadowsky, Michael J; Whitman, Richard L; Wither, Andrew; Caniça, Manuela; Da Fonseca, Rita Carvalho; Duarte, Aida (2016). Beach sand and the potential for infectious disease transmission: observations and recommendations. Journal of the Marine Biological Association of the United Kingdom 96 (1):101-120 [Out of scope - Beach sand focus].

Vogel, Laura J.; Edge, Thomas A.; O'Carroll, Denis M.; Solo-Gabriele, Helena M.; Kushnir, Caitlin S. E.; Robinson, Clare E. (2017). Evaluation of methods to sample fecal indicator bacteria in foreshore sand and pore water at freshwater beaches. Water Research 121:204-212, DOI:10.1016/j.watres.2017.05.021, [Out of scope - Beach sand focus].

Weiskerger, Chelsea J.; Brandao, Joao; Ahmed, Warish; Aslan, Asli; Avolio, Lindsay; Badgley, Brian D.; Boehm, Alexandria B.; Edge, Thomas A.; Fleisher, Jay M.; Heaney, Christopher D.; Jordao, Luisa; Kinzelman, Julie L.; Klaus, James S.; Kleinheinz, Gregory T.; Merilainen, Paivi; Nshimyimana, Jean Pierre; Phanikumar, Mantha S.; Piggot, Alan M.; Pitkanen, Tarja; Robinson, Clare; Sadowsky, Michael J.; Staley, Christopher; Staley, Zachery R.; Symonds, Erin M.; Vogel, Laura J.; Yamahara, Kevan M.; Whitman, Richard L.; Solo-Gabriele, Helena M.; Harwood, Valerie J. (2019). Impacts of a changing earth on microbial dynamics and human health risks in the continuum between beach water and sand. Water Research 162:456-470, DOI:10.1016/j.watres.2019.07.006, [Out of scope - Beach sand focus].

Whiley, Harriet; Austin, Jasmine; da Silva, Graziela Miot; Ross, Kirstin (2018). Faecal Indicator Bacteria Present in Sand at South Port Beach, South Australia. Journal of Coastal Research 34 (1):215-219, DOI:10.2112/JCOASTRES-D-16-00183.1, [Out of scope - Beach sand focus].

Whitman, R. L.; Harwood, V. J.; Edge, T. A.; Nevers, M. B.; Byappanahalli, M.; Vijayavel, K.; Brandão, J.; Sadowsky, M. J.; Alm, E. W.; Crowe, A.; Ferguson, D.; Ge, Z.; Halliday, E.; Kinzelman, J.; Kleinheinz, G.; Przybyla-Kelly, K.; Staley, C.; Staley, Z.; Solo-Gabriele, H. M. (2014). Microbes in beach sands: Integrating environment, ecology and public health. Reviews in Environmental Science and Biotechnology 13 (3):329-368, DOI:10.1007/s11157-014-9340-8, [Out of scope - Beach sand focus].

Whitman, Richard L.; Przybyla-Kelly, Katarzyna; Shively, Dawn A.; Nevers, Meredith B.; Byappanahalli, Muruleedhara N. (2009). Hand-mouth transfer and potential for exposure to *E. coli* and F+ coliphage in beach sand, Chicago, Illinois. Journal of Water and Health 7 (4):623-629, DOI:10.2166/wh.2009.115, [Out of scope - Beach sand focus].

Yamahara, K. M.; Sassoubre, L. M.; Goodwin, K. D.; Boehm, A. B. (2012). Occurrence and persistence of bacterial pathogens and indicator organisms in beach sand along the California coast. Applied and Environmental Microbiology 78 (6):1733-1745, DOI:10.1128/AEM.06185-11, [Out of scope - Beach sand focus].

Yamahara, Kevan M.; Walters, Sarah P.; Boehm, Alexandria B. (2009). Growth of Enterococci in Unaltered, Unseeded Beach Sands Subjected to Tidal Wetting. Applied and Environmental Microbiology 75 (6):1517-1524, DOI:10.1128/AEM.02278-08, [Out of scope - Beach sand focus].

Stewart, I.; Webb, P. M.; Schluter, P. J.; Fleming, L. E.; Burns Jr, J. W.; Gantar, M.; Backer, L. C.; Shaw, G. R. (2006). Epidemiology of recreational exposure to freshwater cyanobacteria - An international prospective cohort study. BMC Public Health 6:, DOI:10.1186/1471-2458-6-93, [Out of scope - Cyanobacteria].

Hass, Charles N.; Rose, Joan B.; Gerba, Charles P. (2014). Quantitative Microbial Risk Assessment. [Book] John Wiley & Sons, Inc :, ISBN:978-1-118-14529-6, [Out of scope - Detailed QMRA methods handbook].

Purnell, Sarah; Halliday, Andrew; Newman, Freya; Sinclair, Christine; Ebdon, James (2020). Pathogen infection risk to recreational water users, associated with surface waters impacted by de facto and indirect potable reuse activities. Science of the Total Environment 722:137799, DOI:10.1016/j.scitotenv.2020.137799, [Out of scope - Environmental flow augmentation (hypothetical)].

Bergron, P.; Courtois, S.; Masse, P. (2009). New analytical tools for the active management of bathing water quality: Application on fresh water and seawater samples. Journal Europeen d'Hydrologie 40 (2):151-164, DOI:10.1051/water/2009010, [Out of scope - French language only].

Biedunkiewicz, A.; Góralska, K. (2016). Microfungi Potentially Pathogenic for Humans Reported in Surface Waters Utilized for Recreation. Clean - Soil, Air, Water 44 (6):599-609, DOI:10.1002/clen.201500696, [Out of scope - Fungi].

Frenkel, M.; Yunik, Y.; Fleker, M.; Blum, S. E.; Sionov, E.; Elad, D.; Serhan, H.; Segal, E. (2020). Fungi in sands of Mediterranean Sea beaches of Israel—Potential relevance to human health and well-being. Mycoses 63 (11):1255-1261, DOI:10.1111/myc.13144, [Out of scope - Fungi].

Graczyk, T. K.; Sunderland, D.; Tamang, L.; Shields, T. M.; Lucy, F. E.; Breysse, P. N. (2007). Quantitative evaluation of the impact of bather density on levels of human-virulent microsporidian spores in recreational water. Applied and Environmental Microbiology 73 (13):4095-4099, DOI:10.1128/AEM.00365-07, [Out of scope - Fungi].

Solo-Gabriele, Helena; Brandão, João; Gordon, Bari; Ferguson, Alesia (2016). Recreational Environment: Pathogenic Fungi in Public Places, Information Gaps in Assessing Public Health Risk. Environmental Mycology in Public Health :167-192 [Out of scope - Fungi].

Sivaganesan, Mano; Aw, Tiong Gim; Briggs, Shannon; Dreelin, Erin; Aslan, Asli; Dorevitch, Samuel; Shrestha, Abhilasha; Isaacs, Natasha; Kinzelman, Julie; Kleinheinz, Greg; Noble, Rachel; Rediske, Rick; Scull, Brian; Rosenberg, Susan; Weberman, Barbara; Sivy, Tami; Southwell, Ben; Siefring, Shawn; Oshima, Kevin; Haugland, Richard (2019). Standardized data quality acceptance criteria for a rapid Escherichia coli qPCR method (Draft Method C):for water quality monitoring at recreational beaches. Water Research 156:456-464, DOI:10.1016/j.watres.2019.03.011, [Out of scope - Interlaboratory comparison].

Dionisi, A.; Schinaia, N.; Arcieri, R.; Ripabelli, G.; Luzzi, I. (2003). Association between sea recreational water and gastroenteritis. Annali dell'Istituto Superiore di Sanita 39 (1):29-34 [Out of scope - Italian language only].

Gobeille, A. K.; Morland, K. B.; Bopp, R. F.; Godbold, J. H.; Landrigan, P. J. (2006). Body burdens of mercury in lower Hudson River area anglers. Environmental Research 101 (2):205-212, DOI:10.1016/j.envres.2005.08.017, [Out of scope - Mercury contamination in anglers].

Ferguson, A.; Del Donno, C.; Obeng-Gyasi, E.; Mena, K.; Altomare, T. K.; Guerrero, R.; Gidley, M.; Montas, L.; Solo-Gabriele, H. M. (2019). Children exposure-related behavior patterns and risk perception associated with recreational beach use. International Journal of Environmental Research and Public Health 16 (15):, DOI:10.3390/ijerph16152783, [Out of scope - Oil spill chemicals].

Lodder, W. J.; Schijven, J. F.; Rutjes, S. A.; Husman, A. M. de Roda; Teunis, P. F. M. (2015). Entero- and parechovirus distributions in surface water and probabilities of exposure to these viruses during water recreation. Water Research 75:25-32, DOI:10.1016/j.watres.2015.02.024, [Out of scope - Opportunistic pathogens - Entero- and parechovirus].

Izquierdo, F.; Castro Hermida, J. A.; Fenoy, S.; Mezo, M.; González-Warleta, M.; Aguila, C. D. (2011). Detection of microsporidia in drinking water, wastewater and recreational rivers. Water Research 45 (16):4837-4843, DOI:10.1016/j.watres.2011.06.033, [Out of scope - Opportunistic pathogens - Microsporidia].

Fogarty, L. R.; Haack, S. K.; Johnson, H. E.; Brennan, A. K.; Isaacs, N. M.; Spencer, C. (2015). Staphylococcus aureus and methicillin-resistant s. aureus (MRSA):at ambient freshwater beaches. Journal of Water and Health 13 (3):680-692, DOI:10.2166/wh.2014.278, [Out of scope - Opportunistic pathogens - MRSA].

Plano, Lisa R. W.; Garza, Anna C.; Shibata, Tomoyuki; Elmir, Samir M.; Kish, Jonathan; Sinigalliano, Christopher D.; Gidley, Maribeth L.; Miller, Gary; Withum, Kelly; Fleming, Lora E.; Solo-Gabriele, Helena M. (2011). Shedding of Staphylococcus aureus and methicillin-resistant Staphylococcus aureus from adult and pediatric bathers in marine waters. Bmc Microbiology 11:5, DOI:10.1186/1471-2180-11-5, [Out of scope - Opportunistic pathogens - MRSA].

Marszewska, A.; Cichy, A.; Heese, T.; Żbikowska, E. (2016). The real threat of swimmers' itch in anthropogenic recreational water body of the Polish Lowland. Parasitology Research 115 (8):3049-3056, DOI:10.1007/s00436-016-5060-z, [Out of scope - Opportunistic pathogens - Schistosomes].

Clark, Catherine D.; De Bruyn, Warren J.; Hirsch, Charlotte M.; Jakubowski, Scott D. (2010). Hydrogen peroxide measurements in recreational marine bathing waters in Southern California, USA. Water Research 44 (7):2203-2210, DOI:10.1016/j.watres.2009.12.044, [Out of scope - Photoinactivation].

Prüss, Annette (1998). Review of epidemiological studies on health effects from exposure to recreational water. International journal of epidemiology 27 (1):1-9 [Out of scope - Published pre 2003].

Fujioka, R. S.; Solo-Gabriele, H. M.; Byappanahalli, M. N.; Kirs, M. (2015). U.S. recreational water quality criteria: A vision for the future. International Journal of Environmental Research and Public Health 12 (7):7752-7776, DOI:10.3390/ijerph120707752, [Out of scope - Regulatory governance review].

Piggot, Alan M; Klaus, James S; Johnson, Sara; Phillips, Matthew C; Solo-Gabriele, Helena M (2012). Relationship between enterococcal levels and sediment biofilms at recreational beaches in South Florida. Applied and environmental microbiology 78 (17):5973-5982 [Out of scope - Sediment biofilms].

Roslev, Peter; Bastholm, Soren; Iversen, Niels (2008). Relationship between fecal indicators in sediment and recreational waters in a Danish estuary. Water Air and Soil Pollution 194 (1-4):13-21, DOI:10.1007/s11270-008-9715-y, [Out of scope - Sediment biofilms].

Doménech-Sánchez, A.; Olea, F.; Berrocal, C. I. (2008). Infections related to recreational waters. Enfermedades Infecciosas y Microbiologia Clinica 26 (SUPPL. 13):32-37, DOI:10.1157/13128778, [Out of scope - Spanish language only].

AbdelZaher, Amir Mahmoud (2010). Microbes At A Non-Point Source Sub-Tropical Recreational Marine Beach And Their Implications On Human Health And Beach Monitoring Practices. [Thesis] URL:https://scholarship.miami.edu/discovery/delivery?vid=01UOML_INST:ResearchRepository&repId=12355279870002976#13355519250002976, [Out of scope - Thesis].

Durant, Brandon (2018). Spatial and Temporal Variability in Bacterial Communities in Surface and Groundwater at Lake Erie Beaches with Varying Water Quality. [Thesis] URL:https://ubir.buffalo.edu/xmlui/bitstream/handle/10477/78464/durant_buffalo_0656m_16040.pdf?sequence=4&isAllowed=y, [Out of scope - Thesis].

Eregno, Fasil Ejigu (2017). Quantitative Microbial Risk Assessment and Water Quality Modelling-On Drinking Water Sources, Recreational and Recycled Waters. [Thesis] URL:https://www.nap.edu/catalog/11010/indicators-for-waterborne-pathogens, [Out of scope - Thesis].

Jacques, Margaret Margaret Rose (2015). Microbial risk assessment for recreational use of the Malden River. [Thesis] URL:http://hdl.handle.net/1721.1/99600, [Out of scope - Thesis].

Kinzelman, Julie Lynn (2005). Investigating bathing water quality failures and initiating remediation for the protection of public health. [Thesis] URL:https://openresearch.surrey.ac.uk/esploro/outputs/doctoral/Investigating-Bathing-Water-Quality-Failures-and-Initiating-Remediation-For-The-Protection-of-Public-Health/99511847502346, [Out of scope - Thesis].

Leonard, Anne Frances Clare (2016). Are bacteria in the coastal zone a threat to human health? [Thesis] URL:https://ore.exeter.ac.uk/repository/handle/10871/22805, [Out of scope - Thesis].

Rothenheber, Derek (2017). Microbial Source Tracking in Coastal Recreational Waters of Southern Maine: Relationships Between Enterococci, Environmental Factors, Potential Pathogens, and Fecal Sources. [Thesis] URL:https://ore.exeter.ac.uk/repository/handle/10871/22805, [Out of scope - Thesis].

Sunger, Neha (2013). Quantitative Health Risk Assessment of Recreational Water Users in Philadelphia. [Thesis] URL:https://idea.library.drexel.edu/islandora/object/idea:4104, [Out of scope - Thesis].

Donofrio, Robert S.; Aridi, Sal; Saha, Ratul; Bechanko, Robin; Schaefer, Kevin; Bestervelt, Lorelle L.; Hamil, Beth (2013). Laboratory validation of an ozone device for recreational water treatment. Journal of Water and Health 11 (2):267-276, DOI:10.2166/wh.2013.198, [Out of scope - Water treatment].

Hoebe, Cjpa; Vennema, H.; Husman, A. M. D.; van Duynhoven, Ythp (2004). Norovirus outbreak among primary schoolchildren who had played in a recreational water fountain. Journal of Infectious Diseases 189 (4):699-705, DOI:10.1086/381534, [Out of scope - Water treatment].

8.3. Primary studies excluded in initial screening

Screening methods are described in Section 3.2. Initial screening was performed on titles, with difficult to classify subsets subsequently screened on abstracts.

Table 8-1. Primary studies screening summary

Summary	Number of citations
Not a recreational water quality study	2044
Out of scope (plus reason)	58
Not OECD member nation	141
Included studies	320
Total	**2563**

8.3.1. Not a recreational water quality study (2044 studies)

Abdipour, Yaser; Khazan, Hooshang; Azargashb, Eznollah; Mahmoudi, Mohammad Reza; Farahnak, Ali; Rostami, Ali (2020). Prevalence of Intestinal Parasitic Infections among Individuals Referred to the Medical Centers of Coastal Cities, Guilan Province, Northern Iran, 2015-2017. Iranian Journal of Public Health 49(6)1157-1163. ISSN:2251-6085 [Not a recreational water quality study].

Abdul Azis, P. K.; Al-Tisan, I. A.; Daili, M. A.; Green, T. N.; Dalvi, A. G. I.; Javeed, M. A. (2003). Chlorophyll and plankton of the Gulf coastal waters of Saudi Arabia bordering a desalination plant. Desalination 154 (3)291-302. DOI:10.1016/S0011-9164(03)80044-9 [Not a recreational water quality study].

Abdulsattar, B. O.; Abdulsattar, J. O.; Rasool, K. H.; Abdulhussein, A. R. A.; Abbas, M. H. (2020). Study of antimicrobial resistance pattern of Escherichia coli and Klebsiella strains and multivariate analysis for water quality assessment of Tigris River, Baghdad, Iraq. Nature Environment and Pollution Technology 19 (3)1327-1334. DOI:10.46488/NEPT.2020.v19i03.050 [Not a recreational water quality study].

Abeywardena, Harshanie; Jex, Aaron R.; Firestone, Simon M.; McPhee, Sandra; Driessen, Nicole; Koehler, Anson V.; Haydon, Shane R.; von Samson-Himmelstjerna, Georg; Stevens, Melita A.; Gasser, Robin B. (2013). Assessing calves as carriers of Cryptosporidium and Giardia with zoonotic potential on dairy and beef farms within a water catchment area by mutation scanning. Electrophoresis 34 (15)2259-2267. DOI:10.1002/elps.201300146 [Not a recreational water quality study].

Abi Saab, M. T.; Jammoul, D.; Makhlouf, H.; Fahed, S.; Lebbous, N.; Hajjar, C.; Abi Saad, R.; Younes, M.; Hajj, M.; Todorovic, M. (2018). Assessing the performance of constructed wetland for water quality management of a Southern Mediterranean river. Water and Environment Journal 32 (4)508-518. DOI:10.1111/wej.12348 [Not a recreational water quality study].

Abia, A. L. K.; Ubomba-Jaswa, E.; Momba, M. N. B. (2016). Occurrence of diarrhoeagenic Escherichia coli virulence genes in water and bed sediments of a river used by communities in Gauteng, South Africa. Environmental Science and Pollution Research 23 (15)15665-15674. DOI:10.1007/s11356-016-6762-6 [Not a recreational water quality study].

Abia, A. L. K.; Ubomba-Jaswa, E.; Momba, M. N. B. (2015). Impact of seasonal variation on Escherichia coli concentrations in the riverbed sediments in the Apies River, South Africa. Science of the Total Environment 537: 462-469. DOI:10.1016/j.scitotenv.2015.07.132 [Not a recreational water quality study].

Abu-Bakar, A.; Ahmadian, R.; Falconer, R. A. (2017). Modelling the transport and decay processes of microbial tracers in a macro-tidal estuary. Water Research 123: 802-824. DOI:10.1016/j.watres.2017.07.007 [Not a recreational water quality study].

Abubakar, A.; Van de Vijver, F. J. R.; Hassan, A. S.; Fischer, R.; Nyongesa, M. K.; Kabunda, B.; Berkley, J. A.; Stein, A.; Newton, C. R. (2017). Cumulative Psychosocial Risk is a Salient Predictor of Depressive Symptoms among Vertically HIV-Infected and HIV-Affected Adolescents at the Kenyan Coast. Annals of Global Health 83 (43987)743-752. DOI:10.1016/j.aogh.2017.10.024 [Not a recreational water quality study].

Ackoundou-N'Guessan, K. C.; Lagou, D. A.; Tia, M. W.; Gnionsahe, D. A.; Guei, M. C. (2011). Risk factors for chronic renal failure in Ivory Coast: a prospective study of 280 patients. Saudi journal of kidney diseases and transplantation : an official publication of the Saudi Center for Organ Transplantation, Saudi Arabia 22 (1)185-190. URL:https://www.scopus.com/inward/record.uri?eid=2-s2.0-79952227521&partnerID=40&md5=b5eb90d7b65ec157981f36f0be68a1bd [Not a recreational water quality study].

Adineh, Maede; Ghaderi, Mostafa; Mousavi-Nasab, Seyed Dawood (2019). Occurrence of Salivirus in Sewage and River Water Samples in Karaj, Iran. Food and Environmental Virology 11 (2)193-197. DOI:10.1007/s12560-019-09377-1 [Not a recreational water quality study].

Adriaenssens, E. M.; Farkas, K.; Harrison, C.; Jones, D. L.; Allison, H. E.; McCarthy, A. J. (2018). Viromic analysis of wastewater input to a river catchment reveals a diverse assemblage of RNA viruses. mSystems 3 (3). DOI:10.1128/MSYSTEMS.00025-18 [Not a recreational water quality study].

Aemig, Q.; Chéron, C.; Delgenès, N.; Jimenez, J.; Houot, S.; Steyer, J. P.; Patureau, D. (2016). Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in sludge organic matter pools as a driving force of their fate during anaerobic digestion. Waste Management 48: 389-396. DOI:10.1016/j.wasman.2015.11.045 [Not a recreational water quality study].

Aguilera, R.; Gershunov, A.; Benmarhnia, T. (2019). Atmospheric rivers impact California's coastal water quality via extreme precipitation. Science of the Total Environment 671: 488-494. DOI:10.1016/j.scitotenv.2019.03.318 [Not a recreational water quality study].

Aguirre-Martínez, G. V.; Okello, C.; Salamanca, M. J.; Garrido, C.; Del Valls, T. A.; Martín-Díaz, M. L. (2016). Is the step-wise tiered approach for ERA of pharmaceuticals useful for the assessment of cancer therapeutic drugs present in marine environment? Environmental Research 144: 43-59. DOI:10.1016/j.envres.2015.10.028 [Not a recreational water quality study].

Agunbiade, F. O.; Moodley, B. (2016). Occurrence and distribution pattern of acidic pharmaceuticals in surface water, wastewater, and sediment of the Msunduzi River, Kwazulu-Natal, South Africa. Environmental Toxicology and Chemistry 35 (1)36-46. DOI:10.1002/etc.3144 [Not a recreational water quality study].

Ahmad, Eissa A.; Duane, Michael J. (2020). Selective microbial-induced biomineralization of a siliciclastic zoned coastline in a constricted modern tidal flat, Kuwait (Northern Arabian Gulf). Arabian Journal of Geosciences 13 (19)1017. DOI:10.1007/s12517-020-05941-3 [Not a recreational water quality study].

Ahmed, M. S.; Bibi, S. (2010). Uptake and bioaccumulation of water borne lead (Pb) in the fingerlings of a freshwater cyprinid, Catla catla L. Journal of Animal and Plant Sciences 20 (3)201-207. URL:https://www.scopus.com/inward/record.uri?eid=2-s2.0-77957367082&partnerID=40&md5=feea340947ccac44a301ac3b727be404 [Not a recreational water quality study].

Ahmed, T.; Ohta, K.; Nagafuchi, O.; Maruo, M. (2012). Binding interactions of 1-naphthol with dissolved organic matter of Lake Biwa and treated sewage wastewater: The role of microbial fulvic acid. Environmental Toxicology and Chemistry 31 (10)2201-2209. DOI:10.1002/etc.1934 [Not a recreational water quality study].

Ahmed, W.; Goonetilleke, A.; Gardner, T. (2010). Human and bovine adenoviruses for the detection of source-specific fecal pollution in coastal waters in Australia. Water Research 44 (16)4662-4673. DOI:10.1016/j.watres.2010.05.017 [Not a recreational water quality study].

Ahmed, W.; Gyawali, P.; Toze, S. (2016). Evaluation of Glass Wool Filters and Hollow-Fiber Ultrafiltration Concentration Methods for qPCR Detection of Human Adenoviruses and Polyomaviruses in River Water. Water, Air, and Soil Pollution 227 (9). DOI:10.1007/s11270-016-3026-5 [Not a recreational water quality study].

Ahmed, W.; Hargreaves, M.; Goonetilleke, A.; Katouli, M. (2008). Population similarity analysis of indicator bacteria for source prediction of faecal pollution in a coastal lake. Marine Pollution Bulletin 56 (8)1469-1475. DOI:10.1016/j.marpolbul.2008.04.043 [Not a recreational water quality study].

Ahmed, W.; Katouli, M. (2008). Phenotypic variations of enterococci in surface waters: analysis of biochemical fingerprinting data from multi-catchments. Journal of Applied Microbiology 105 (2)452-458. DOI:10.1111/j.1365-2672.2008.03763.x [Not a recreational water quality study].

Ahmed, W.; Neller, R.; Katouli, M. (2005). Host species-specific metabolic fingerprint database for enterococci and Escherichia coli and its application to identify sources of fecal contamination in surface waters. Applied and Environmental Microbiology 71 (8)4461-4468. DOI:10.1128/AEM.71.8.4461-4468.2005 [Not a recreational water quality study].

Ahmed, W.; Payyappat, S.; Cassidy, M.; Harrison, N.; Besley, C. (2020). Interlaboratory accuracy and precision among results of three sewage-associated marker genes in urban environmental estuarine waters and freshwater streams. Science of the Total Environment 741. DOI:10.1016/j.scitotenv.2020.140071 [Not a recreational water quality study].

Ahmed, W.; Sawant, S.; Huygens, F.; Goonetilleke, A.; Gardner, T. (2009). Prevalence and occurrence of zoonotic bacterial pathogens in surface waters determined by quantitative PCR. Water Research 43 (19)4918-4928. DOI:10.1016/j.watres.2009.03.041 [Not a recreational water quality study].

Ahmed, W.; Staley, C.; Sadowsky, M. J.; Gyawali, P.; Sidhu, J. P. S.; Palmer, A.; Beale, D. J.; Toze, S. (2015). Toolbox Approaches Using Molecular Markers and 16S rRNA Gene Amplicon Data Sets for Identification of Fecal Pollution in Surface Water. Applied and Environmental Microbiology 81 (20)7067-7077. DOI:10.1128/AEM.02032-15 [Not a recreational water quality study].

Ahmed, W.; Tucker, J.; Bettelheim, K. A.; Neller, R.; Katouli, M. (2007). Detection of virulence genes in Escheyichia coli of an existing metabolic fingerprint database to predict the sources of pathogenic E-coli in surface waters. Water Research 41 (16)3785-3791. DOI:10.1016/j.watres.2006.12.026 [Not a recreational water quality study].

Ahmed, Warish; Gyawali, Pradip; Toze, Simon (2015). Quantitative PCR measurements of Escherichia coli including shiga toxin-producing *E. coli* (STEC) in animal feces and environmental waters. Environmental science & technology 49(5)3084-3090. ISSN:0013-936X [Not a recreational water quality study].

Ahmed, Warish; Hamilton, Kerry; Toze, Simon; Cook, Stephen; Page, Declan (2019). A review on microbial contaminants in stormwater runoff and outfalls: Potential health risks and mitigation strategies. Science of the Total Environment 692: 1304-1321. ISSN:0048-9697 [Not a recreational water quality study].

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and compilation of computational model. Environmental Monitoring and Assessment 191 (7). DOI:10.1007/s10661-019-7577-y [Out of scope - treated water].

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8.3.4. Studies assessed for eligibility (320 studies)

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McQuaig, Shannon; Sinigalliano, Christopher D.; Gidley, Maribeth L.; Wanless, David; Plano, Lisa R. W.; Garza, Anna C.; Zhu, Xiaofang; Stewart, Jill R.; Dickerson, Jerold W.; Yampara-Iquise, Helen; Carson, Charles; Fleisher, Jay M.; Fleming, Lora E. (2011). Daily measures of microbes and human health at a non-point source marine beach. Journal of Water and Health 9 (3)443-457. DOI:10.2166/wh.2011.146 [Include - short list].

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Appendix 1 - Definitions of Uses and Users of Recreational Water

Recreational water:

Included: Any natural or artificial water bodies without a chemical disinfectant residual that might be used for recreating including coastal, estuarine and freshwater environments. Includes public, private, commercial and non-commercial recreational water sites. Includes unique unregulated sites such as wave pools, ocean- or river-fed swimming pools, artificial lagoons and water ski parks.

Excluded: Aquatic facilities using chemical disinfection including swimming pools, spas, splash parks, ornamental water sites.

Recreational water use:

Included: Any designated or undesignated activity relating to sport, pleasure and relaxation that involves whole body contact or incidental exposure (through any exposure route) to recreational water (e.g. swimming, diving, boating, fishing)

Excluded: Consuming the catch from fishing or foodstuffs collected from recreational water or its surroundings. Therapeutic uses of waters (e.g. hydrotherapy pools). Occupational exposure.

Recreational water users:

Recreators or users of recreational water bodies including:

- the general public including all relevant life stages, ages and states of health other than persons that are explicitly advised to avoid such activities (e.g. for specific medical conditions)
- tourists
- specialist sporting users (e.g. athletes, anglers, kayakers, divers, surfers)
- any groups that may have high exposures to recreational water.

Target audience of the Guidelines:

The Guidelines are intended for end users that will implement the Guidelines (government agencies, local councils, private recreational water managers); however, it is anticipated that there will also be significant public interest. It is anticipated that tailored guidance (e.g. plain English fact sheets or summaries) will be developed for specific groups where necessary.

Appendix 2 – Keywords (search terms)

The initial list of keywords (sorted alphabetically) approved by the Committee is set out below. The keywords were used to search for publications based upon the PECO elements and research questions – these were used across all databases for consistency.

For the review, keywords were sorted into categories, search strings and search strategies for search the selected databases (see Section 2.4)

Key search terms

16s microbial community fingerprinting, aboriginal, Accidental Faecal Discharge, Acinetobacter, adenovirus, adenoviruses, adverse effects, *Aeromonas*, aerosols, allergic reaction/s, Amoebiasis, analysis, anglers, angling, antibiotic resistant bacteria, antimicrobal resistance, *Arcobacter*, *Ascaris,* Astrovirus, athletes, bacteria, bacteriodales, bacteriophages, bacteroides, *Balantidium*, bather acquired , bather shedding, bathing, bathing beaches, beach/es, *Blastocystis*, boating, body-boarding, body-surfing, Caliciviruses, *Campylobacter*, canoeing, case control study, cattle, children, Cholera biotypes, classification, *Clonorchis sinensis*, *Clostridium perfringens*, coast, coastal, cohort study, control, cross-sectional study, Cross-sectional study (mix of case-control and cohort), *Cryptosporidium*, *Cyclospora cayetanensis, Cystoisospora (Isospora) belli,* DALY, dam, dermal irritation, dermatologic, diagnostic test study, diarrhea, diarrhoea, Diphyllobothriidae, direct pathogen monitoring, disability adjusted life year, disease, divers, diving, domestic animals, dose-response, *E. coli* diarrhoeagenic, *E. coli* enteropathic, *E. coli* enterotoxigenic, *E. coli* O157:H7, *E. coli*, *Echinococcus*, Echinostomatidae, echovirus, elderly, *Entamoeba histolytica*, Enteric Fevers, enterococci, enterococcus, enteroviruses, epidemiology, *Escherichia coli*, estuaries, exposure, eye irritation, Faecal Discharge, faecal indicators, fecal indicators, fever, FIB, fishing, fishing canoe, fishing kayak, fishing riverbank, fishing shoreline, fishing wading, flu-like, freshwaters, gastroenteritis, gastrointestinal, gastrointestinal illness, *Giardia*, hay fever-like, headache, health, health effects, health outcome/s, *Helicobacter pylori*, Hepatitis A, Hepatitis E, hepatotoxicity, Heterophyidae, Hookworms, illness/es, immunocompromised, indicator, indigenous, induction of asthma, ingestion, inhalation, inhalation-related symptoms, Intestinal Flukes, jet skiing, jet-skiing, jurisdiction, kayakers, kayaking, kiteboarding, kitesurfing, lake, legislation, *Leptospira*, Leptospirosis, Liver Flukes, livestock, marine, *Metorchis*, microbial, microbial source tracking, microbiological, Microsporidia, *Moraxella*, nausea, neurologic/al, neurotoxicity, non-microbial indicators, non-point source pollution, norovirus, Norwalk virus, *Opisthorchis*, oral, outbreaks, outfall, paddling, Papillomavirus, *Paragonimus*, parasailing, pathogen, pentathlon, pneumonia-like symptoms, point source pollution, Polioviruses, Polyomavirus, pregnant women, prevention, primary contact recreation, protozoa, pruritis, *Pseudomonas aeruginosa*, QMRA, qualitative research, quantitative microbial risk assessment, randomised controlled trial, recreation/al, recreational exposure, recreational guidelines, recreational water quality, risk, river, rotavirus, rowing, sail boarding, sailing, saline waters, *Salmonella*, Salmonellosis, sand, Sapovirus, *Schistosoma*, scuba, sea kayaking, seagulls, secondary contact recreation, sewage, *Shigella*, Shigellosis, shortness of breath, skin irritation, skin rash/es, snorkelling, source tracking, source

vulnerability, spearfishing, standards, *Stenotrophomonas*, stormwater, sunbathing (no contact), surfers, surfing, swimmer acquired, swimming, symptoms, systematic review, *Taenia*, Torres Strait Islander, tourists, *Toxocara*, *Toxoplasma gondii*, triathlon, *Trichuris trichiura*, *Vibrio*, viruses, vomiting, wading, wakeboarding, water contamination, water parks, water pollution, water quality, water skiing, water sports, waterborne diseases, waterfowl, wave-boarding, whitewater canoeing, wildlife, wind surfing, wind-surfing, *Yersinia*, zoonotic.

The opportunistic taxa *Naegleria fowleri* and *Burkholderia* were excluded from the above list since they are the focus of a separate narrative review. Other opportunistic waterborne pathogens were listed based mainly on their citation in the Global Water Pathogens Project (GWPP, 2020).

Appendix 3 – Existing recreational water quality guidelines/reports supplied by members of the Committee

Institution	Existing recreational water guidelines /reports suggested by members of the Committee	Review result
NHMRC	Recreational guidelines 2008.	Included in literature evaluation
MoE (NZ)	MoE 2003. New Zealand guidelines 2003. https://www.mfe.govt.nz/publications/fresh-water/microbiological-water-quality-guidelines-marine-and-freshwater-0	Excluded in screening phase
	MoE 2018. Regional information for setting draft targets for swimmable lakes and rivers A report on work underway to improve water quality in terms of effects on human health. https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/Regional%20information%20for%20setting%20draft%20targets%20for%20swimmable%20lakes%20and%20rivers-final.pdf	Excluded in screening phase
OEH NSW 2011	OEH NSW, 2011. Protocol for assessment and management of microbial risks in recreational waters. Office of Environment & Heritage, NSW, Sydney.	Excluded in screening phase
EPA Victoria	Pending publication related to QMRA study in Port Phillip Bay, Victoria.	2021 version of report included in literature evaluation
US EPA	U.S. EPA 2005. The EMPACT Beaches Project: results from a study on microbiological monitoring in recreational waters. National Exposure Research Laboratory, Office of Research and Development, United States Environmental Protection Agency, Cincinnati, Ohio. USEPA 2012. Recreational Water Quality Criteria. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 820-F-12-058 Available at: https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf U.S. EPA 2010. Quantitative Microbial Risk Assessment to Estimate Illness in Fresh water Impacted by Agricultural Animal Sources of Fecal Contamination. EPA 822-R-10-005. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/P4-QMRA508.pdf US EPA, 2010. Comparison and Evaluation of Epidemiological Study Designs of Health Effects Associated with Recreational Water Use. US EPA, 2014. Microbial Risk Assessment (MRA) Tools, Methods and Approaches for Water Media. US EPA Office of Water, Washington DC. US EPA, 2016. 2016 Coliphage Experts Workshop: Discussion Topics and Findings No. EPA 823-F-16-001. Washington D.C.	Excluded in screening phase
State of Hawaii	State of Hawaii Water Quality Standards, 2014. Available at: https://health.hawaii.gov/cwb/files/2013/04/Clean_Water_Branch_HAR_11-54_20141115.pdf Beach report available at: http://www.beachapedia.org/State_of_the_Beach/State_Reports/HI/Water_Quality#Identifying_Sources_of_Contamination_in_Nawiliwili_Bay_and_Hanalei_Bay	Excluded in screening phase
WHO	WHO, 2003. Guidelines for Safe Recreational-water Environments, Coastal and Fresh-waters, vol. 1. World Health Organization, Geneva. WHO, 2016. Quantitative Microbial Risk Assessment: Application for Water Safety Management. World Health Organization, Geneva https://www.who.int/water_sanitation_health/publications/srwe1/en/	Excluded in screening phase
enHealth, 2012.	Environmental health risk assessment: - Guidelines for assessing human health risks from environmental hazards. Commonwealth of Australia	Excluded in screening phase
NRMMC 2006	Australian Guidelines for water recycling: Managing health and environmental risks (Phase 1). Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Minister's Conference, Canberra, Australia.	Excluded in screening phase
Health Canada 2012	Health Canada 2012. Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.	Excluded in screening phase

Appendix 4 - CASP (Critical Appraisal Skills Program) Combined query table

Q.	Choose appropriate query category for paper: Systematic review	Qualitative research	Case control study	Cohort study	Diagnostic test Study	Randomised Controlled Trial	Cross-sectional study (mix of case-control and cohort)*	Quantitative research*	Paper for appraisal and reference: *insert name of paper here*			
Section A1: Are the results of the trial valid?									**Yes**	**Can't Tell**	**No**	**Comments**
1	*Did the review address a clearly focused question?*	*Was there a clear statement of the aims of the research?*	*Did the study address a clearly focused issue?*	*Did the study address a clearly focused issue?*	*Was there a clear questionfor the study to address?*	*Did the study address a clearly focused issue?*	*Did the study address a clearly focused issue?*	*Did the study address a clearly focused issue?*				
2	*Did the authors look for the right type of papers?*	*Is a qualitative methodology appropriate?*	*Did the authors use an appropriate method to answer their question?*	*Was the cohort recruited in an acceptable way?*	*Was there a comparison with an appropriate reference standard?*	*Was the assignment of patients to treatments randomised?*	*Was the cohort recruited in an acceptable way?*	*Is a quantitative methodology appropriate?*				
3						*Were all of the patients who entered the trial properly accounted for at its conclusion?*						
Section A2: Is it worth continuing?									**Yes**	**Can't Tell**	**No**	**Comments**
3	*Do you think all the important, relevant studies were included?*	*Was the research design appropriate to address the aims of the research?*	*Were the cases recruited in an acceptable way?*	*Was the exposure accurately measured to minimise bias?*	*Did all patients get the diagnostic test and reference standard?*		*Was the exposure accurately measured to minimise bias?*	*Was the research design appropriate to address the aims of the research?*				
4	*Did the review's authors do enough to assess quality of the included studies?*	*Was the recruitment strategy appropriate to the aims of the research?*	*Were the controls selected in an acceptable way?*	*Was the outcome accurately measured to minimise bias?*	*Could the results of the test have been influenced by the results of the reference standard?*	*Were patients, health workers and study personnel 'blind' to treatment?*	*Were the controls selected in an acceptable way?*	*Was the recruitment strategy appropriate to the aims of the research?*				
5	*If the results of the review have been combined, was it reasonable to do so?*	*Was the data collected in a way that addressed the research issue?*	*Was the exposure accurately measured to minimise bias?*	*(a) Have the authors identified all important confounding factors?*	*Is the disease status of the tested population clearly described?*	*Were the groups similar at the start of the trial*	*Was the exposure accurately measured to minimise bias?*	*Was the data collected in a way that addressed the research issue?*				
5				*(b) Have they taken account of the confounding factors in the design and/or analysis?*								
6		*Has the relationship between researcher and participants been adequately considered?*	*(a) Aside from the experimental intervention, were the groups treated equally?*	*(a) Was the follow up of subjects complete enough?*	*Were the methods for performing the test described in sufficient detail?*	*Aside from the experimental intervention, were the groups treated equally?*		*Were objective outcomes predetermined?*				
6			*(b) Have the authors taken account of the potential confounding factors in the design and/or in their analysis?*	*(b) Was the follow up of subjects long enough?*			*Have the authors taken account of the potential confounding factors in the design and/or in their analysis?*					

Q.	Choose appropriate query category for paper: Systematic review	Qualitative research	Case control study	Cohort study	Diagnostic test Study	Randomised Controlled Trial	Cross-sectional study (mix of case-control and cohort)*	Quantitative research*	Paper for appraisal and reference: *insert name of paper here*			
Section B: What are the results?									**Yes**	**Can't Tell**	**No**	**Comments**
6	*What are the overall results of the review?*											
7	*How precise are the results?*	*Have ethical issues been taken into consideration?*	*How large was the treatment effect?*	*What are the results of this study?*	*What are the results?*	*How large was the treatment effect?*	*What are the results of this study?*	*What are the results of this study?*				
8		*Was the data analysis sufficiently rigorous?*	*How precise was the estimate of the treatment effect?*	*How precise are the results?*	*How sure are we about the results? Consequences and cost of alternatives performed?*	*How precise was the estimate of the treatment effect?*	*How precise are the results?*	*How precise are the results?*				
9		*Is there a clear statement of findings?*	*Do you believe the results?*	*Do you believe the results?*			*Do you believe the results?*					
Section C: Will the results help locally?									**Yes**	**Can't Tell**	**No**	**Comments**
8	*Can the results be applied to the local population?*											
9	*Were all important outcomes considered?*				*Can the results be applied to your patients/the population of interest?*	*Can the results be applied to the local population, or in your context?*	*Can the results be applied to the local population, or in your context?*					
10	*Are the benefits worth the harms and costs?*	*How valuable is the research?*	*Can the results be applied to the local population?*	*Can the results be applied to the local population?*	*Can the test be applied to your patient or population of interest?*	*Were all clinically important outcomes considered?*	*Were all clinically important outcomes considered?*	*Can the results be applied to the local population?*				
11			*Do the results of this study fit with other available evidence?*	*Do the results of this study fit with other available evidence?*	*Were all outcomes important to the individual or population considered?*	*Are the benefits worth the harms and costs?*	*Do the results of this study fit with other available evidence?*	*Do the results of this study fit with other available evidence?*				
12				*What are the implications of this study for practice?*	*What would be the impact of using this test on your patients/population?*							
	Overall risk of bias rating											
-	Reviewer's conclusion (exclude or include based on risk of bias assessment)											

Source: Oxford CTVH (2020), * Questions derived by reviewer for this narrative review based on the CASP approach.

Hints for queries

Compiled from CASP - Critical Appraisal Skills Programme (Oxford CTVH 2020).

Q.	Paper for appraisal and reference:	Hints
Section A1: Are the results valid?		
1	Was there a clear statement of the aims of the research?	Consider •what was the goal of the research •why it was thought important •its relevance
2	Is the methodology appropriate?	Consider •If the research seeks to interpret or illuminate the actions and/or subjective experiences of research participants •Is qualitative research the right methodology for addressing the research goal
Section A2: Is it worth continuing?		
3	Was the research design appropriate to address the aims of the research?	Consider • if the researcher has justified the research design (e.g. have they discussed how they decided which method to use) • Has a validated risk assessment framework been used? Note framework used and describe any concerns.
4	Was the chosen hypothetical population or subpopulation appropriate for addressing the study research aims?	Consider • If the researcher has explained how the participants were selected • If they explained why the participants selected were the most appropriate to provide access to the type of knowledge sought by the study • If there are any discussions around recruitment (e.g. why some people chose not to take part)
5	Was the data collected in a way that addressed the research issue?	Consider • If the setting for the data collection was justified • If it is clear how data were collected (e.g. focus group, semi-structured interview etc.) • If the researcher has justified the methods chosen • If the researcher has made the methods explicit (e.g. for interview method, is there an indication of how interviews are conducted, or did they use a topic guide) • If methods were modified during the study. If so, has the researcher explained how and why • If the form of data is clear (e.g. tape recordings, video material, notes etc.) • If the researcher has discussed saturation of data
6	Has the relationship between researcher and participants been adequately considered?	Consider • If the researcher critically examined their own role, potential bias and influence during (a) formulation of the research questions (b) data collection, including sample recruitment and choice of location • How the researcher responded to events during the study and whether they considered the implications of any changes in the research design

Q.	Paper for appraisal and reference:	Hints
Section B : What are the results?		
7	Have ethical issues been taken into consideration?	Consider • If there are sufficient details of how the research was explained to participants for the reader to assess whether ethical standards were maintained • If the researcher has discussed issues raised by the study (e.g. issues around informed consent or confidentiality or how they have handled the effects of the study on the participants during and after the study) • If approval has been sought from the ethics committee
8	Was the data analysis sufficiently rigorous?	Consider • If there is an in-depth description of the analysis process • If thematic analysis is used. If so, is it clear how the categories/themes were derived from the data • Whether the researcher explains how the data presented were selected from the original sample to demonstrate the analysis process • If sufficient data are presented to support the findings • To what extent contradictory data are taken into account • Whether the researcher critically examined their own role, potential bias and influence during analysis and selection of data for presentation • Are there any concerns about the characterisation of: o Hazards o Exposure o Risk Consider any factors that form part of the assessment (modelling, dose response, mode of action etc.) and whether these were applied/considered effectively and according to industry standards.
9	Is there a clear statement of findings?	Consider whether • If the findings are explicit • If there is adequate discussion of the evidence both for and against the researcher's arguments • If the researcher has discussed the credibility of their findings (e.g. triangulation, respondent validation, more than one analyst) • If the findings are discussed in relation to the original research question
Section C: Will the results help locally?		
10	How valuable is the research?	Consider • If the researcher discusses the contribution the study makes to existing knowledge or understanding (e.g. do they consider the findings in relation to current practice or policy, or relevant research-based literature • If they identify new areas where research is necessary • If the researchers have discussed whether or how the findings can be transferred to other populations or considered other ways the research may be used
Overall risk of bias rating		• Consider how reliable the findings of the study are using your assessment above and make a judgement on the overall quality of the study based on risk of bias and uncertainties (as below). Provide justification.

Appendix 5 - Declaration of interests

The Authors of this Review have the following declared interests:

Interest Details	Summary
Dr Nick O'Connor	
Consultant in science and engineering to the Australian water industry. Recent major clients are listed below.	As principal consultant at Ecos Environmental Consulting, I am involved in many consulting projects for clients in the public and private sectors. However, the majority of my clients are regional and metropolitan water corporations for whom I provide consultancy advice in the areas of water-related human health and ecological risk assessment.
Consultant to Melbourne Water	I provide consultancy advice in the areas of water-related human health and ecological risk assessment.
Consultant to VicWater (Victorian Water Industry Association)	I provide consultancy advice about chemicals of concern in recycled water.
Member of Scientific Services Consultancy Panel for South East Water	I provide consultancy advice in the areas of water-related human health and ecological risk assessment.
Consultant to Victorian Department of Environment, Land, Water and Planning, Victorian Department of Health and Human Services and Victorian Environment Protection Authority.	I recently undertook a project in conjunction with Atura P/L and Water Futures P/L to develop the 2020 version of the Victorian Recycled Water Guidelines.
Dr Yufei Wang	
Researcher in chemical and environmental engineering, with a focus on industry-based water research. Recent projects summarised below:	As a researcher at Royal Melbourne Institute of Technology University, I am involved in several water research projects, performing analysis and providing consultancy advice to our industrial partners.
Photolysis of emerging contaminants, R&D project for Melbourne Water	I perform research activities and report findings assessing the environmental impact on the attenuation of chemicals of concern and provide consultancy advice on their associated risks in recycled water.
Validation framework review and drinking water supply system performance assessment, R&D project for Water Source Australia	I provide consultancy advice about assessment of disinfection performance of a Point of Entry drinking water supply system.
Publication of journal articles	I report findings of my research on behaviour and risk assessment of chemicals of concern in recycled water
Ms Tracy Clark	
Consultant in science and engineering to the Australian water industry. Recent major clients are listed below.	As consultant at Ecos Environmental Consulting, I am involved in many consulting projects for clients in the public and private sectors. My role requires that I support the Principal Consultant at Ecos in undertaking projects. The majority of Ecos's clients are regional and metropolitan water corporations for whom we provide consultancy advice in the areas of water-related human health and ecological risk assessment.
Consultant to Melbourne Water	I support the Principal Consultant at Ecos in providing consultancy advice in the areas of water-related human health (microbiological) and ecological risk assessment.
Consultant to VicWater (Victorian Water Industry Association)	I support the Principal Consultant at Ecos in providing consultancy advice about chemicals of concern in recycled water.