Evidence Evaluation Report for Narrative Review in support of the NHMRC Recreational Water Quality Guidelines: Chemical Hazards

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Executive Summary

Background

The National Health and Medical Research Council (NHMRC) commissioned Ecos Environmental Consulting Pty Ltd (Ecos) to conduct this Evidence Evaluation Report as part of a narrative review on chemical hazards in recreational waters that will be used to update the *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) (the Guidelines).

Chemical hazards 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. It is generally considered that exposures to chemical hazards in recreational waters will be low and usually within safe levels (i.e. below guideline levels). However, for the update to the Guidelines, NHMRC considers it important to determine the current status of the evidence for any potential human health risks resulting from exposure to chemical hazards in recreational water. This includes reviewing any site-specific issues that could lead to higher exposures or types of chemical substances that may be problematic in most recreational water use situations The review will provide NHMRC with an independent body of evidence to ensure that the revision of the Guidelines is based on the most up-to-date and relevant scientific literature.

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 three secondary research questions supplied by NHMRC's Recreational Water Quality Advisory Committee (the Committee). The primary research question was:

> *Are exposures to the following hazards: per- and polyfluoroalkyl substances (PFAS), pesticides, nanomaterials, hydrocarbons, metals, endocrine-disrupting chemicals (EDCs), surfactants, or combinations thereof, likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*

The secondary questions were:

1. *What chemicals (that potentially pose a risk to humans) are present at elevated concentrations in recreational waters and what are their sources?*
2. *What chemicals are of most concern due to their physicochemical properties which may enhance their uptake via dermal, inhalation or ingestion exposure pathways? How can we adjust exposure assumptions for these chemicals?*

3. *Should the focus be on "hot spots" i.e. site-specific rather than chemical specific, and/or include periodic toxicity screening of sites to complement chemical testing?*

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) existing guidelines that were mainly regulatory guidelines or technical guidance publications produced by federal and state agencies in support of regulatory compliance goals. Such literature is also commonly included in the classification "grey literature".

The publication date-range for inclusion was from 1 January 2003 to 30 October 30 2020.

The methodological quality of guidelines 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 for 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 Programme (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). For existing guidelines, the assessment methodology for the body of evidence drew on the GRADE approach as well as the outcomes of relevance to the primary and secondary research questions.

Results

Searches for grey literature identified 40 documents. Each document was evaluated for its relevance to the primary and secondary research questions and excluded if not relevant. This process identified 11 guideline documents relevant to the primary and secondary research questions. Following quality assessments, four documents were considered ineligible on quality grounds, leaving seven guidelines for evaluation and synthesis.

For primary studies, search results by database yielded 3523 citations initially. After removal of duplicates the number was 1769. Further screening for relevancy identified six studies. These were assessed for eligibility (quality, including risk of bias), which resulted in three studies remaining for evaluation and synthesis.

Conclusions

Primary research question

The body of evidence assembled was inadequate to answer the primary research question. It did not provide any significant quantitative or qualitative information on the relationship between concentrations of the listed chemical hazards in recreational waters and human health risks. The minor exceptions were single studies on heavy metals and polycyclic aromatic hydrocarbons (PAHs) at a tiny number of locations globally.

The GRADE quality assessment for the primary studies literature was “Low” and this led to a final certainty rating of “limited confidence in the reported associations”. This was mainly due to the small quantity of relevant studies of satisfactory quality that were identified. None of the factors that could influence a change in the grading of the certainty of the body of evidence were identified

The evidence base from the guidelines was also limited as they generally only addressed broad chemical classes and did not clearly identify the source of information upon which their conclusions were drawn. The exception was the NHMRC *Guidance on Per- and Polyfluoroalkyl Substances (PFAS) in Recreational Water* (NHMRC, 2019), which cited two recent Australian studies.

Secondary research questions

Evidence for the secondary research questions was limited to existing guidelines or reviews as outlined in the research protocol, with different suites of guidelines relevant depending on the research question.

In relation to secondary research question 1, from the review of guidelines, it was concluded that there was a lack of specificity about which chemicals harmful to human health might be present at elevated concentrations in recreational waters and their sources.

For secondary research question 2, there was limited discussion in the guideline literature on physicochemical properties of chemical hazards that may enhance uptake. It is likely that better information can be obtained in the broader literature on chemical environmental fate beyond the recreational water use context of the current review. In addition to the above comments, there was also no information in the guideline literature on methods for adjusting exposure assumptions for problematic chemicals.

In relation to secondary research question 3, the guideline literature contained no information to support a focus on “hot spots” or site-specific over chemical-specific assessment apart from some indirect commentary in some of the reviewed documents.

Summary of conclusions

An evaluation of evidence contained in four guidelines and three qualitative research primary studies indicated that the available evidence was inadequate to determine if exposure to listed chemical hazards (PFAS, pesticides, nanomaterials, hydrocarbons, heavy metals, EDCs, surfactants, or combinations) could give rise to any significant human health risks in recreational waters, given that such exposures are generally low.

An evaluation of the evidence contained in seven guidelines indicated that the evidence in the available guideline literature lacked sufficient detail to determine which chemicals harmful to human health might be present at elevated concentrations in recreational waters and their sources. Similarly, evidence for the physicochemical properties of chemical hazards that may enhance uptake via dermal, inhalation or ingestion exposure pathways was generally limited. Furthermore, there was no information in the guideline literature on methods for adjusting exposure assumptions for problematic chemicals.

Table of Contents

Table of Tables

Table of Figures

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
BMDL	Benchmark dose level
BTEX	Benzene, toluene, ethylbenzene and xylene
CASP	Critical Appraisal Skills Programme
CR	Carcinogenic risk
DBP	Disinfection by-product
EDC	Endocrine-disrupting chemical
EPA	Environmental Protection Agency
EPHC	Environment Protection and Heritage Council
GRADE	Grading of Recommendations Assessment, Development and Evaluation
HBT	Health-based target
HEPA	Heads of Environmental Protection Agency Australia and New Zealand
HQ/HI	Hazard quotient / hazard index
MoE	Margin of Exposure
MW	Molecular weight
NDMA	N-Nitrosodimethylamine
NHMRC	National Health and Medical Research Council
NRMMC	National Resource Management Ministerial Council
OECD	Organisation for Economic Co-operation and Development
OHAT	Office of Health Assessment and Translation
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PDTA	Propylenedinitrilotetraacetic acid
PECO	Population, Exposure, Comparator, Outcome
PFHxS	Perfluorohexane sulfonate
PFAS	Per- and poly-fluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QSAR	Quantitative Structure Activity Relationship
RoB	Risk of bias

RWQAC	Recreational Water Quality Advisory Committee (the Committee)
STP	Sewage treatment plant
TE	Trace element
TEF	Toxicity equivalence factors
US EPA	United States Environmental Protection Agency
VOC/SVOC	Volatile/semi-volatile organic compound
WHO	World Health Organization

1 Introduction

The National Health and Medical Research Council (NHMRC) commissioned Ecos Environmental Consulting Pty Ltd (Ecos) to 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 Chemical Hazards.

Chemical hazards 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. It is generally considered that exposures to chemical hazards in recreational waters will be low and usually within safe levels. There may, however, be site-specific issues that could lead to higher exposures or types of chemical substances that may be problematic in recreational water use situations. For the update to the Guidelines, NHMRC considers it important to determine the current status of the evidence for any potential human health risks resulting from exposure to chemical hazards in recreational water, including any site-specific issues. 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.

Ecos developed a research protocol to guide the review of the evidence (O'Connor, 2020). The research protocol sets 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 Evidence Evaluation Report summarises the methodology used to find and select the studies and the findings of the literature search and evaluation process. It synthesises the results of key studies identified in the evaluation process into evidence statements and assesses this body of evidence taking into account its strengths or limitations.

A draft of this Evidence Evaluation Report was considered by the NHMRC Recreational Water Quality Advisory Committee (the Committee) who provided advice on its revision.

1.1. Purpose and objectives of review

The purpose of the Chemical Hazards review is to inform the update to information provided in Chapter 9 of the 2008 NHMRC Guidelines and any relevant sections throughout the rest of the document with respect to the chemical hazards associated with the recreational use of water. This review, undertaken using a systematic approach, aims to 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 Methodology

2.1. Review Period

Publications published between 1 January 2003 and 30 October 2020 were considered for the review. Although the current 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, 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 Evidence Evaluation Report, “Chemical Hazards” refers to risks associated with the contamination of recreational waters by chemical substances including organic compounds (e.g. PFAS, pesticides, hydrocarbons, surfactants), metals, nanoparticles and EDCs. For the purposes of this review, this does not include endotoxins. Endotoxins such as cyanotoxins and algal toxins are considered in another review commissioned by NHMRC.

Definitions of types, uses and users of recreational water are given in Appendix 1 of the companion Technical Report to this study (O’Connor, 2022).

2.3. Research Questions

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

2.3.1. Primary question

The primary question is: *Are exposures to the hazards listed in Table 2-1 likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?* The hazards listed in Table 2-1 are also referred to as the PECO-listed hazards in the Technical Report due to their inclusion in the Population, Exposure, Comparator, Outcome (PECO) in Table 2-2 of that report.

Table 2-1. Chemical hazards to recreational water quality identified by the Committee and their potential sources.

Hazard	Sources
PFAS chemicals (not just regulated ones)	Military facilities, airports, fire stations and training grounds, sewage treatment plant (STP) effluent & sewer overflows, groundwater
Pesticides	Rural and urban runoff
Other nanomaterials e.g. zinc oxide nanoparticles in sunscreens	Industrial discharges, STP effluent, sunscreens
Hydrocarbons (especially benzene, toluene, ethylbenzene and xylene or BTEX chemicals) and volatiles	Stormwater, fuel spills
Heavy metals (especially methylated)	Industrial discharges, stormwater, mine discharges (incl. ‘legacy’ mines), groundwater

Hazard	Sources
Endocrine-disrupting chemicals	STP effluent and sewer overflows, animal production runoff
Surfactants, nonylphenols	STP discharges
Possible chemical interactions	Many. Synergistic interactions of most concern

2.3.2. Secondary questions

The secondary questions are:

1. *What chemicals (that potentially pose a risk to humans) are present at elevated concentrations in recreational waters and what are their sources?*
2. *What chemicals are of most concern due to their physicochemical properties which may enhance their uptake via dermal, inhalation or ingestion exposure pathways? How can we adjust exposure assumptions for these chemicals?*
3. *Should the focus be on "hot spots" i.e. site-specific rather than chemical specific, and/or include periodic toxicity screening of sites to complement chemical testing?*

To keep the workload manageable within the available resources the Committee agreed that the secondary research questions could be addressed through a review of existing guidance or reviews rather than though a review of primary studies (see Section 2.5.1 for definitions of these categories.)

2.3.3. Additional commentary and guidance from the Committee

The Committee listed the following topics in relation to chemical hazards in recreational water that may assist in developing responses to the above questions:

- Substances of interest to include:
  - Key contaminants of concern in recreational waters;
  - Metals and metalloids, halogenated organic compounds and PAHs, nutrients, water soluble trace organic contaminants, PFAS;
  - Other high-risk chemicals and chemical hazards such as sunscreens and nanoparticles;
- Risk assessment methods (including exposure assessment calculations and assumptions);
- Consideration of short, medium- and long-term exposures; and
- Consideration of the use of indicator substances for chemical risk assessment and monitoring.

As noted earlier, the primary and secondary research requestions were the focus of the review, however, in responding to those questions, it was understood that consideration of the additional commentary and guidance from the Committee and associated questions, as listed above, would be helpful.

2.4. Search Strategy and Selection of Evidence

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

- Preparation of a list of keywords (search terms) which was subsequently approved 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. This was based on a list provided by the Committee plus a search of websites of key international environmental and public health agencies e.g., World Health Organization (WHO), United States Environment Protection Agency (US EPA);
- Lists of citations were exported to Microsoft Excel spreadsheets and sorted and filtered based on relevancy and quality, including risk of bias;
- Shortlisted literature was imported from Excel into a bibliographic software package (Zotero) for management of associated full text 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

2.4.1. Inclusion and exclusion criteria

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

- Only studies in English language were included.
- Only studies with human health outcomes were included for health-related research questions.
- The publication date-range for inclusion was from 1 January 2003 to 30 October 2020.
- Only peer reviewed publications 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).
- Studies of biotoxins e.g. cyanotoxins, endotoxins were excluded as most of these are being dealt with via the related Cyanobacteria and Algae review being conducted for NHMRC.
- Studies investigating illnesses acquired from chemically treated recreational water (e.g. swimming pools, spas, hot tubs) were excluded as such facilities were beyond the guideline/review scope.
- Studies of health outcomes as a result of domestic exposure (e.g. drinking water or water used for washing) or occupational exposure to natural waters were excluded as they were beyond the guideline/review scope
- Relevancy – studies that were irrelevant to the research questions and guideline/review scope were excluded, e.g., studies on dental hygiene.

Apart from the exclusions listed above, all other study 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.

2.5. Evidence Collection

2.5.1. Classification of the evidence

To assist in the literature assessment, citation search results were classified into two broad categories:

(i) primary studies that were largely peer-reviewed journal articles, and;

(ii) existing guidelines that were mainly regulatory guidelines or technical guidance publications produced by federal and state agencies in support of regulatory compliance goals. Such literature is also commonly included in the classification "grey literature", which refers to literature produced by organisations other than conventional academic journal publishers.

2.5.1.1. Existing guidelines

The quality assessment criteria for existing guidelines (Section 2.5.2.1) were different from those for primary studies due to the different structure and purposes of each class of study. Grey literature guideline 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) or more general international guidance (e.g. WHO documents), whereas primary studies are mainly focused on the results of original research undertaken in response to narrowly focused study objectives. For the purposes of this evidence evaluation report and corresponding technical report, grey literature should not be confused with the term "systematic review" used in the primary studies classification below. Systematic reviews generally have a much narrower focus and are published in peer-reviewed journals. Guidelines 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.

2.5.1.2. Primary studies

The quality of each study to be included was assessed using an appraisal tool based on the CASP (Oxford CTVH, 2020)[1] quality assessment protocols for observational studies with an additional risk of bias rating similar to the OHAT Risk-of-Bias Tool (OHAT, 2015). To assist in the selection of appropriate CASP tools, the studies were categorised according to a selected list of CASP study type definitions based on the adopted research protocol (O'Connor, 2020). These study categories were used to guide a critical appraisal of study quality and selection for the review.

1. Systematic review

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

2. Qualitative research
3. Case control study
4. Cohort study
5. Diagnostic test study
6. Randomised controlled trial
7. Cross-sectional study (mix of case-control and cohort)
8. Quantitative research

See the Technical Report (O'Connor, 2022) for definitions.

2.5.2. Quality assessment (by types)

2.5.2.1. Existing guidelines

The methodological quality of existing guidelines was assessed using administrative and technical criteria via a draft assessment tool developed by NHMRC. The criteria listed in the tool 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). A form for capturing the data is described in the Technical Report (O'Connor, 2022). Based on the responses in the form, a decision was made on whether that guideline should be included or excluded from the review on quality grounds. Due to the paucity of material on chemical hazards in recreational waters the decision on inclusion/exclusion was weighted towards inclusion.

In addition to this formal quality assessment approach, the close inspection of the full text document in some cases indicated that the evidence contained in the document did not satisfactorily contribute to answering the primary and/or secondary research questions. Where that was the case, the document was classified as "Quality satisfactory but content not relevant (or obsolete)" and excluded on relevance.

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 selection 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 were posed within the three categories above that are designed to assist the reviewer to consider the issues systematically.

Primary data studies selected for review were assessed for internal validity, which is also known as "risk of bias", with bias classification according to the OHAT risk of bias assessment tool (OHAT, 2015). The tool 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 2-2).

Table 2-2. 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.

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 assessing the limited shortlisted studies remaining after the screening process. Consequently, the CASP critical appraisal tools were used to conduct quality assessments for qualitative research studies because they were simpler and more efficient to use 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 OHAT tool provided a colour-coded visual scheme to summarise the risk of bias assessments and was applied based on the response to the CASP question. The combination of the two critical appraisal tools allowed for a reasonable assessment of study quality within the resources available for the review.

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 to determine overall risk of bias across the body of evidence.

2.6. Data Extraction

Data were extracted from individual studies using standardised data extraction forms designed for each class of literature. Samples of the data extraction forms are presented in the Technical Report (O’Connor, 2022).

2.7. Process for Assessing the Body of Evidence

Overview

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 existing guidelines and primary studies different approaches were required to review and evaluate the body of evidence for each class of literature. The assessment methodology for each literature class is described in the following sections.

2.7.1. Assessment of the body of evidence – primary studies

A process described by Ryan and Hill (2016) based on the OHAT approach to using the GRADE system (developed by Guyatt, Oxman, et al., 2011) was used to assess the certainty of the body of evidence from primary studies. Evidence streams for each research question were tabulated together by outcome, where possible. The domains used to assess certainty in the GRADE framework were applied to the body of evidence, after which an overall certainty rating was then assigned to each evidence stream. The domains are:

- Overall risk of bias across studies;
- Unexplained inconsistency;
- Imprecision;
- Indirectness; and
- Publication bias.

Each evidence stream was assigned an initial certainty rating based on the form shown in Table 2-3, which is based on guidance from the OHAT Handbook (OHAT, 2019). For example, evidence from randomised controlled trials could initially be graded as high certainty and evidence from qualitative studies could be initially graded as low certainty.

Table 2-3. Summary of findings – body of evidence form (adapted from OHAT Handbook (OHAT 2019) and transposed to fit page).

Item	Classification	Description	Research question	Outcome 1.* Study Type **		Outcome 2. etc. Study Type	
				1	2	1	2
Body of evidence	*Evidence stream or study type*	*(# studies) initial certainty rating*	Research question: e.g. Are exposures to the hazards outlined in the PECO Table likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?				
Risk of bias	*Serious, not serious, unknown*	Describe trends, key questions, issues					
Unexplained inconsistency	*Serious, not serious, not applicable*	Describe results in terms of consistency, explain apparent inconsistency (if it can be explained)					
Indirectness	*Serious or not serious*	Discuss use of upstream indicators or populations with less relevance, any time-related exposure considerations (see OHAT Risk-of-Bias tool)					
Imprecision	*Serious, not serious, unknown*	Discuss ability to distinguish treatment from control, describe confidence intervals (if available)					
Publication bias	*Detected, undetected, unknown*	Discuss factors that might indicate publication bias (e.g., funding, lag)					
Magnitude of effect	*Large, not large, unknown*	Describe magnitude of response					
Dose Response	*Yes, no, unknown*	Outline evidence for or against dose response					
Residual confounding	*Yes, no, unknown*	Address whether there is evidence that confounding would bias toward null					
Consistency across species/model	*Yes, no, not applicable (NA)*	Describe cross-species, model, or population consistency					
Other reason to increase confidence?	*Yes or no*	Describe any other factors that increase confidence in the results					
Final certainty rating (GRADE assessment)	***High, moderate, low or very low***	List reasons for downgrading or upgrading					

*e.g PECO listed hazard measured in recreational waters, ** e.g. Qualitative studies, Systematic review etc.

2.7.1.1. Outcome definition and prioritisation

Definitions of outcomes and the outcome measures to be included in the review were developed based on:

(i) general guidance supplied by NHMRC and the Committee,
(ii) the research questions, and;
(iii) the nature of the available literature.

The outcomes to be included in this review are presented in Table 2-4.

Table 2-4. Outcomes from the review to be included in the evidence evaluation

Outcome	Definition of outcome	Examples of health impacts under this outcome	Outcome measures	Rationale for selecting this outcome
Primary research question: *Are exposures to the hazards outlined in the PECO Table likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*				
Presence of PECO listed hazard	PECO listed hazard measured in recreational waters.	Hazard measured above regional or national chronic exposure criteria for protection of human health. Health impact inferred due to criteria exceedance.	Concentration in recreational waters in relation to human health protection criteria (e.g. hazard quotient > 1).	Given that chemical concentrations in recreational waters are generally low, detection of acute health impacts is unlikely. Consequently, measurement of concentrations of hazards listed in the PECO table against chronic exposure health criteria are considered to be the most useful research finding in response to the primary research question.

2.7.1.2. GRADE assessment

Under the GRADE system, the overall quality of the evidence for an outcome was categorised as High, Moderate, Low or Very Low, reflecting the degree of confidence in the effect estimate (Table 2-5).

Table 2-5. GRADE ratings and their interpretation from Ryan and Hill (2016)

Symbol	Quality	Interpretation
⊕⊕⊕⊕	**High**	We are very confident that the true effect lies close to that of the estimate of the effect.
⊕⊕⊕O	**Moderate**	We are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
⊕⊕OO	**Low**	Our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
⊕OOO	**Very Low**	We have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

To assist in the development of the GRADE assessment, an evaluation summary matrix for each primary study was constructed (Table 2-6). The summary matrices assisted in developing a response to each of the GRADE assessment categories.

Table 2-6. Evaluation summary matrix of individual primary studies

Item	Description
Study, Design, Quality	Study ID, Type of study, Quality assessment
Population	Population studied (e.g. adult, children, etc.)
Exposures	Exposure pathway, identity of chemical hazards studied
Location type	Type of location
Outcome	Metrics constructed for evaluation
Analysis	Nature of the statistical analysis conducted on the data
Results	The value of field measurements or metrics used to evaluate the effect studied

Item	Description
Effect estimate	The magnitude of the measured values or metrics
Significance	The level of significance of any test of a statistical hypothesis (i.e. p-value)

2.7.1.3. Upgrading or downgrading certainty of evidence

The certainty of the evidence was downgraded or upgraded from the initial rating if any of the conditions in Figure 2-1 (elaborated in Table 2-7) were met. If none were met, the initial certainty rating was kept. These domains are explained in more detail in the OHAT Handbook (OHAT, 2019). Conflicts of interest and funding sources were also considered as a reason to downgrade if there were serious concerns that these had influenced the findings from the body of evidence.

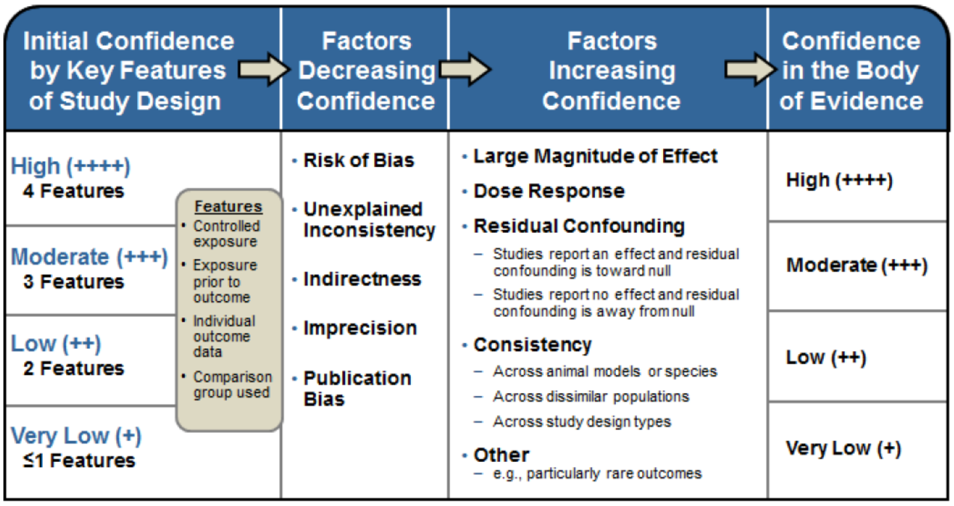

Figure 2-1. OHAT method for assessing confidence in the body of evidence (OHAT, 2019)

Table 2-7. OHAT reasons for down grading or upgrading certainty of evidence (OHAT, 2019)

Reasons to Downgrade	Reasons to Upgrade
• **Risk of bias** - Serious or very serious concerns about study quality across the body of evidence (reliability) (see Appendix 9 of Technical Report, O'Connor 2022) • **Unexplained inconsistency** - Important inconsistency of results across the included studies that can't be explained by study design • **Indirectness** - Some or major uncertainty about directness (relevance to the research question that is being answered) • **Imprecision** - Imprecise or sparse data • **Publication bias** - High probability of reporting bias (selective reporting of results across the body of evidence that might skew results)	• **Consistency** - Strong or very strong evidence of association based on consistent evidence from two or more observational studies, with no plausible confounders • **Magnitude of effect** - Very strong evidence of association based on direct evidence with no major threats to validity • **Dose-response** - Evidence of a dose-response gradient • **Residual confounding** - All plausible confounders would have reduced the effect • **Other reasons** – any topic-specific reasons as determined by experts in the field

The results of the certainty assessment process were tabulated in a similar manner to that described for the OHAT risk of bias assessment tool (OHAT, 2019). Where a conclusion was unable to be made by the reviewer around any of the domains this was recorded as ‘not applicable’ or ‘unknown’.

2.7.2. Assessment of the body of evidence – Existing guidelines

Existing guidelines or guidance documents have been largely developed with the goal of providing guidance for management of water quality for differing environmental requirements and contained no primary data but are usually informed by an evidence review. If the GRADE criteria (summarised in Table 2-3) were to be applied to the guideline literature, the results would be weak or null responses, and since no effect estimates are reported, no determination of a final certainty rating can be made. Nevertheless, the guideline documents do contain authoritative information that collectively represents the current state of knowledge and practice on chemical hazards from recreational water quality, and therefore is worthy of inclusion in this Evidence Evaluation Report.

Consequently, the assessment methodology for the body of evidence from existing guidelines drew on the GRADE approach as well as the outcomes of relevance to the primary and secondary research questions described in Table 2-3. The criteria for assessing the body of evidence for existing guidelines in Table 2-8 were largely derived from the guidance and commentary supplied by the Committee (Section 2.3.3) to assist in developing responses for the research questions.

Table 2-8. Criteria for assessing the body of evidence for existing guidelines

Item	Description (responses)
Existing guideline	Document identity
Contribution to primary research question outcome?	Does the document contain any information useful for responding to the primary research question? (Yes or No)
Contribution to secondary research questions outcomes?	Does the document contain any information useful for responding to the secondary research questions? (If Yes list which question, No)
Lists key contaminants of concern in recreational waters?	Does the document list any key contaminants of concern in recreational waters? (If Yes, list information, No)
Contains risk assessment methods?	Does the document contain risk assessment methods, including exposure assessment calculations and assumptions? (If Yes, list information, No).
Consideration of short, medium- and long-term exposures;	Does the document provide any information on short-, medium- or long-term exposures to chemical hazards in the context of recreational water use? (If Yes, list information, No)
Consideration of the use of indicator substances for chemical risk	Does the document discuss the use of indicator substances for the assessment of risk for chemical hazards in the context of recreational water use? (If Yes, list information, No)
Reviewer’s comments	Reviewer’s comments on key attributes of the document justifying its inclusion in the review.
Overall assessment	Reviewer’s concise assessment of the overall contribution made by the document in responding to the primary and secondary questions.

3 Literature search results

3.1. Existing guidelines

Searches for grey literature[2] identified 40 documents. Each document was evaluated for its relevance to the primary and secondary research questions and excluded if not relevant. This process identified 11 documents relevant to the primary and secondary research questions (i.e., addresses chemical hazards in recreational water), including four documents listed by the Committee. Each of the 11 shortlisted documents was subject to the quality assessment process described in 2.5.2.1, which resulted in a further four documents being screened out on eligibility grounds. Although the four documents were of satisfactory quality, the closer inspection afforded by the full text review led to the conclusion that the documents did not adequately address the primary or secondary research questions and thus were ineligible for inclusion in the final list of documents for review. The final list of seven guidelines meeting the eligibility criteria are shown in Table 5-1, Section 5.1. The screening process is summarised graphically in Figure 3-1.

3.2. Primary studies

Search results by database initially yielded 3523 citations. After removal of duplicates within each database (i.e. Scopus, Web of Science, PubMed) this number was reduced to 2486 citations. After combining the lists, further removal of citations that were duplicated between the databases brought the number of citations down to 1769. Initial duplicate filtering focussed on easy-to-detect exact matches whilst later filtering of harder-to-identify non-exact duplicate records was carried out iteratively during the screening process. After screening, six full text articles were assessed for eligibility (see Section 4.2) of which three were excluded on the basis of quality and relevance. A description of the stepwise screening process is summarised graphically in Figure 3-2.

[2] See Technical Report (O'Connor, 2022), Section 2, for method.

PRISMA Flow Diagram – Guidelines

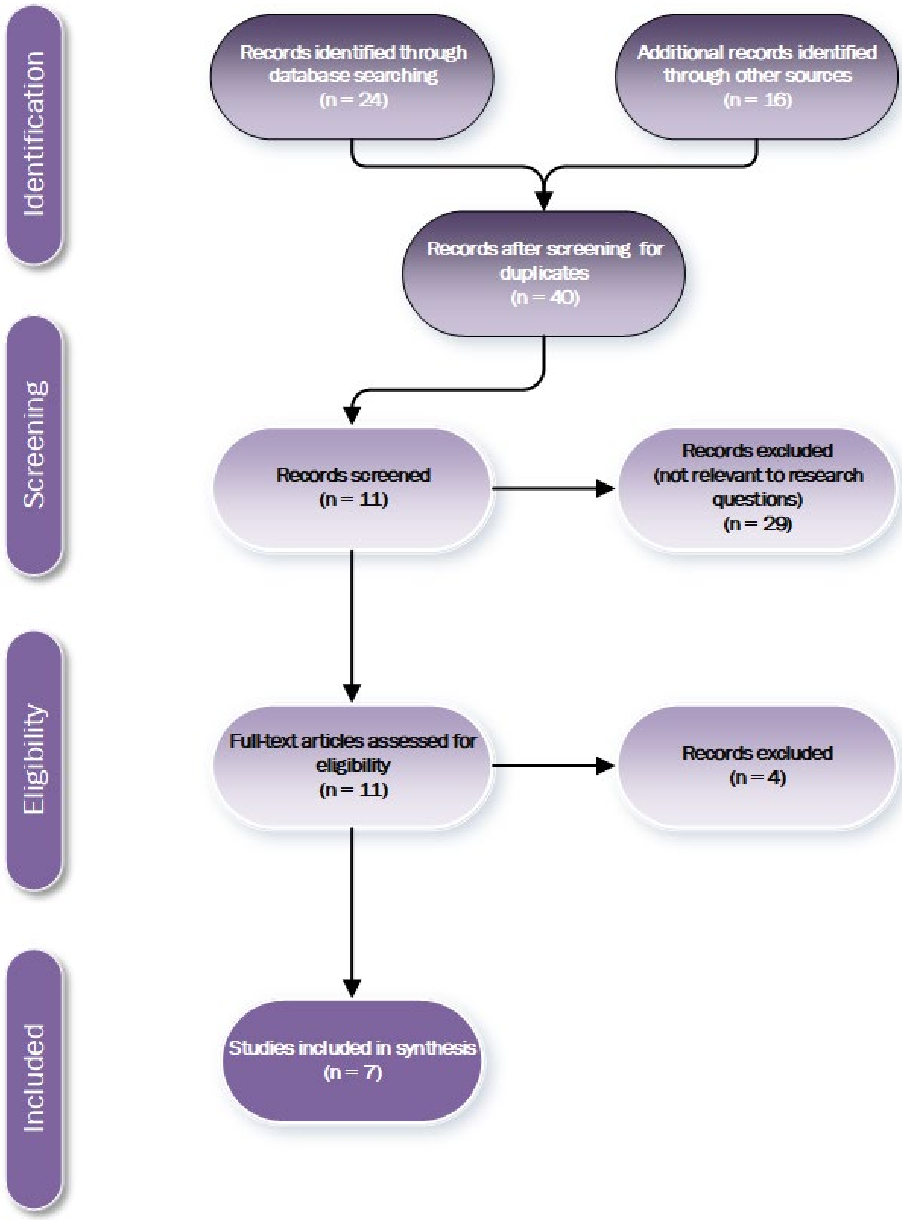

Figure 3-1. PRISMA summary of the citation review process for guidelines

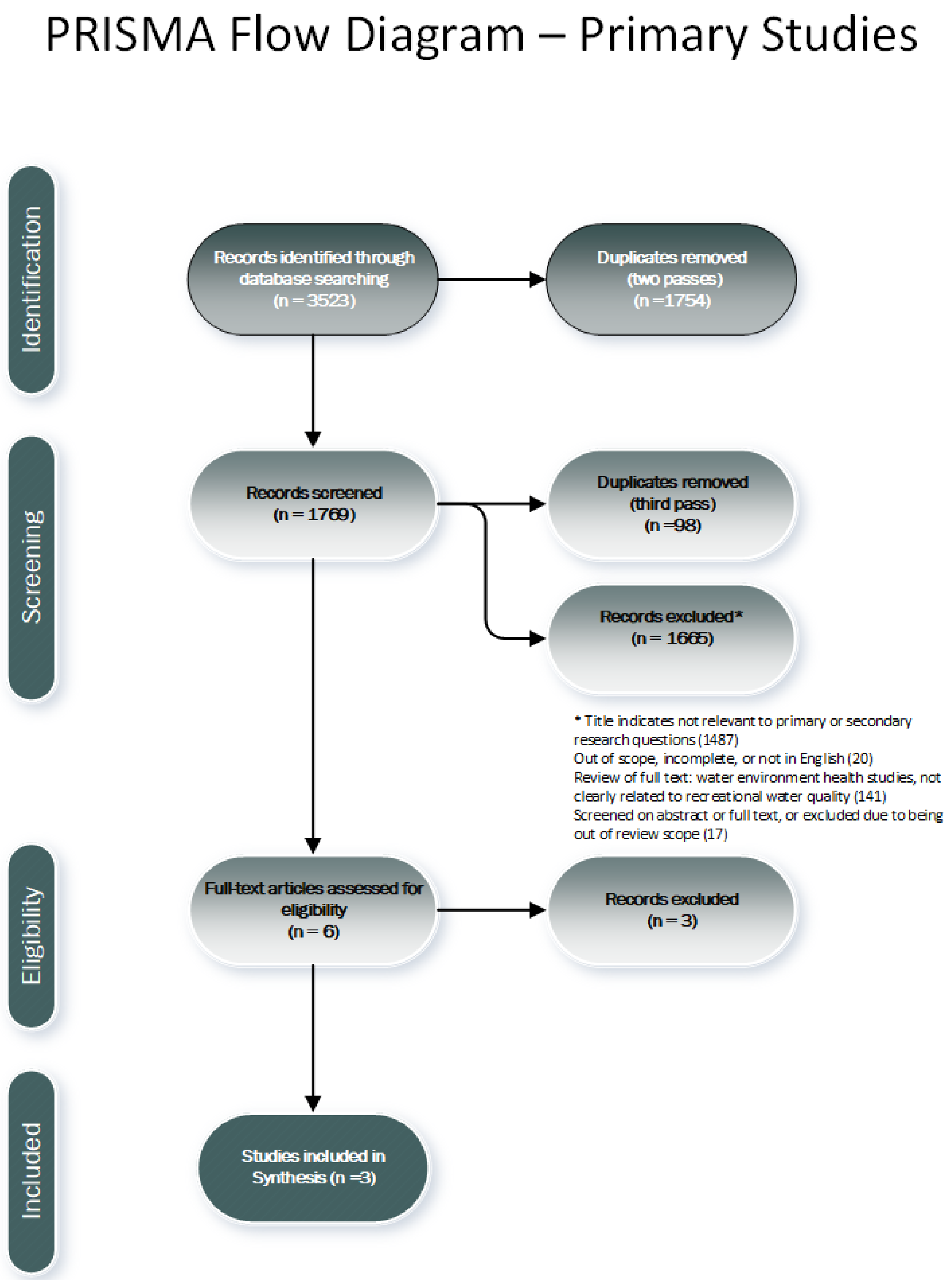

Figure 3-2. PRISMA summary of the citation review process for primary studies

Despite the large number of studies screened, there were few citations relevant to the primary and secondary research questions. This reflected a general paucity of published research on the risk to recreational water quality posed by chemical hazards. This is most likely due to the generally greater relative risks posed by microbiological pathogens in such environments.

4 Quality of evidence

4.1. Existing guidelines

4.1.1. Quality of included guidelines

Out of 11 guideline documents identified from the literature search or suggested by the Committee, seven were found to be relevant to answering the research questions and included in the final synthesis. They were also found suitable for potential adoption/adaption based on their administrative and technical processes (Table 4.1). Full details on the completed quality assessment forms for the seven guideline documents considered eligible for inclusion in the final synthesis can be found in Section 5 of the Technical Report.

When measured for compliance with the administrative and technical assessment criteria outlined in the assessment tool, the overall quality of the body of literature was limited with respect to methodological quality. This reflects the lack of appropriate methods and limited data available with respect to chemical hazards and recreational water quality. This lack of evidence was also apparent in the primary studies since such studies would normally inform the development of guideline literature. As noted earlier, due to the paucity of high-quality guideline documentation, it was necessary to weight the threshold for inclusion slightly more in favour of including documents than excluding such documents. This was to provide sufficient material for a synthesis of the available evidence, albeit a limited base of evidence. This approach was considered appropriate for the assessment of existing guidelines, since such documents represent the best available guidance at a national or international level, despite their apparent limitations.

Table 4-1. 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, n/a =Yes, No or Not Applicable. Individual assessments are available in the Technical Report (O'Connor 2022).

Administrative and Technical Criteria	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11
Overall guidance/advice development process											
Are the key stages of the organisation's advice development processes compatible with Australian processes?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Are the administrative processes documented and publicly available?	N	N	N	Partly	N	N	Y	N	N	Y	N
Was the work overseen by an expert advisory committee? Are potential conflicts of interest of committee members declared, managed and/or reported?	Y	Y	Can't tell	Y	Y	Y	Can't tell	Can't tell	Can't tell	Y	Y
	N	N	N	N	N	N	N	N	N	N	N
Are funding sources declared?	N	N	N	N	N	N	N	N	N	N	N
Was there public consultation on this work? If so, provide details.	Can't tell	Can't tell	Y	Y	Can't tell	Can't tell	Y	Can't tell	Can't tell	N	Can't tell
Is the advice peer reviewed? If so, is the peer review outcome documented and/or published?	Y	Can't tell	Can't tell	Y	Can't tell	Can't tell	Can't tell	Can't tell	Y	Y	Y
	N	N	N	N	N	N	N	N	N	N	N
Was the guidance/advice developed or updated recently? Provide details.	N	N	Y	N	N	N	N	Y	Y	N	Y
Evidence review parameters											
Are decisions about scope, definitions and evidence review parameters documented and publicly available?	N	N	N	N	N	N	N	Can't tell	N	N	Can't tell
Is there a preference for data from studies that follow agreed international protocols or meet appropriate industry standards?	N	N	N	N	N	N	N	Can't tell	N	N	Can't tell
Does the organisation use or undertake systematic literature review methods to identify and select data underpinning the advice? Are the methods used documented clearly?	N	N	N	N	N	N	Y	Can't tell	Y	Can't tell	Can't tell
If proprietary/confidential studies or data are considered by the agency, are these appropriately described/recorded?	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Can't tell	Can't tell
Are inclusion/exclusion criteria used to select or exclude certain studies from the review? If so, is justification provided?	N	N	N	N	N	n/a	Y	Can't tell	Y	Can't tell	Can't tell
Does the organisation use or adopt review findings or risk assessments from other organisations? What process was used to critically assess these external findings?	N	N	N	N	Y	Y	N	N	N	N	Can't tell
Can grey literature such as government reports and policy documents be included?	Y	Y	Y	Y	Y	Y	Y	Can't tell	Y	Y	Y
Is there documentation and justification on the selection of a toxicological endpoint for use as point of departure for health-based guideline derivation?	Y	N	N	N	N	Y	n/a	N	n/a	n/a	N
Evidence search											
Are databases and other sources of evidence specified?	N	N	N	N	N	n/a	Y	N	N	N	n/a
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	N	N	N	N	n/a	Y	n/a	Can/t tell	Can't tell	n/a
Is it specified what date range the literature search covers? Is there a justification?	N	N	N	N	N	N	Y	N	Y	N	N
Are search terms and/or search strings specified?	N	N	N	N	N	N	Y	N	Y	N	N
Are there any other exclusion criteria for literature (e.g. publication language, publication dates)? If so, what are they and are they appropriate?	N	N	N	N	N	N	N	Can't tell	N	N	N

Administrative and Technical Criteria	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11
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?	N	N	N	N	N	N	N	Can't tell	N	N	N
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.	N	N	N	N	N	N	Y	N	N	N	Can't tell
Does the organisation assess the overall certainty of the evidence and reach recommendations? If so, provide details.	N	N	N	N	N	N	Y	Can't tell	Y	N	Can't tell
Derivation of health-based guideline values*											
Is there justification for the choice of uncertainty and safety factors?	n/a	N	N	N	N	Y	n/a	n/a	N	n/a	N
Are the parameter value assumptions documented and explained?	n/a	N	N	N	N	Y	n/a	n/a	Y	n/a	N
Are the mathematical workings/algorithms clearly documented and explained?	Y	N	N	N	N	Y	n/a	n/a	Y	n/a	Y
Does the organisation take into consideration non-health related matters to account for feasibility of implementing the guideline values (e.g. measurement attainability)?	N	N	N	N	N	N	n/a	n/a	N	n/a	N
Is there documentation directing use of mechanistic, mode of action, or key events in adverse outcome pathways in deriving health-based guideline values?	Y	N	N	N	N	N	N	N	Can't tell	n/a	N
If expert judgement is required, is the process documented and published?	Y	N	N	N	N	N	n/a	n/a	N	n/a	N
Is dose response modelling (e.g. BMDL) routinely used?	Y	N	N	N	N	N	n/a	n/a	Can't tell	n/a	N
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?	Y	N	N	N	N	Y	n/a	n/a	Can't tell	n/a	N
If applicable: For carcinogens, what is the level of cancer risk used by the organisation to set the health-based guideline value?	n/a	n/a	n/a	n/a	N	n/a	n/a	n/a	Can't tell	n/a	n/a
Comments*											
Useful for answering primary research question?	N	Y	Partly	N	Partly	Partly	N	N	N	Partly	Partly
Useful for answering secondary research questions?	N	Partly	Partly	N	Partly	Partly	Partly	Partly	Partly	Partly	Partly
Include in review	**N**	**Y**	**Y**	**N**	**Y**	**Y**	**N**	**N**	**Y**	**Y**	**Y**

G1: EnHealth (2012), G2: Health Canada (2012), G3: HEPA (2020), G4: NHMRC (2008), G5: NRMMC, EPHC, and AHMC (2006), G6: NRMMC, EPHC, and NHMRC (2008), G7: US EPA (2017), G8: US EPA (2019), G9: US EPA (2019), G10: WHO (2016), G11. NHMRC (2019)

4.2. Primary studies

4.2.1. Quality of included studies

Six qualitative primary research studies remained after screening and were further assessed for eligibility through a risk of bias assessment. Three studies were subsequently excluded due to "high" or "probably high" overall risk of bias ratings (Table 4-2). As noted above, there is a paucity of quality research studies devoted to the effects of chemical hazards on recreational water quality.

The decision to exclude study J1 (Black, Welday, et al. (2016), *Risk Assessment for Children Exposed to Beach Sands Impacted by Oil Spill Chemicals*) was marginal. Although the study is rigorous, clear and well-written and follows a standard risk assessment methodology, the authors undermine the wider applicability of the findings with a statement to the effect that the risk assessment conducted should be considered preliminary and specific to the nature of the Deep Water Horizon oil spill (Gulf of Mexico, 2010) due to considerable weathering of the oil prior to beaching. Thus, the results do not have wider applicability in relation to re-opening beaches for recreational use following an oil spill event. Given the authors' statement that the results are specific to the particular events studied, the study can be considered to be "biased" towards those events. Consequently, it is classified as having a Probably high risk of bias (to local conditions) and was excluded on that basis.

The decision to exclude study J4 (Li, Feng, et al. (2017), *Spatiotemporal Variability of Contaminants in Lake Water and Their Risks to Human Health: A Case Study of the Shahu Lake Tourist Area, Northwest China*) was somewhat less problematic. Although the study is rigorous, clear and follows a standard risk assessment methodology, the methodology is based on People's Republic of China guidance with slightly different model assumptions, e.g. standard body weight, etc.) and is set in an environment not found in Australia (high elevation, arid zone lake that freezes over in winter). Since the results are specific to the particular country and environment studied, the study can be considered to be "biased" towards those conditions. Consequently, it is classified as having a "Probably high risk of bias" (to local conditions) and therefore was excluded from further review.

Table 4-2. Primary research studies overall risk of bias (body of evidence) (protocol adapted from the CASP appraisal tool [Oxford VTH, 2020] and the OHAT Risk-of-Bias ratings system []. Note all studies were in the qualitative research category.

Q.	Paper for appraisal and reference:	Study ID J1	J2	J3	J4	J5	J6
	Section A1: Are the results valid?						
1	Was there a clear statement of the aims of the research?	++	+	+	++	++	++
2	Is the methodology appropriate?	++	++	++	++	++	--
	Section A2: Is it worth continuing?						
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?	n/a	n/a	n/a	n/a	n/a	n/a
	Section B: What are the results?						
7	Have ethical issues been taken into consideration?	n/a	n/a	n/a	n/a	n/a	n/a
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?	-	+	+	-	+	-
	Overall risk of bias rating	-	+	+	-	+	--

++	***Definitely Low*** *risk of bias:*	+	***Probably Low*** *risk of bias*	-	***Probably High*** *risk of bias:*	--	***Definitely High*** *risk of bias:*

J1: Black, Welday, et al. (2016), *Risk Assessment for Children Exposed to Beach Sands Impacted by Oil Spill Chemicals*.
J2: Canpolat, Varol, et al. (2020), *A comparison of trace element concentrations in surface and deep water of the Keban Dam Lake (Turkey) and associated health risk assessment*.
J3: Dor, Bonnard, et al. (2003), *Health risk assessment after decontamination of the beaches polluted by the wrecked ERIKA tanker*.
J4: Li, Feng, et al. (2017), *Spatiotemporal Variability of Contaminants in Lake Water and Their Risks to Human Health: A Case Study of the Shahu Lake Tourist Area, Northwest China*.
J5: Swartjes and Janssen (2016), *Assessment of health risks due to arsenic from iron ore lumps in a beach setting*.
J6: Björklund, Bondelind, et al. (2018), *Hydrodynamic modelling of the influence of stormwater and combined sewer overflows on receiving water quality: Benzo(a)pyrene and copper risks to recreational water*.

5 Full list of included studies

5.1. Existing guidelines

The seven guideline documents included after screening and quality assessment consisted of Australian, US and Canadian guidelines and one international (WHO) guideline (Table 5-1). Only the *Guidelines for Canadian Recreational Water Quality* (Health Canada, 2012) addressed the spectrum of chemical hazards in recreational water quality, albeit at a high level. The remaining documents either addressed single groups of substances (e.g. PFAS in NHMRC, 2019), or were developed for other purposes but did contain some useful material of relevance to the management of chemical hazards in the context of recreational water quality.

Table 5-1. List of guidelines included after screening and quality assessment

ID	Title
G2: Health Canada (2012)	Health Canada (2012) Guidelines for Canadian Recreational Water Quality. Third Edition, Ottawa, Health Canada. [online] https://central.bac-lac.gc.ca/.item?id=H129-15-2012-eng&op=pdf&app=Library (Accessed December 17, 2020).
G3: HEPA (2020)	HEPA (2020) PFAS National Environmental Management Plan Version 2.0', Heads of EPA Australia and New Zealand (HEPA), [online] https://www.environment.gov.au/system/files/resources/2fadf1bc-b0b6-44cb-a192-78c522d5ec3f/files/pfas-nemp-2.pdf.
G5: NRMMC, EPHC, and AHMC (2006)	NRMMC, EPHC, and AHMC (2006) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), Canberra, Australia, Natural Resource Management Ministerial Council. Environment Protection and Heritage Council Australian Health Ministers' Conference. [online] https://www.nhmrc.gov.au/about-us/publications/australian-guidelines-water-recycling.
G6: NRMMC, EPHC, and NHMRC (2008)	NRMMC, EPHC, and NHMRC (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. https://www.nhmrc.gov.au/about-us/publications/australian-guidelines-water-recycling
G9: US EPA (2019)	US EPA (2019) Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin. EPA Document Number: 822-R-19-001, and online at http://www.epa.gov/ncea/efh., U.S. Environmental Protection Agency (EPA). [online] http://www.epa.gov/ncea/efh.
G10: WHO (2016)	WHO (2016) Protecting surface water for health: Identifying, assessing and managing drinking-water quality risks in surface-water catchments, World Health Organization. [online] https://apps.who.int/iris/bitstream/handle/10665/246196/9789241510554-eng.pdf?sequence=1.
G11. NHMRC (2019)	NHMRC (2019) Guidance on Per- and Polyfluoroalkyl Substances (PFAS) in Recreational Water, Canberra, A.C.T., National Health and Medical Research Council. [online] https://www.nhmrc.gov.au/sites/default/files/documents/attachments/guidance-on-PFAS-in-recreational-water.pdf (Accessed October 18, 2020).

5.2. Primary studies

The three primary studies included were each classified as qualitative studies using the CASP classification criteria for quality and risk of bias. This classification includes observational studies that measure or predict concentrations of contaminants in recreational water environments and on the basis of those concentrations infer the extent of exposure against health guidelines. In other contexts, such studies are commonly considered quantitative risk assessments. For the CASP approach used here, a classification as qualitative was considered appropriate, since no health impacts were observed and measured.

Each of the three studies focussed on a different spectrum or medium of chemical hazards. Collectively, they provide only a limited contribution to our knowledge on chemical hazards in relation to recreational water.

Table 5-2. List of primary studies included after consideration of risk of bias

Study ID	Citation
J2	Canpolat, Ozgur; Varol, Memet; Okan, Ozlem Oztekin; Eris, Kursad Kadir; Caglar, Metin (2020) A comparison of trace element concentrations in surface and deep water of the Keban Dam Lake (Turkey) and associated health risk assessment. *Environmental Research* 190 (2020) 110012. 10.1016/j.envres.2020.110012
J3	Dor, F.; Bonnard, R.; Gourier-Frery, C.; Cicolella, A.; Dujardin, R.; Zmirou, D. (2003) Health risk assessment after decontamination of the beaches polluted by the wrecked ERIKA tanker. *Risk Analysis* 23(6)1199-1208. 10.1111/j.0272-4332.2003.00394.x
J5	Swartjes, Frank A.; Janssen, Paul J. C. M. (2016) Assessment of health risks due to arsenic from iron ore lumps in a beach setting. *The Science of the Total Environment* 563-564 (2016) 405-412. 10.1016/j.scitotenv.2016.04.100

6 Significance of risks to human health from chemical hazards in recreational waters

6.1. Review of existing guidelines

6.1.1. Primary research question

Are exposures to the hazards listed in Table 2-1 likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?

None of the guideline documents included systematic reviews of evidence consistent with the primary research question and no such reviews were identified in the wider scientific literature. As a result, the body of evidence contained in the guideline literature is limited, and patchy with respect to detail (Table 6-5). Four of the seven guideline documents contained satisfactory material for consideration in response to the primary research question (G2, G5 G6 and G11, Table 6-1, Table 6-5).

The *Guidelines for Canadian Recreational Water Quality, Third Edition* (Health Canada, 2012) make limited reference to the topic of chemical hazards to recreational water quality. The focus is largely on management of microbiological risks. They report that national surveys of the water quality of lakes and rivers used for recreational activities indicate that concentrations of organic and inorganic chemicals, such as heavy metals, are considerably below those recommended as guidelines for drinking water quality. The Canadian guidelines consider ingestion to be the primary pathway of exposure and that risks due to dermal exposure are not likely to be significant due to the low concentrations and expected exposure scenarios during recreational water activities.

The Canadian guidelines conclude that there is insufficient information for developing chemical-specific recreational water quality guidelines. They state that since such chemical water quality hazards are dependent on the particular circumstances of the area in question they should be assessed on a case-by-case basis.

The Canadian guidelines also state that:

- Exposure to chemical hazards in recreational waters constitutes much less risk than exposure to microbiological hazards, citing (WHO, 2003);
- The likely concentrations of chemical hazards in recreational waters would not be sufficient to elicit either an acute or chronic illness response;
- The risk of human exposure to chemical contaminants in Canadian waters through recreational activities is considered low;
- However, scenarios exist that justify the use of a multi-barrier approach which is considered the most-effective way of protecting recreational water users from chemical hazards;
- Multi-barrier approaches include the use of:
    - Environmental health and safety surveys;
    - Application of precautionary measures including restricting swimming to public beaches and showering with soap and water after recreational activities to minimise risk.

The Phase 1 *Australian Guidelines for Water Recycling* (AGWR Phase 1) (NRMMC, EPHC, et al., 2006) do not directly address recreational water quality. However, since discharge of treated effluent (recycled water) in the vicinity of recreational bathing areas is not uncommon, it is useful to consider such discharges as a potential source of chemical hazards.

Citing US data, and some confirmatory Australian data, AGWR Phase 1 notes that analyses of recycled water indicate that chemical quality generally complies with drinking water quality requirements for most parameters, including heavy metals, pesticides, disinfection by-products (DBPs), and other organic chemicals (see Technical Report for further details).

AGWR Phase 1 concludes that the Australian data indicate a high rate of compliance with drinking water guideline values. Chemical concentrations that exceeded the values in the *Australian Drinking Water Guidelines* (ADWG)[3] (NHMRC and NRMMC, 2018) were acceptable, taking into account the reduced exposure compared with drinking water, discussed above. Based on these observations, concentrations of contaminants listed by AGWR Phase 1; i.e., nutrients, heavy metals, DBPs, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phenol, toluene and benzene, would not likely pose a risk to users of recreational waters influenced by recycled water discharges.

The Phase 2 *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies* (AGWR Phase 2) (NRMMC, EPHC, et al., 2008) provide a more extensive list of contaminants of interest in recycled water than AGWR Phase 1. They provide guidelines for an additional list of substances that the ADWG does not list. AGWR Phase 2 also provide a detailed methodology for the derivation of guidelines for substances for which there are currently ADWG values.

In response to recent heightened concern over the environmental and public health effects of PFAS substances, NHMRC released the guideline document, *Guidance on Per- and Polyfluoroalkyl Substances (PFAS) in Recreational Water* (NHMRC, 2019). The document lists guidelines for PFAS for Australian recreational waters (2 µg/L for total PFOS and PFHxS, 10 µg/L for PFOA) and notes that published data on recreational water samples are scarce. Reference is made to environmental studies including:

- a study on the Brisbane River undertaken to provide an estimate of the release of PFAS from flooded urban areas. PFOA (mean 0.0001- 0.006 µg/L) and PFOS (mean 0.0002 - 0.02 µg/L) were the most frequently detected and abundant PFAS (citing Gallen et al. 2014).
- a study of PFAS (citing Thompson et al., 2011) in environmental samples taken from Homebush Bay in the upper reaches of Sydney Harbour and the Parramatta River Estuary. In these urban/industrial areas, detected concentrations of PFOA and PFOS were 0.004-0.006 µg/L and 0.007-0.2 µg/L, respectively.

[3] Citing the version of the ADWG current in 2006.

These measurements suggest background concentrations of PFAS in recreational water areas would generally be well below guideline levels, unless a major source, such as a contaminated site, was present in the water catchment area.

Table 6-1. Summary of guideline review results for the Primary Research Question: Are exposures to the hazards outlined in the PECO Table (Table 2-1) likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?

Guideline	Summary

G2: Canadian 2012 RWQ Guidelines*	• Surveys of Canadian freshwater recreational areas indicate that chemical hazard concentrations are below drinking water quality guideline levels;
	• Ingestion is considered to be the primary pathway of exposure;
	• Because chemical water quality hazards are dependent on local factors they should be assessed on a case-by-case basis;
	• The risk of human exposure to chemical contaminants in recreational waters is considered low, and not sufficient to induce acute or chronic illness response;
	• There is insufficient information for developing chemical-specific recreational water quality guidelines;
	• Nevertheless, scenarios exist that justify the use of a multi-barrier approach which is considered the most-effective way of protecting recreational water users from chemical hazards. Multi-barrier actions include;
	  ○ Environmental health and safety surveys;
	  ○ Application of precautionary measures including restricting swimming to public beaches and showering with soap and water after recreational activities to minimise risk.

G3: HEPA 2020 Environmental Management Plan	• Based on the published guideline values and the information cited in reference G11, it is reasonable to conclude that PFAS would generally occur well below guideline values and thus would not constitute a significant health risk in recreational waters.
G5: AGWR Phase 1 2006*	• This guideline document was included in the review because discharge of treated effluent (recycled water) in the vicinity of recreational bathing areas is not uncommon, therefore it is useful to consider such discharges as a potential source of chemical hazards; • The review cites studies indicating that recycled water chemical quality generally complies with drinking water quality criteria. When accounting for reduced exposure volumes, observed exceedances were considered acceptable; • The review implies that concentrations of contaminants such as heavy metals, disinfection by-products, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phenol, toluene and benzene, would not likely pose a risk to users of recreational waters influenced by recycled water discharges.
G6: AGWR Phase 2 2008*	• Provides a more extensive list of contaminants of interest in recycled water than AGWR Phase 1 and furthermore provides guidelines for an additional list of substances that ADWG does not list (Table 4.4, pp.33-38). Appendix A, pp. 101 to 134, also provides a detailed methodology for the derivation of guidelines for many substances for which there were currently no (c. 2008) ADWG values.
G9: US EPA 2019 Algal toxins criteria	• Although this document is focused on Microcystins and Cylindrospermopsin only, 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.
G10: WHO 2016 Surface Water RA	• A very general discussion on chemical hazards in surface waters including sources and types of substances is presented.
G11: NHMRC 2019 PFAS Recreational WQ Guidance*	• The guidelines note that published data on recreational water samples are scarce. • Reference is made to environmental studies including a study on the Brisbane River (Qld) and Homebush Bay in the upper reaches of Sydney Harbour and Parramatta River Estuary (NSW) where measurements suggest background concentrations of PFAS at recreational water areas would be generally well below guideline levels, unless a major source such as a contaminated site, was present in the water catchment area.

* Guideline documents that contained satisfactory material for consideration in response to the research question.

6.1.2. Secondary research questions

1. What chemicals (that potentially pose a risk to humans) are present at elevated concentrations in recreational waters and what are their sources?

Three of the seven guideline documents contained satisfactory material for consideration of secondary research question 1 (G3, G6 and G10, Table 6-2, Table 6-5).

The *PFAS National Environmental Management Plan* (Version 2.0, HEPA, 2020) does not provide data on concentrations in recreational waters. It does, however, provide useful information on potential sources. Specifically, tables B1 and B2 in Appendix B of the document provide lists of activities associated with PFAS contamination due to fire management (Table B1) and with PFAS contamination more broadly (Table B2). These tables provide guidance on potential sources of PFAS that could occur in catchment areas of recreational water bodies. They may be useful for guiding monitoring and risk management planning for recreational waters.

As noted above, discharges of recycled water/treated effluent are a potentially important source of chemical hazards to recreational waters. AGWR Phase 2 (NRMMC, EPHC, et al., 2008) lists broad classes of chemical groups as potentially present in recycled water but most likely to be below drinking water quality guideline concentrations. The listed classes are so broad as to be not particularly useful (see Technical Report Section 5.4.2 for lists). However, elsewhere in the document it is stated that data (not cited) for organic chemicals indicate exceedances for a number of disinfection by-products, pesticides and trace organics. The largest exceedances were for:

- Benzo(a)pyrene (a PAH);
- Bromodichloromethane, chloroform and NDMA (N-Nitrosodimethylamine) (all disinfection by-products);
- Demeton S (a pesticide);
- Diatrizoic acid (a contrast medium);
- 2,6-di-tert-butyl-1,4-benzoquinone (an antioxidant);
- 5-methyl-1H-benzotriazole (an industrial anticorrosive);
- Paraxanthine (a caffeine metabolite);
- Propylenedinitrilotetraacetic acid (PDTA, a chelating agent).

For recreational water influenced by treated wastewater discharges, such compounds could be considered a higher priority for monitoring.

The WHO document *Protecting surface water for health* (WHO, 2016) provides guidance on the identification, assessment, and management of drinking-water quality risks in surface water catchments and therefore is not directly focussed on recreational water quality. Nevertheless, the document contains clear general guidance for management of surface water quality that is relevant to recreational waters. It provides some general commentary on broad classes of chemicals, with some specific substances listed, and potential sources in surface waters. Chemical groups discussed include major ions, nutrients, metals, pesticides, natural organic matter, volatile and semi-volatile organic compounds (VOCs and SVOCs) and chemicals of emerging concern.

Overall, there is a lack of specificity in the Guideline literature about which chemicals harmful to human health might be present at concentrations of concern in recreational waters and the sources of such chemicals.

Table 6-2. Summary of guideline review results for Secondary Research Question 1: What chemicals (that potentially pose a risk to humans) are present at elevated concentrations in recreational waters and what are their sources?

Guideline	Summary
G2: Canadian 2012 RWQ Guidelines	• No data
G3: HEPA 2020 Environmental Management Plan*	• No data on concentrations in recreational waters but provides useful information on potential sources. Tables B1 and B2 in Appendix B of the document provide lists of activities associated with PFAS contamination due to fire risk (Table B1) and with PFAS contamination more broadly (B2). These tables provide guidance on potential sources of PFAS in catchment areas of recreational water bodies and may be useful for guiding monitoring and risk management planning.
G5: AGWR Phase 1 2006	• "Emerging chemicals and complex mixtures" are addressed on p. 110 of the document. However, the discussion is brief and quite dated.
G6: AGWR Phase 2 2008*	• States (p. 42) that data (not cited) for organic chemicals indicate exceedances in recycled water for a number of disinfection by-products, pesticides and trace organics. The largest exceedances were for: o Benzo(a)pyrene (PAH); o Bromodichloromethane, chloroform and NDMA (disinfection by-products); o Demeton S (pesticide); o Diatrizoic acid (contrast medium); o 2,6-Di-tert-butyl-1,4-benzoquinone (antioxidant); o 5-Methyl-1H-benzotriazole (industrial anticorrosive); o Paraxanthine (caffeine metabolite); o Propylenedinitrilotetraacetic acid (PDTA, chelating agent) • [Reviewer's note: concentrations of these compounds would most likely be diluted 10-fold or more in the receiving waters and it would also be likely that the recreational water quality guideline would be based on an assumed dose of 10% or less than the drinking water guideline. Thus, additional safety factors of 100 or more would apply in a recreational water environment]
G9: US EPA 2019 Algal toxins criteria	• No data
G10: WHO 2016 Surface Water RA*	• Provides general commentary on broad classes of chemicals, with some specific substances listed, and potential sources in surface waters. Chemical groups discussed include major ions, nutrients, metals, pesticides, natural organic matter, volatile and semi-volatile organic compounds (VOCs and SVOCs).
G11: NHMRC 2019 PFAS Recreational WQ Guidance	• No data

* Guideline documents that contained satisfactory material for consideration in response to the research question.

2. What chemicals are of most concern due to their physicochemical properties which may enhance their uptake via dermal, inhalation or ingestion exposure pathways? How can we adjust exposure assumptions for these chemicals?

Three guideline documents contained satisfactory material for consideration in response to secondary research question 2 (G5, G9 and G10, Table 6-3, Table 6-5).

AGWR Phase 2 (NRMMC, EPHC, et al., 2008) notes that the presence of emerging compounds in treated sewage, such as endocrine-disrupting chemicals (EDCs), pharmaceuticals, new disinfection by-products (e.g. NDMA), and complex mixtures, is less well understood and required further research. Although these guidelines were published in 2006 and this conclusion may be dated, such compounds are known for their persistence through conventional wastewater treatment processes and should be considered for evaluation in recreational water sources influenced by treated wastewater discharges.

Aside from certain cyanotoxins, which are out of the scope of this Evidence Evaluation report, the *US EPA Recreational Ambient Water Quality Criteria for Cyanotoxins* (US EPA, 2019) does not list any other chemicals of concern. However, the document does provide a clear method for quantifying chemical uptake due to ingestion, inhalation and dermal exposure for water-associated chemical toxins. Exposure formulas described in the document identify the relevant physicochemical properties for which estimates are required (details are given in the Technical Report in Section 5.5.2). Key physico-chemical properties are:

- Log_{10} K_{OW} = octanol-water partition coefficient (dimensionless); and
- MW = molecular weight (g/mole).

These attributes are used in the determination of dermal permeability which is used in the dermal absorbed dose. For the cyanotoxin concentration in air, a standard value is used (citing Cheng, Yue, et al., 2007). [Reviewers comment: For non-cyanotoxin chemicals, it seems likely that chemical specific values could be determined from knowledge of each substances' Henry's Law Constant, concentration in water and assumptions on the air-water exchange rate].

The WHO guideline *Protecting surface water for health* (WHO, 2016) describes key physical properties of VOCs and SVOCs that influence their environmental fate and potential for uptake via dermal, inhalation or ingestion pathways. WHO notes that:

- VOCs are small, often relatively polar, molecules that are sparingly to very soluble in water, with solubilities spanning 100–20 000 mg/L;
- VOCs are poorly sorbed to solids (due to their low log K_{OW}) and are primarily attenuated in surface waters by simple volatilisation to the atmosphere. This significantly reduces VOC risks to surface waters;
- In comparison, SVOCs have boiling points higher than water and include PAHs, chloro- and nitro-phenols, anilines, phthalates, halogenated benzenes and ethers;
- As a generalisation, with increasing molecular weight (size), SVOCs are likely to be less volatile, have lower aqueous solubility, be increasingly hydrophobic (higher Log K_{OW}) and prone to greater sorption to sediments. They will also be less bioavailable for biodegradation, and undergo greater partitioning to biota and to bioaccumulation (i.e. the accumulation of a compound in the tissue of an organism over time). An approximate trigger value of log K_{OW} > 3 is used to identify compounds that may bioaccumulate or significantly sorb to sediments.

Although the WHO document provides useful discussion on environmental fate of certain chemical hazards in surface waters and their likely exposure pathways, the document is largely aimed at a general audience and lacks the technical detail necessary to provide confidence in its conclusions and recommendations. For example, if chemicals with a log K_{OW} > 3 sorb to sediments, does this reduce their concentration in the water column and thus reduce the risk of exposure for recreational water users (notwithstanding the possibility of resuspension)?

No specific discussion of methods for adjusting exposure assumptions for persistent, bioaccumulative, mobile or toxic chemicals was identified in the guideline literature. Although such information is likely to be abundant in the broader scientific literature the scope of the current review was limited to assessing existing guidance and reviews on recreational waters.

Table 6-3. Summary of guideline review results for Secondary Research Question 2: What chemicals are of most concern due to their physicochemical properties which may enhance their uptake via dermal, inhalation or ingestion exposure pathways? How can we adjust exposure assumptions for these chemicals?

Guideline	Summary
G2: Canadian 2012 RWQ Guidelines	• No data
G3: HEPA 2020 Environmental Management Plan	• No data
G5: AGWR Phase 1 2006*	• AGWR notes that the presence of emerging compounds in treated sewage, such as endocrine-disrupting chemicals (EDCs), pharmaceuticals, new disinfection by-products (e.g. NDMA), and complex mixtures, was less well understood and required further research. [Reviewer's note: The guidelines were published in 2006 and this conclusion is somewhat dated].
G6: AGWR Phase 2 2008	• No data
G9: US EPA 2019 Algal toxins criteria*	• The document provides a method for quantifying chemical uptake due to ingestion, inhalation, and dermal exposure for water-associated chemical toxins. Exposure formulas presented identify the relevant physicochemical properties for which estimates are required. The octanol-water partition coefficient (K_{OW}) and molecular weight are used in calculations for dermal absorbed dose.
G10: WHO 2016 Surface Water RA*	• Describes key physical properties of VOCs and SVOCs that influence their environmental fate and potential for uptake via dermal, inhalation or ingestion pathways. • Compounds with a log Kow < 3 are more likely to be found in surface waters as above this value, the compounds are likely to sorb to sediments.
G11: NHMRC 2019 PFAS Recreational WQ Guidance	• No data

* Guideline documents that contained satisfactory material for consideration in response to the research question.

3. Should the focus be on "hot spots" i.e. site-specific rather than chemical specific, and/or include periodic toxicity screening of sites to complement chemical testing?

As noted earlier, the body of evidence contained in the guideline literature is limited and this is particularly the case with respect to secondary research question 3. Only one document contained satisfactory material for consideration of secondary research question 3 (G5, Table 6-4, Table 6-5).

In this review we have included lines of evidence from the AGWR. This is because discharges of treated municipal wastewater/recycled water in the catchment area of recreational water bodies are common in Australia and the recycled water constituents are more consistent and better understood than other sources. AGWR Phase 1 (NRMMC, EPHC, et al., 2006) notes that:

- The risk to human health from chemicals in treated sewage is low, providing that preventive measures (e.g. trade-waste programs) are established and maintained to ensure that industrial discharges do not lead to elevated chemical concentrations in recycled water.
- Small treatment plants and on-site recycled water treatment plants are more susceptible than large plants to unauthorised discharges of industrial and domestic origin and greater vigilance is required in managing recycled water quality of such plants.

Overall, aside from the AGWR Phase 1 commentary, there was no significant discussion of site-specific versus chemical-specific approaches to chemical hazard risk management for recreational water quality in the guideline literature.

Earlier, in response to the primary research question, it was noted that the Canadian recreational water quality guidelines recommended that since chemical water quality hazards are dependent on the particular circumstances of the area in question they should be assessed on a case-by-case basis. This suggests that the dichotomy between site-specific versus chemical-specific approaches is not particularly useful.

With respect to the use of use of periodic toxicity screening of sites to complement chemical testing, no discussion of this topic was identified in the guideline literature.

Table 6-4. Summary of guideline review results for Secondary Research Question 3: Should the focus be on "hot spots" i.e. site-specific rather than chemical specific, and/or include periodic toxicity screening of sites to complement chemical testing?

Guideline	Summary
G2: Canadian 2012 RWQ Guidelines	• No data
G3: HEPA 2020 Environmental Management Plan	• No data
G5: AGWR Phase 1 2006*	• AGWR concludes that the risk to human health from chemicals in treated sewage is low, providing that preventive measures (e.g. trade-waste programs) are established and maintained to ensure that industrial discharges do not lead to elevated chemical concentrations in recycled water. • It is noted (AGWR Section 3.5.5, p.11) that small treatment plants and on-site recycled water treatment plants are more susceptible than large plants to unauthorised discharges of industrial and domestic origin. • Greater vigilance is required to minimise the occurrence of unauthorised discharges if small plants are used as sources of recycled water.
G6: AGWR Phase 2 2008	• No data
G9: US EPA 2019 Algal toxins criteria	• No data
G10: WHO 2016 Surface Water RA	• No data, but the broader catchment or source water safety plan development described in the document would be a useful approach to consider for management of recreational water quality areas
G11: NHMRC 2019 PFAS Recreational WQ Guidance	• No data

* Guideline documents that contained satisfactory material for consideration in response to the research question.

Table 6-5. Body of evidence summary for included guidelines

Guideline	Contribution to primary research question outcome?	Contribution to secondary research questions outcomes?	Lists key contaminants of concern in recreational waters?	Contains risk assessment methods?	Consideration of short, medium- and long-term exposures?	Consideration of the use of indicator substances for chemical risk?	Reviewer's comments	Overall Assessment
G2: Health Canada (2012)	Yes	No	No	No	No	No	Important qualitative contribution to response to primary research question. Produced by a national expert group (Canadian National Committee on Health and the Environment).	Contains helpful commentary relevant to primary research question
G3: HEPA (2020)	No	Yes (Q.1)	Yes, cites recreational water quality guideline for PFAS for Australia and provides context for this group of substances.	No	Yes, PFAS guidelines are based on chronic exposure only.	Yes, for total PFAS recommends PFOA, and sum of PFOS and PFHxS.†	No data on concentrations in recreational waters but provides useful information on potential sources.	Of minor relevance to primary and secondary research questions.
G5: NRMMC, EPHC, and AHMC (2006)	Yes	Yes (Q. 2 & 3)	Yes, lists some classes of contaminants of concern in recycled waters.*	No (no data for chemical risk assessment)	No	No	No data on concentrations in recreational waters but provides useful information on potential sources.	Of minor relevance to primary and secondary research questions.
G6: NRMMC, EPHC, and NHMRC (2008)	Yes	Yes (Q.1)	Yes, extensive listing of contaminants of concern in recycled waters.*	No	Yes, listed guidelines are based on chronic exposure only.	No	Extensive listing of contaminants of concern and their potential concentration in recycled waters.*	Important Australian reference for understanding chemical hazards in recycled waters.*
G9: US EPA (2019)	No	Yes (Q.2)	No	Yes	No	No	High quality guidance on exposure assessment for chemical hazards in recreational waters, including identification of relevant physico-chemical properties.	Of moderate relevance to the secondary research questions.
G10: WHO (2016)	No	Yes (Q. 1 & 2)	Yes, lists some classes of contaminants of concern in surface waters.	Yes^	No	No	Contains some clear general guidance for management of surface water quality that is relevant to recreational waters.	Of minor relevance to primary and secondary research questions.
G11. NHMRC (2019)	Yes	No	Yes, cites recreational water quality guideline for PFAS for Australia and provides context for this group of substances.	Yes§	Yes, PFAS guidelines are based on chronic exposure only.	Yes, for total PFAS recommends PFOA, and sum of PFOS and PFHxS.†	Provides a potential precedent for deriving substance specific recreational water guidelines in the Australian context.	Important Australian reference deriving a recreational water guideline.

† Reviewer's comment: These are indicators for Total PFAS in recreational waters and not necessarily indicators of other contaminants. However, they could be useful as part of a small suite of such indicators that could be used to assess the risks to recreational waters due to chemical hazards.

* No specific reference to recreational water but treated wastewater (i.e. recycled water) discharges in the vicinity of recreational water use areas are common in Australia. Thus, by implication, understanding such sources can assist in understanding risks from chemical hazards in recreational waters influenced by wastewater discharges.

^ Contains general discussion on chemical hazards in surface waters including physico-chemical properties that contribute to their detection.

§ Describes an approach for deriving substance specific recreational water guidelines in the Australian context including exposure assessment calculations and assumptions.

6.2. Review of primary studies

Primary research question: Are exposures to the hazards outlined in Table 2-1 likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?

Canpolat, Varol, et al. (2020) undertook a risk assessment study of ingestion and dermal exposure for recreational swimmers to trace element metals: mercury (Hg), cadmium (Cd), lead (Pb), arsenic (Ar), chromium (Cr), aluminium (Al), copper (Cu), manganese (Mn), cobalt (Co), barium (Ba), nickel (Ni), iron (Fe), zinc (Zn), uranium (U), vanadium (V), zirconium (Zr) and strontium (Sr) in a Turkish freshwater lake (Table 6-6). Hazard Quotients (HQs) metrics (measured value divided by US EPA-derived toxicity reference doses – section 6.1.2 of the Technical Report for details) were computed for all trace elements, and a Hazard Index (HI) metric was computed from the sum of all trace element HQs for carcinogenic risks. Separate values of each metric were computed for ingestion and dermal pathways. All metrics were derived using US EPA standard equations (as described section 2.3 of the document – citations for the US EPA methods are listed in section 6.1.2 of the Technical Report).

All HQ and HI values were below the risk threshold of unity. HI values for children were significantly higher than those for adults, although still at safe levels (i.e. below guideline levels). Arsenic and uranium by water ingestion were the primary contributors to total risk (HI), while vanadium and chromium were highest for the dermal pathway.

Carcinogenic risk values of arsenic and chromium in surface and deep water were below the US EPA target risk of 1×10^{-4} (lifetime risk of cancer).

Dor, Bonnard, et al. (2003) undertook a standard human health risk assessment of ingestion and dermal exposure of recreational swimmers and beach goers to polycyclic aromatic hydrocarbons (PAHs) in oil spill residues on marine sandy beaches in Brittany, France (Table 6-7). The authors measured a toxic equivalency factor (TEF), derived from 16 carcinogenic PAHs relative to benzo(a)pyrene (BaP, TEF = 1), for 36 spill-affected beaches versus 7 “control” beaches not affected by the spill.

Excess cancer risk (all cancers and cutaneous cancers) was calculated as lifetime probabilities and compared against a reference value of 1×10^{-5}. Values greater than this threshold were deemed to be excessive.

Beach sand and water, after decontamination, were slightly polluted (respectively, 7.8 µg/kg and 23.3 ng/l for total PAHs), with values similar to those found in the control beaches. By contrast, the rocky areas in some places were still highly polluted (up to 23 mg/kg on the surface layer).

Risks were considered low, both in the long-term and short-term future, for recreational users. Cancer risks did not differ substantially from those estimated on control beaches, except when depollution work had not been completed. Consequently, it could be hypothesized that risks of cancer at beaches not cleaned yet, or recently spoiled by fuel deposits, would be of concern and would justify temporary closing of the beaches.

The health impact on children (2-12 yrs) playing on a Dutch sandy beach contaminated with iron ore lumps containing arsenic was studied by Swartjes and Janssen (2016) (Table 6-8). The estimated exposure to arsenic (as total arsenic) was 0.045–0.091 µg/kgBW/day which implies an increase of 8 to 16% against the Dutch background exposure.

The estimated exposure was compared with the benchmark dose level (BMDL) [95% lower confidence limit of the benchmark-dose]. The appraisal of the contaminated site depended on the Margin of Exposure (MoE), i.e., the quotient between the BMDL and estimated exposure. In general, a lower MoE implies higher health concern. The estimated exposure gave a calculated Margin of Exposure (MoE) range of 33−67.

The lack of a widely accepted benchmark MoE was noted. Nevertheless, the predicted range was considered to indicate a relatively low health concern (i.e., considered safe) compared to MoEs for background exposure via food and drinking water in the Netherlands.

Table 6-6. Results summary for Canpolat et al., (2020)

Study, Design, Quality	Population	Exposures	Location type	Outcome	Analysis	Results	Effect estimate	Significance
Research question: *e.g. Are exposures to the hazards outlined in the PECO Table likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*								
Outcome 1. PECO listed chemical hazards measured in recreational waters above chronic health criteria (e.g. national recreational water quality guidelines).								
J2, Canpolat et al., (2020) Qualitative study, Acceptable.	Adults and children (designated as "recreational receptors")	Ingestion and dermal exposure for recreational swimmers to trace element metals*: Hg, Cd, Pb, As, Cr, Al, Cu, Mn, Co, Ba, Ni, Fe, Zn, U, V, Zr and Sr.	Freshwater Lake (impoundment on Euphrates River). Temperate environment.	Hazard Quotients (HQs) and Hazard Index (HI) = ∑ HQs for all TEs Carcinogenic Risks (CRs). Separate values of each metric computed for ingestion and dermal pathways.	US EPA standardized equations used to assess risks posed by each individual chemical, with HQs and CRs. One-way ANOVA was applied to determine differences in TE concentrations among sampling sites ($p < 0.05$, Duncan's test). Also, Student's t-test was used to determine significant differences in TE concentrations between seasons and between surface water samples and deep water samples ($p < 0.05$).	Cu, Zn, Ba, Ni, Mn and Pb levels measured in deep water were higher than those in surface water. Total TE level in deep water (30m) was higher in wet season, whereas that in surface water was higher in dry season. *All HQ (hazard quotient) and HI (hazard index) values were below the risk threshold of unity. HI values for children were significantly higher than those for adults, although still at safe levels.* As and U for water ingestion were the primary contributors to total risk (HI), while V and Cr were highest for the dermal pathway. *Carcinogenic risk values of As and Cr in surface and deep water were below the US EPA target risk of* 1×10^{-4} *(life time risk of cancer).*	Not clearly stated and varies with site, location and trace element metal.	$p < 0.05$.

Table 6-7 Results summary for Dor et al. (2003).

Study, Design, Quality	Population	Exposures	Location type	Outcome	Analysis	Results	Effect estimate	Significance
Research question: *e.g. Are exposures to the hazards outlined in the PECO Table likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*								
Outcome 1. PECO listed chemical hazards measured in recreational waters above chronic health criteria (e.g. national recreational water quality guidelines).								
J3, Dor *et al.* (2003). Qualitative study, Acceptable.	Standard human health risk assessment population (i.e., adults) and sensitive subpopulation (i.e., children).	Ingestion and dermal exposure of recreational swimmers and beach goers to PAHs in oil spill residues. Sixteen PAHs listed by the US EPA as potential carcinogens were measured. Their carcinogenic potency was taken into account using a toxic equivalent factor (TEF) of PAH in reference to benzo(a)pyrene (BaP, TEF = 1). The carcinogenic potency of a PAH mixture	Marine sandy beach and adjacent bathing waters - temperate environment (on coast of Brittany, France). Thirty-six spill affected beaches were sampled vs seven "control" beaches, unspoiled by the oil spill.	Excess cancer risk (all cancers and cutaneous cancers) was calculated as lifetime probabilities and compared against a reference value of 1×10^{-5}. Values greater than this threshold were deemed to be excessive. Values were presented using medians and 90th percentiles.	Individual risks were estimated for each health effect by combining exposures for each scenario and toxicological values for each effect. For noncarcinogenic effects, a "hazard quotient" (exposure dose/toxicological value) was calculated. For all cancers, individual excess risk was calculated. For all cancers, individual excess risk was calculated according to the following equation: $ERI = ERU \times NA/70 \times \sum DEi \times TEFi$ where ERI: individual excess risk for cancer following pollutant intake, ERU: oral unit risk of benzo(a)pyrene $(mg/kg\ bw/d)^{-1}$, DEi: exposure dose for each route of exposure (mg/kg/j), TEF: toxic equivalent factor of PAH in reference to BaP, NA: duration of exposure (year), and 70: the average time exposure (year).	The sand and water, after decontamination, were slightly polluted (respectively, 7.8 µg/kg and 23.3 ng/l for 16 total PAHs), with values similar to those found in the control beaches (Note: both decontaminated and control beaches reported some minor exceedance of the BaP equivalent HBT of 1×10^{-5} excess lifetime risk of cancer). By contrast, the rocky areas in some places were still highly polluted (up to 23 mg/kg on the surface layer). Risks were considered low, both in the long-term and short-term future, for recreational users. Cancer risks did not differ substantially from those estimated on control beaches, except when depollution work had not been completed. Consequently, it could be hypothesized that risks of cancer at beaches not cleaned yet, or recently spoiled by fuel deposits, would be of concern and would justify temporary closing of the beaches.	Not clearly stated and varies with exposure scenario and metric (i.e., median, 90th%ile). However, all measured exceedances were minor (max = 8.1×10^{-5} for 90th%ile) for exposure to still polluted rocks.	n/a

Table 6-8. Results summary for Swartjes and Janssen (2016)

Study, Design, Quality	Population	Exposures	Location type	Outcome	Analysis	Results	Effect estimate	Significance
Research question: *e.g. Are exposures to the hazards outlined in the PECO Table likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*								
Outcome 1. PECO listed chemical hazards measured in recreational waters above chronic health criteria (e.g. national recreational water quality guidelines).								
J5, Swartjes and Janssen (2016). Qualitative study, Acceptable.	Children of age group of 2–12 years.	Soil ingestion of soft grit coating the lumps that adheres to children's hands when they handle the iron ore lumps. This results in a "hand loading". The higher of 95th percentile estimate was used of 1.7 mg/cm^2 due to the efficacy of the soil attachment.	Sandy beaches, Netherlands (temperate environment).	Children (2-12 yrs), average residence time on beach = 4hrs/day. Two scenarios (i) Conservative: 21 days daily exposure and (2) Precautionary: 42 days. Beach contaminated with iron ore lumps containing As. The estimated exposure was compared with the BMDL [95% lower confidence limit of the BMD - Benchmark-dose]. The appraisal of the contaminated site depended on the Margin of Exposure (MoE), i.e., the quotient between the BMDL and estimated exposure. Generally speaking, a lower MoE implies higher health concern.	The exposure is compared with the average As background exposure to children in The Netherlands in the age of 2 to 6 years of 0.56 µg/kgBW/day.	The conservative and precautionary scenarios gave an estimated exposure of 0.045–0.091 µg/kgBW/ day which implies an increase in background exposure of 8 to 16% due to exposure to As in the iron ore lumps.	The estimated exposure gave a calculated Margin of Exposure (MoE) range 33−67. The lack of a widely accepted benchmark MoE was noted. Nevertheless, the predicted range was considered to indicate a relatively low health concern (i.e. considered safe) compared to MoEs for background exposure via food and drinking water in the Netherlands.	n/a

* mercury (Hg), cadmium (Cd), lead (Pb), arsenic (Ar), chromium (Cr), aluminium (Al), copper (Cu), manganese (Mn), cobalt (Co), barium (Ba), nickel (Ni), iron (Fe), zinc (Zn), uranium (U), vanadium (V), zirconium (Zr) and strontium (Sr).

6.3. Assessment of the certainty in the body of evidence

6.3.1. Frading the certainty of evidence of primary studies

As described in the research protocol (O'Connor, 2020), a process based on the OHAT approach to using the GRADE framework was used to assess the certainty of the body of evidence for the three primary studies used to answer the primary research question (OHAT, 2019). As all of these studies had been assessed as qualitative studies, there were combined into a single evidence stream.

As noted in Section 2.3.2, at the direction of the Committee, secondary research questions were addressed through the review of existing guidelines and reviews only, rather than through review of the primary studies and thus were not included in the GRADE assessment.

Initial confidence ratings

The evidence stream was assigned an initial certainty rating similar to that described in the OHAT Handbook (OHAT, 2019). Qualitative studies were given the same initial rating as observational studies ("low certainty").

Risk of bias

While none of the studies reviewed were designed as randomised control trials or similar clinical trials, there was a general low risk of bias across the included studies.

Unexplained inconsistency

A large amount of heterogeneity was observed across the body of evidence; however, this can be explained by the inconsistent nature of the exposure scenarios for recreational water exposure (different recreational water exposures, durations, locations and types) and study designs. This resulted in a rating of 'not serious' across all study types and outcomes.

Indirectness

Most of the included studies were relevant to the primary research question and the populations and recreational exposure types could be assessed for Australian settings. This resulted in a rating of 'not serious'.

Imprecision

Reasonable efforts were made to assess the statistical significance of the findings across the body of evidence. This resulted in a rating of 'not serious' across all study types.

Publication bias

Publication bias was not detected.

Reasons for upgrading

There was insufficient information to determine if there were any further reasons to upgrade the certainty of the overall body of evidence using the GRADE system.

Overall certainty rating

The GRADE assessment of the overall quality of the primary studies body of evidence was undertaken for the outcome identified for the primary research question which was “PECO listed hazard measured in recreational waters” (i.e. the hazards listed in Table 2-1).

The overall certainty rating was “low” for the evidence stream of three qualitative studies (Table 6-9) and this led to a final certainty rating of “*limited confidence in the reported associations*”. This result stems largely from the very limited number of quality studies that made it through the screening and quality assessment stages of the literature review, as each of the three final studies was considered to be of reasonable quality. Substantial heterogeneity in study focus and corresponding results was observed, however, such heterogeneity is readily explained due to the different chemical suites studied and the chosen study environments. None of the factors that could influence a change in the grading of certainty of the body of evidence (Figure 2-1, Table 2-7) were identified (Table 6-9).

It is worth noting that methods and approaches for systematic reviews of environmental health evidence is still an area of research and development, and further modification of the available frameworks and tools is beyond the scope of services required for this review. Further analysis and evaluation of the primary studies by the Committee can be undertaken if required.

Table 6-9. GRADE report for presence of significant human health risks due to chemical hazards[#] in recreational water

Body of evidence	Risk of bias	Unexplained inconsistency	Indirectness	Imprecision	Publication bias	Magnitude of effect	Dose Response	Residual confounding	Consistency across species/model	Other reason to increase confidence?	Final certainty rating
Evidence stream or study type (# studies) *Initial certainty rating (OHAT,2019)*	*Serious, not serious, unknown* Describe trends, key questions, issues	*Serious, not serious, not applicable (NA)* Describe results in terms of consistency, explain apparent inconsistency	*Serious or not serious, NA* Discuss use of upstream indicators or populations with less relevance, any time-related exposure considerations	*Serious, not serious, unknown, NA* Discuss ability to distinguish treatment from control, describe confidence intervals (if available)	*Detected, undetected* Discuss factors that might indicate publication bias (e.g., funding, lag)	*Large, not large, unknown, NA* Describe magnitude of response or strength of association	*Yes, no, unknown* Outline evidence for or against dose response	*Yes, no, unknown* Address whether there is evidence that confounding would bias toward null	*Yes, no, NA* Describe cross-species, model, or population consistency	*Yes or no* Describe any other factors that increase confidence in the results	*High, moderate, low or very low* List reasons for down-grading or upgrading
Research question: *Are exposures to the hazards listed in Table 2-1 likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?*											
Outcome: PECO listed hazard measured in recreational waters (i.e. the hazards listed in Table 2-1).											
Qualitative studies (3) Low certainty	Not serious Overall risk of bias is Probably Low	Not serious[1]	Not serious[2]	Not serious	Undetected	Unknown[3]	Unknown[4]	No[5]	N/A[6]	No	**⊕⊕OO** **Low certainty**

[#]. Chemical hazards as listed in Table 2-1. For qualitative studies, significance is defined as measured values detected above relevant HBTs

[1].Substantial (high) heterogeneity present. However, this is due to the three included studies each focussing on a different spectrum or medium of chemical hazards.

[2].Indirectness of evidence is not serious. No changes to the nature of the proposed risks, or their settings would be expected to have occurred since the publication of the studies.

[3]. The notional effect is the presence of the listed chemical hazards (Table 2-1). Since the spectrum of hazards was small for each of the 3 studies, the magnitude of the effect is difficult to judge. For a large effect, many studies with a wide spectrum of chemical hazards detected would be required

[4]. Each of the three studies involved assessment of environmental measurements against a human health guideline value. The dose response aspect is intrinsic to the guideline value and since such values are derived by external agencies through a separate process their evaluation is beyond the scope of the present review.

[5]. No evidence of confounding of evidence was identified in any of the studies.

[6]. Each study was a risk assessment of one or more measured chemical hazard values compared with published human health guidelines and different substances or exposure pathways are considered in each study, thus the question of consistency of health response is not applicable.

Key to GRADE quality of evidence:
⊕⊕⊕⊕ = High; We are very confident in the reported associations;
⊕⊕⊕◯ = Moderate; We are moderately confident in the reported associations;
⊕⊕◯◯ = Low; Our confidence in the reported associations is limited;
⊕◯◯◯ = Very Low; We are not confident about the reported associations.

7 Discussion

7.1. Primary research question

Are exposures to the hazards listed in Table 2 1 likely to give rise to any significant human health risks given that chemical concentrations in recreational waters are generally low?

In response to the primary research question evidence was sought to determine if any of the chemical hazards[4] listed in Table 2-1 could give rise to significant human health risks in recreational waters. The list contains broad chemical classes based on use (e.g. pesticides), potential modes of toxicity (e.g. EDCs), structure (e.g. PFAS) and other physical properties (e.g. surfactants). It can be considered to address most chemical contaminants in the context of recreational water quality.

The following guidelines were found to be relevant and suitable to adopt/adapt based on an assessment of administrative and technical processes.

The *Guidelines for Canadian recreational water quality* (Health Canada, 2012) consider two broad chemical classes: organic and inorganic chemicals, and based on national surveys, conclude that their concentrations in Canadian recreational waters are generally well below drinking water guidelines.

Similar conclusions were reached in the AGWR (Phase 1 or 2) in the context of recycled water, where Australian data indicates a high rate of compliance with the AWDG. Since licensed wastewater discharges constitute one of the most influential sources of potential chemical hazards to recreational water quality, evidence of their compliance with the ADWG suggests that recreational waters would normally be expected to be compliant to the same guidelines. Following this line of reasoning, it can be concluded that the concentrations of contaminants listed in the AGWR (Phase 1 or 2); i.e., nutrients, heavy metals, DBPs, PCBs, PAHs, phenol, toluene and benzene, would not likely pose a risk to users of recreational waters influenced by recycled water discharges.

Citing PFAS measurements of selected estuarine and marine recreational water environments, NHMRC (2019) concluded that background concentrations of PFAS at recreational water areas would generally be well below guideline levels, unless a major source, such as a contaminated site, was present in the water catchment area.

There was low certainty in the following primary studies based on their risk of bias assessments. This led to a finding of limited confidence in the reported associations.

Evidence from the primary studies literature was limited and somewhat heterogeneous, reflecting the paucity of quality research studies devoted to the effects of chemical hazards on recreational water quality.

A study of a large Turkish water storage which is also used for primary contact recreation found that all trace element metals (mercury, cadmium, lead, arsenic,

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[4] Chemical hazards to recreational water quality listed by the Committee for consideration in this review: PFAS, pesticides, nanomaterials, hydrocarbons, heavy metals, EDCs, surfactants, interactions between chemicals (potentiation). See Table 2-1 for more detail.

chromium, aluminium, copper, manganese, cobalt, barium, nickel, iron, zinc, uranium, vanadium, zirconium and strontium,) were compliant with local health guidelines (derived from US EPA guidance, see Technical Report section 6.1.2).

In a French oil spill impact study, concentrations of PAHs in beach sand and waters were similar to control beaches after clean-up, whereas some rocky areas were still considered to be polluted. Interestingly, background risks due to PAH exposure, as measured at control sites, indicated some minor exceedances of excess lifetime cancer risk thresholds (1×10^{-5}) via dermal and ingestion pathways, suggesting other sources of PAHs were present along the coast.

A less common recreational exposure pathway was examined by researchers from the Netherlands who concluded that the health risk to children playing with arsenic contaminated iron rocks scattered along a sandy beach was at safe levels.

Overall, the body of evidence assembled to respond to the primary research question was inadequate to fully answer the question. It did not provide any significant quantitative or qualitative information on the relationship between concentrations of the listed chemical hazards in recreational waters and human health risks. The minor exceptions were single studies on heavy metals and polycyclic aromatic hydrocarbons at a tiny number of locations globally.

The GRADE quality assessment for the primary studies literature was “Low” and this led to a final certainty rating of “limited confidence in the reported associations”. This was mainly due to the small quantity of relevant studies of satisfactory quality that were identified. None of the factors that could influence a change in the grading of certainty of the body of evidence were identified. The evidence base from the guidelines was also limited as they generally only addressed broad chemical classes and did not clearly identify the source of information upon which their conclusions were drawn. The exception was the NHMRC *Guidance on Per- and Poly-fluoroalkyl Substances (PFAS) in Recreational Water* (NHMRC, 2019) which cited two recent Australian studies.

As a result of the limited evidence base available from the review of guidelines and primary studies, the recommendation of the *Guidelines for Canadian recreational water quality* (Health Canada, 2012) that chemical water quality hazards should be assessed on a case-by-case basis since they are dependent on local circumstances, remains appropriate.

7.2. GRADE assessment of primary studies

The overall certainty rating was “low” for the three quantitative studies and this led to a final certainty rating of “limited confidence in the reported associations”. These results stemmed from the high degree of heterogeneity among the small number of studies identified. None of the factors that could influence a change in the grading of certainty of the body of evidence were identified.

It is worth noting that methods and approaches for systematic reviews of environmental health evidence is still an area of research and development, and further modification of the available frameworks and tools is beyond the scope of services required for this review. Further analysis and evaluation of the identified primary studies and grey literature documents by the Committee can be undertaken if required.

7.3. Secondary research questions

Evidence for the secondary research questions was limited to available relevant guidelines to make the workload manageable within available resources as set out in the research protocol, with different suites of guidelines relevant depending on the research question.

7.3.1. (i) What chemicals (that potentially pose a risk to humans) are present at elevated concentrations in recreational waters and what are their sources?

In relation to secondary research question 1, from the review of guidelines, it was concluded that there was a lack of specificity in the guideline literature about which chemicals harmful to human health might be present at elevated concentrations in recreational waters and their sources. Some evidence for PFAS sources was identified. However, although currently a class of chemicals of concern internationally, PFAS were not reported at elevated concentrations in recreational waters. Several other candidate substances reported in AGWR Phase 2 as exceedances in recycled water were identified (listed in Section 6.1.2 above) and thus could be considered as priorities for monitoring in recreational water influenced by recycled water discharges. In addition to these substances, the WHO guideline for protecting the quality of surface waters provided useful general guidance on classes of chemicals and their potential sources.

7.3.2. (ii) What chemicals are of most concern due to their physicochemical properties which may enhance their uptake via dermal, inhalation or ingestion exposure pathways? How can we adjust exposure assumptions for these chemicals?

For secondary research question 2, the guideline literature listed some chemical groups such as EDCs, pharmaceuticals, and DBPs that are considered environmentally persistent and toxic. It also identified other physicochemical properties that are useful for quantifying uptake via dermal, inhalation or ingestion exposure pathways (e.g. log K_{OW}, MW, etc.). Nevertheless, the discussion on physicochemical properties of chemical hazards that may enhance uptake was generally limited in the guideline literature. It is likely that better information can be obtained in the broader literature on chemical environmental fate and bioavailability beyond the recreational water use context of the current review.

In addition to the above comments, there was also no information in the guideline literature on methods for adjusting exposure assumptions for problematic chemicals. However, information on this topic is also likely to be available in the broader literature on chemical environmental fate. For example, there are a number of online tools for determining environmental fate factors such as biodegradation, volatilisation, and adsorption to solids such as EPI Suite (US EPA, 2012) or QSAR Toolbox (OECD, 2018).

7.3.3. (iii) Should the focus be on "hot spots" i.e. site-specific rather than chemical specific, and/or include periodic toxicity screening of sites to complement chemical testing?

In relation to secondary research question 3, the guideline literature contained no information to support a focus on "hot spots" or site-specific over chemical-specific assessment apart from some indirect commentary in the AGWR Phase 1 and Canadian recreational water quality guidelines. The AGWR Phase 1 suggested small wastewater treatment systems were more problematic than large plants with respect to quality of recycled water discharged to the environment. The Canadian guidelines recommended chemical water quality hazards be assessed on a case-by-case basis. Both suggestions support the view that monitoring of chemical hazards in recreational water environments should be risk-based, similar to the approach commonly used for management of microbiological risks in recreational waters.

The application of periodic toxicity screening of sites to complement chemical testing was not addressed in the guideline literature.

7.4. Conclusions

An evaluation of evidence contained in four guidelines and three qualitative research primary studies indicated that the available evidence was inadequate to determine if exposure to listed chemical hazards (PFAS, pesticides, nanomaterials, hydrocarbons, heavy metals, EDCs, surfactants, or combinations) could give rise to any significant human health risks in recreational waters, given that such exposures are generally low.

An evaluation of the evidence contained in seven included guidelines indicated that the evidence in the guideline literature lacked sufficient detail to determine which chemicals harmful to human health might be present at elevated concentrations in recreational waters and their sources. Similarly, evidence for the physicochemical properties of chemical hazards that may enhance uptake via dermal, inhalation or ingestion exposure pathways was generally limited. Furthermore, there was no information in the included guideline literature on methods for adjusting exposure assumptions for problematic chemicals.

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