WESTERN INDIAN OCEAN

Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas

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Cover photo: © Matthew Richmond – Mnazi Bay-Ruvuma Estuary Marine Park in southern Tanzania.

Photo: © Matthew Richmond – Sewage waste draining into Msimbazi mangrove forest in Tanzania.

EXECUTIVE SUMMARY

The Nairobi Convention is an important regional platform for addressing challenges facing coastal and marine ecosystems in the Western Indian Ocean (WIO) through catalytic interventions, dialogue, and partnerships. The Contracting Parties to the Nairobi Convention include Kenya, Mozambique, Somalia, South Africa, Tanzania and the island states of Comoros, Mauritius, Madagascar, Reunion (France) and Seychelles. The governments of these countries have agreed, through a highly consultative process, on a suite of national and regional collective actions that are required to address major stresses on the coastal and marine environment of the region, including:

- “Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP)” – funded by the Global Environment Facility (GEF);
- “The Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms (WIO LME SAPPHIRE)” – funded by the Global Environment Facility (GEF) and implemented by the United Nations Development Programme (UNDP); and
- “Enforcing Environmental Treaties in African, Caribbean and Pacific (ACP) Countries (ACP-MEA Phase III)” – funded by The European Union.

In terms of coastal and marine water quality management (C&MWQM), it is expected that through improved capacity and the implementation of appropriate strategic frameworks, ecosystem integrity could be improved, leading to local socio-economic and environmental benefits, in addition to global environmental benefits.

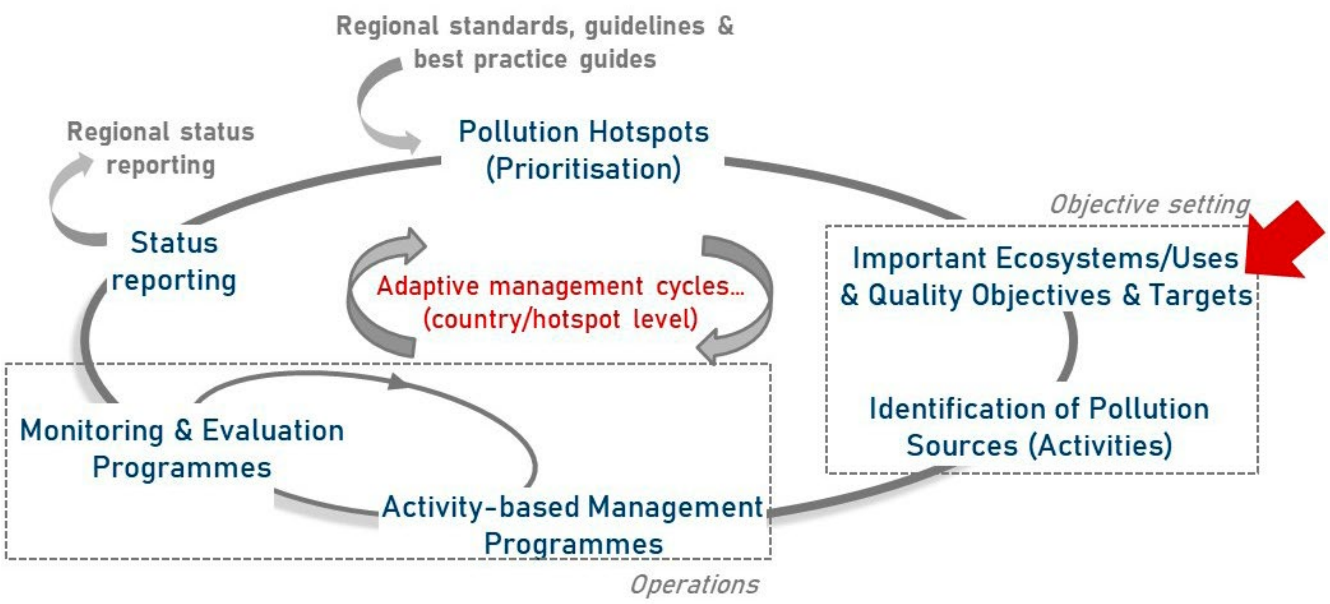
C&MWQM specifically focuses on mitigating **coastal and marine pollution**, where the ultimate goal is to keep the resource suitable for designated uses – both existing and future uses (this includes the protection of biodiversity and aquatic ecosystem functioning). To achieve this goal, it is important to identify important aquatic ecosystems and other beneficial uses of coastal and marine areas that rely on good water and sediment quality. Internationally, these have typically been divided into four broad categories, namely:

- Protection of aquatic ecosystems
- Recreational use (including tourism)
- Marine aquaculture (including the collection of seafood for human consumption)
- Industrial uses (e.g. intakes for desalination, cooling water intake and seafood processing).

Drawing on an existing model for Integrating Coastal Management (the broader domain within which C&MEQM is nested) *an ecosystem-based Implementation Framework for C&MWQM* has been development for the WIO region (Figure 1), as part of the overarching *Strategic Framework for C&MWQM*. To wisely apply human and financial resources, it may be necessary to tackle C&MWQM in a phased approach. In this regard, the identification of marine pollution **hotspots** or emerging hotspots, provides a transparent mechanism to prioritize study areas where coastal and marine environmental quality is most at risk or impacted by human activities. The identification and mapping of **important ecosystems, and key socio-economic beneficial uses** in a specific area, as well as their environmental quality objectives and associated targets are key components in a C&MWQM programme.

As part of the objective setting phase, another key component is the identification and characterization (including location and quantification) of potential **marine pollution sources** (both land-based and sea-based) that may alter water and sediment quality within a specific study area, as well as setting limits. **Activity-based management programmes** involve the operational management of specific activities potentially contributing to marine pollution. These types of programmes often show a strong sectoral focus (i.e. activities are managed by different governing authorities through activity-specific statutory systems).

Figure 1 **Ecosystem-based Implementation Framework for C&MWQM in the WIO region, also showing the context of these guidelines.**



The design and implementation of environmental quality **monitoring and evaluation programmes** forms an integral and critical element in the Implementation Framework's operational phase. **Status reporting** provides for a high-level reflection on progress and transparency on issues of concern which need to be addressed through a cycle of adaptive management. National level status reports, in turn, feed into the overarching regional status assessment processes, such as the WIO State-of-Coast reporting.

The *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine Areas* align with the *Objective setting phase* of the ecosystem-based Implementation Framework for C&MWQM (Figure 1). The aim of these *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine Areas* is to assist **responsible authorities and water quality managers in developing site-specific quality targets (QTs) for their particular coastal and marine areas towards the effective implementation of national-level C&MWQM**. For this reason, the document also includes practical guidance on deriving and/or applying site-specific water and sediment QTs.

Recommended water and sediment QTs as proposed here are usually developed on a regional or national scale, either as numerical targets or descriptive statements. To accommodate natural variability, but minimize the risk of impact, these QTs are usually broad-based and fairly conservative. Therefore, these recommended QTs should be considered as a first-phase in setting site-specific QTs. Depending on site-specific conditions (ecological, social and/or economic) they may have to be refined at specific national or local seascapes before they can be accepted as legal standards. As a result, the recommended QTs proposed in these regional guidelines cannot automatically become legally binding. Guided by international best-practice, the selected water and sediment quality constituents, as well as their relevance to the protection of aquatic ecosystems and other beneficial uses are indicated in Table 1.

Table 1 **Summary of constituent types for which QTs are addressed in these guidelines, as well as relevance to broad categories of beneficial uses.**

Type of constituent		Protection of aquatic ecosystem	Recreation	Marin aquaculture	Industrial use
Water	Objectionable matter	●	●	Similar to Protection of Aquatic Ecosystems	Based on site-specific requirements of industries
	Physico-chemical properties	●	Refer to Drinking water guidelines		
	Nutrients	●			
	Toxicants	●			
	Microbiological indicators		●	●	
	Tainting substances			●	
Sediment	Toxicants	●		Similar to Protection of Aquatic Ecosystems	

It is very important to note that the existence of recommended QTs **does not imply that water and sediment quality should or could automatically be degraded to those levels**. A continuous effort should be made to ensure that coastal and marine environment is of the highest attainable quality, taking into account economic and social opportunities and constraints, and considering principles such as:

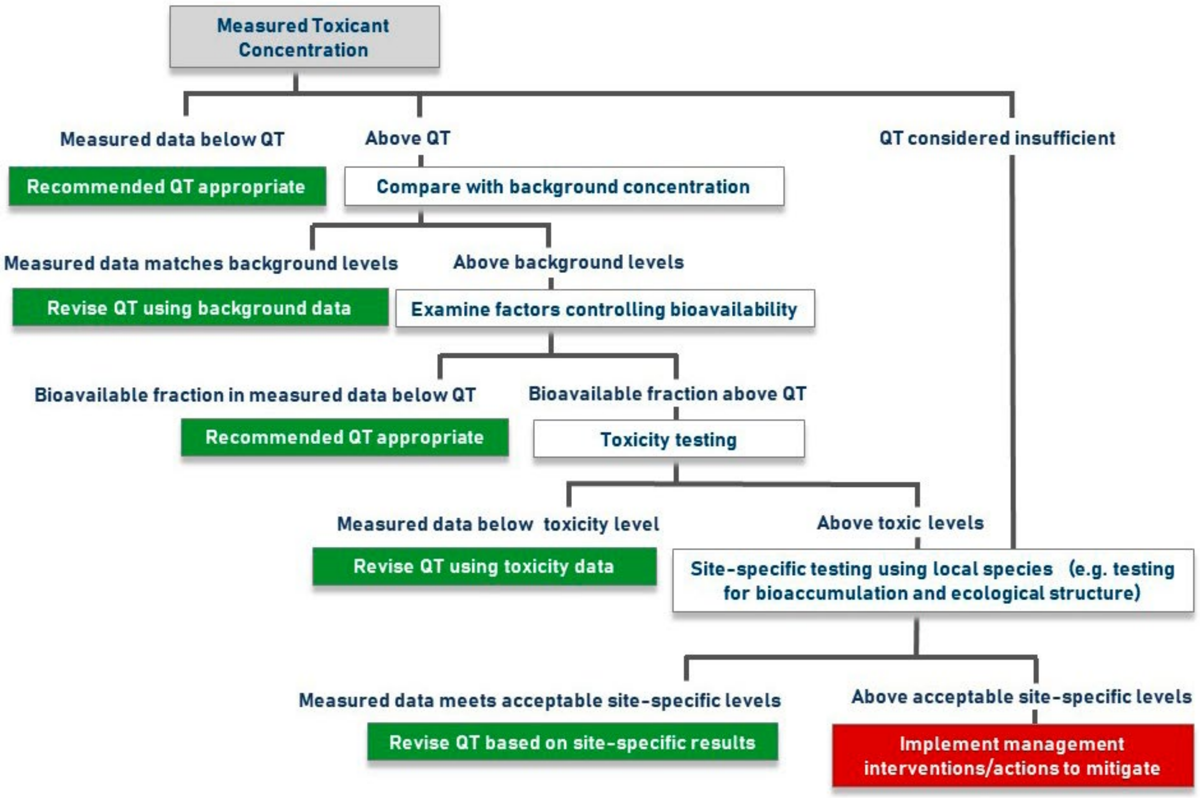
- Precautionary approach
- Pollution prevention
- Waste minimization
- Recycling and re-use
- Best available or best attainable technologies.

Protection of Aquatic Ecosystems

For Protecting Aquatic Ecosystems, the primary environmental quality objective is: *The physical, chemical and biological conditions defining the structure of, and processes within, a particular coastal ecosystem are maintained*. From a C&MWQM perspective, this broad objective needs to be translated into measurable water and sediment QTs. Table 1 summarizes the constituent types that were considered in setting QT for the protection of aquatic ecosystems (see Table 2.2 in main document for summary of recommended water and sediment QTs for the protection of aquatic ecosystems).

For physico-chemical properties and inorganic nutrients, QTs were derived using a Reference Data Approach. This approach uses an appropriate percentile (e.g. 20th and/or 80th percentile) of data collected from a specific site prior to modification (or an appropriate Reference site) to derive QTs. It is recommended that such target values be compared with the **median** or **average** (whichever is considered most appropriate) of measured data (either measured spatially across various locations within a test area or over an appropriate time period at specific sites). Statis-

Figure 2 **Proposed phased approach to refine site-specific QTs for protection of aquatic ecosystems in WIO region.**



tically, the median usually represents the most robust descriptor of the test site data.

In the case of toxicants, the (single) recommended QTs were derived from most appropriate international experience based on large, international toxicological data sets, providing a general (conservative) tolerance of biota to constituent concentrations. However, these targets may not necessarily take into account site-specific (natural) background conditions. Therefore, where site-specific studies show non-compliance with recommended QTs (or in the event that recommended QTs are considered to underestimate site-specific tolerance levels), a phased risk assessment process should be applied to refine QTs as illustrated in Figure 2.

When applying these (single) recommended QTs to measured data to test for compliance, **all data points should comply with such target values**. Similarly, it is good practice to apply the recommended QTs for the **protection of coastal and marine aquatic ecosystems** as widely as possible in coastal and marine areas, and not just limit their application to protected or conservation areas.

Recreational Use

For recreational use of coastal and marine waters, the environmental quality objective, in essence is: *Environmental quality is suitable for recreational use from an aesthetic, safety and hygienic point of view*. Most important QTs for recreational use relate to objectionable matter and microbiological contaminants pertaining to aesthetics and protection human health, respectively (Table 1; see Table 3.2

in main document for summary of recommended water and QTs for recreational use).

Where pollution sources are present in recreational areas that may potentially introduce pollutants that can cause deterioration in aesthetics or put users at risk as a result of unacceptable pH, temperature or toxicants, conditions should be monitored and compared with recommended QTs.

Based on international best practice, the assessment of **water quality of marine recreational waters** should ideally be comprised of:

- A microbiological quality assessment (applying the rating as per the recommended QTs)
- Regular sanitary inspections.

In the case of the **microbiological water quality assessment**, statistical analyses are required for comparison with the recommended target values. Where microbiological assessments are rated against a percentile target value it is important to ensure an appropriate sample size. For example, in rating beach water quality using microbiological data collected on a weekly or bi-weekly basis it is recommended that a 12-month running period is applied (in contrast to the typical 5-year period recommended internationally). This is considered most appropriate for situations where the microbiological quality of recreational waters can change markedly over short period.

The aim of the **sanitary inspection** is to identify all potential sources of faecal pollution (particularly human faecal pollution) and to grade a recreational area accordingly. In this regard, the three most important sources of human faecal contamination are:

- Sewage (e.g. wastewater discharges, sewage pump station overflow, seepage from septic/conservancy tanks, contaminated storm-water run-off);
- Riverine discharges (e.g. where rivers are receiving sewage discharges);
- Contamination from bathers (e.g. excreta); and
- Shipping and boating activities (e.g. inappropriate sewage disposal practices).

International practice recommends that the sanitation inspection should be conducted at least once a year, but where significant intra-annual variability is expected in pollution sources potentially impacting on recreational areas, inspection may need to be done more frequently.

Recreational water also can be classified using the results from the Microbiological Quality Assessment and the Sanitary Inspection (Table 2), linked to the recommended water QTs. A grade of “Very Good” reflects consistent compliance with microbiological targets with few sources of faecal contamination in the area and surrounds, and where there is consequently a low risk of illness from contact recreation.

At the other extreme “Very Poor” reflects significant sources of faecal contamination and rare compliance with microbiological targets. The risk of illness from contact recreation in such waters is high, and swimming is not recommended.

Table 2 **Classification matrix for recreational waters.**

		Microbiological quality assessment category (95th %ile enterococci per 100 ml)				
		Excellent/A	**Good/B**	**Sufficient/C**	**Poor/D**	**Exceptional circumstances**[3]
Sanitary inspection category	**Very Low**	Very good	Very good	Follow-up[1]	Follow-up[1]	Take mitigating action
	Low	Very Good	Good	Fair	Follow-up[1]	
	Moderate	Good	Good	Fair	Poor	
	High	Good	Fair	Poor	Very poor	
	Very high	Follow-up[2]	Fair	Poor	Very poor	
	Exceptional circumstances	Take mitigating action				

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1 Implies non-sewage sources of faecal indicators (e.g. livestock), and this should be verified.

2 Indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most commonly associated with Combined Sewer Overflow presence. These results should be investigated further and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include "event" periods. Confirm analytical results. Review possible analytical errors.

3 Exceptional circumstances relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

Marine Aquaculture

For marine aquaculture activities (including harvesting or collecting of organisms for human consumption) the primary environmental quality objective is: *Environmental quality sustains acceptable product quality and prevents any health risks to consumers*.

Where pollution sources are present in marine aquaculture areas that potentially introduce pollutants that can cause mechanical interference (e.g. objectionable matter) or affect the health of marine organisms or potentially taint seafood, conditions should be monitored and compared with recommended QTs for the Protection of Aquatic Ecosystems (Table 1). In terms of human health, a summary of the recommended QTs proposed for shellfish farming and harvesting areas in the WIO region are summarized in Table 4.3 of the main document.

It is recommended that a classification system for shellfish growing areas be adopted for the WIO region. **Major export markets may eventually dictate** such an approach for countries in the WIO region that export seafood internationally. The classification of coastal and estuarine areas for the harvesting of shellfish (e.g. clams, oysters, scallops, mussels and other bivalve molluscs) is based on the results for Sanitary Surveys that consist of:

- Sanitary survey – identification and evaluation of all potential and actual pollution sources in the harvesting area
- Microbiological survey – based on faecal coliform monitoring results obtained from harvesting area

The proposed classification system for shellfish growing areas in the WIO region is provided Table 3.

Table 3 **Recommended classification of shellfish waters in WIO region.**

Category	Classification requirements
Approved	Sanitary survey determines area is not subject to contamination from human or animal faecal matter presenting actual or potential public health hazard or toxic substances exceeds required levels. Microbiological levels must comply with *E. coli* QTs (direct consumption)
Conditionally Approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period are known, predictable and not so complex as to prevent a reasonable management approach. Microbiological levels must comply with *E. coli* QTs (direct consumption)
Restricted	Sanitary survey finds area is subject to only a limited degree of pollution and level(s) of faecal pollution, human pathogens and toxic or deleterious substances are at such an amount that shellfish can be made fit for human consumption by either relaying or depuration. Microbiological levels must comply with *E. coli* QTs (relaying or depuration required)
Conditionally Restricted	Sanitary survey finds area open for purposes of harvesting shellfish for relaying or depuration for a reasonable period of time and factors determining this period are known, predictable and are not so complex as to preclude a practical management approach. Microbiological levels must comply with *E. coli* QTs (relaying or depuration required)
Prohibited	Shellfish so highly or frequently contaminated that harvesting controls cannot be implemented to adequately ensure protection of public health

Industrial Uses

It is proposed that industrial water use be recognized as a (beneficial) use of coastal and marine waters in the WIO region. In waters used for industrial purposes, the primary environmental quality objective is: *Environmental quality does not result in mechanical interferences, sustains acceptable product quality and prevents any health risks to consumer*s.

While industrial activities are intuitively sources of marine pollution, numerous industries also rely on acceptable quality of coastal and marine waters, including:

- Fish processing – seawater intake used in the processing, washing and canning of seafood which requires good quality intake water to ensure product quality and safety for human consumption
- Salt production – pumping of water into solar evaporation ponds
- Desalination – abstracting seawater for the production of potable water
- Oceanariums – abstracting seawater directly from the sea
- Cooling water – seawater intake for cooling purposes in various industries
- Ballast water intake – intake of seawater for vessel trim, stability and manoeuvrability, usually occurs inside harbours and ports
- Exploration drilling – using seawater in oil and gas exploration drilling operations
- Scrubbing and scaling – using seawater to scrub smokestack to remove dust particles.

Internationally, recommended QTs for industrial use are generally no longer posed as a result of the large variation in environmental quality requirements that are mainly driven by specific processes and technologies applied. QTs should thus be site-specifically derived, based on the specific requirements of industries in the area.

Photo: © Kadir van Lohuizen/NOOR – A coral nursery between Cousin and Cousine Island near Praslin, Seychelles.

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ACRONYMS

ACP	African, Caribbean and Pacific
ACP-MEA	Enforcing Environmental Treaties in African, Caribbean and Pacific (ACP) Countries
AFRI	Acute febrile respiratory illness
ANZECC	Australia and New Zealand Environment and Conservation Council
AS	Assessment factor
ASSAC	Australian Shellfish Sanitation Advisory Committee
BAV	Beach action value
BEC10	10% bounded effect concentration
BEDS	Biological effects database for sediments
BOD	Biochemical oxygen demand
BTEX	Benzene, toluene, ethylbenzene xylene
BWD	Bathing Water Directive
CCC	Criterion Continuous Concentration
CCME	Canadian Council of Ministers of the Environment
CEC	Council of European Community
CF	Conversion Factor
cfu	Colony forming unit
CMC	Criterion Maximum Concentration
COD	Chemical Oxygen Demand
CSSP	Canadian Shellfish Sanitation Program
CTDS	Conductivity-Temperature-Depth-Salinity
CWA	Clean Water Act
D	Dissolved
DEA	Department of Environmental Affairs (South Africa)
DEFF	Department of Environment, Fisheries and Forestry (South Africa)
DIN	Dissolved inorganic nitrogen (nitrite, nitrate plus total ammonia)
DO	Dissolved oxygen
DSP	Diarrhetic shellfish poisoning
DWAF	Department of Water Affairs and Forestry (South Africa)
EC	Effect concentration
EC	European Community
EC50	Half maximal effective concentration, referring to concentration of contaminant affects response halfway between baseline and maximum effect after a specified exposure time
ECOTOX	ECOTOXicology knowledgebase
QT	Quality Target

ACRONYMS *CONTINUED*

ERL	Effects Range-Low
ERM	Effects Range-Median
FTU	Formazin turbidity unit
GEF	Global Environmental Facility
GI	Gastrointestinal illness
HPLC	High-performance liquid chromatography
IC	Inhibition concentration
IRIS	Integrated Risk Information System
LC	Lethal concentration
LC50	Concentration that is lethal to 50% of the test organisms
LME	Large Marine Ecosystems
LOE	First line of evidence
LOEC	Lowest Observable Effects Concentration
MAC	Maximum allowable concentration
MF	Membrane filter
mg/ℓ	milligrams per litre
mℓ/ℓ	millilitre per litre
µg/g	microgram per gram
µg/ℓ	microgram per litre
MPN	Most probable number
mS/m	millisiemens per metre
NAS/NAE	National Academy of Sciences/National Academy of Engineering
NEC	No effect concentrations
NER-H	No Effect Range High
NERM	No Effect Range Median
NGI	Estimated Illness rate
NOAA	National Oceanic and Atmospheric Administration
NOEC	No Observable Effect Concentration
NSP	Neurotoxic shellfish poisoning
NSSP	National Shellfish Sanitation Program
NTU	Nephelometric turbidity unit
NZME	New Zealand Ministry of Environment
°C	Degrees Celsius
OC	Organic content

ACRONYMS *CONTINUED*

PAH	Poly aromatic hydrocarbon
PCB	Polychlorinated biphenyls
PEL	Probable Effect Level
PSP	Paralytic shellfish poison
%ile	Percentile
qPCR	Quantitative Polymerase Chain Reaction
RSA	Republic of South Africa
RWQC	Recreational Water Quality Criteria
SAPPHIRE	Strategic Action Programme Policy Harmonisation and Institutional Reforms
SI	International System of Units
SSD	Species sensitivity distribution
STV	Statistical threshold values
T	Total
TDS	Total dissolved solids
TEL	Threshold Effect Level
TOC	Total Organic Carbon
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USA	United States of America
US-EPA	United States Environmental Protection Agency
US-FDA	United States Food and Drug Administration
WHO	World Health Organization
WIO	Western Indian Ocean
WIOSAP	Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities
WOE	Weight of evidence
WSP	Waste stabilization pond

GLOSSARY OF TERMS

Abundance	The total number of individuals of an animal group in an area.
Adsorption	Attachment of molecules or ions to a substrate by manipulation of electrical charge or pH.
Aerobic	Where oxygen is available or where molecular oxygen is required for respiration.
Anaerobic	Where insufficient oxygen is available or where molecular oxygen is not required for respiration.
Anoxic	Limited or no oxygen availability.
Anthropogenic	Caused by humans or their activities, e.g. storm water is an anthropogenic source of pollution to the sea.
Bacteria	Extremely small, relatively simple prokaryotic microorganisms.
Benthic	Inhabiting the bottom of a water body.
Biocide	Substance that destroys living plants and organisms, such as pesticide, fungicide, or herbicide.
Biomass	The dry weight of living matter, including stored food, present in a species population and expressed in terms of a given area or volume of habitat.
Bio-transference	The process by which a chemical or element is absorbed from one organism by another.
Buffering capacity	A measure of the relative sensitivity of a solution to pH changes on addition of acids or bases.
Chlorophyll a	Chlorophyll a Refers to the green pigment in plants and algae which is fundamentally part of the process of photosynthesis. Chlorophyll is used as a measure of the amount of algae (phytoplankton) in water.
Chromatography	Preferential absorption of chemical compounds (gases or liquids) in an ascending molecular weight sequence onto a solid adsorbent material, such as activated carbon, silica gel or alumina.
Clarity	Refers to the depth to which light can penetrate in a water body.
Colloidal suspension	A mixture of two substances, one of which, called the dispersed phase (or colloid), is uniformly distributed in a finely divided state through the second substance, called the dispersion medium (or dispersing medium). Both phases may be a gas, liquid or solid.
Conservancy tank	Tanks used for the retention or temporary retention of wastewater, and which must be emptied at intervals.
Constituent concentration	Concentration of a chemical (constituent) in water, sediment or flesh.
Cytological responses	Reponses that happens within cells of organisms.
Descriptor	Number, word or expression used to describe or identify something.
Diarrhetic shellfish poison	Algal toxin causing gastrointestinal problems.
Dinoflagellate	An order of flagellate protozoan, most members having fixed shapes determined by thick covering plates.
Ecosystems	A functional system which includes the organisms of a natural community together with their abiotic environment.
Enterococci	A streptococcus of a group that occurs naturally in the intestine.
Episodic events	Events such as large floods, or sea storms that may from results is a marked change in environmental characteristics.
Euphotic zone	The surface water layer up to a depth where 1% of the surface illumination still penetrates.
Eutrophication	Excessive algal or plant growth caused by high nutrient concentrations.
Flora	Plant life characterising a specific geographic region or environment.
Gas chromatography	A separation technique whereby a sample is distributed between two phases. One of these is a stationary bed of large surface area, and the other a gas (carrier gas) which percolates through the stationary phase.
Gram-positive	Refers to bacteria which hold the colour of the primary stain when treated with Gram's stain.

GLOSSARY OF TERMS *CONTINUED*

Heterotrophic	Obtain nourishment from the ingestion and breakdown of organic matter.
Humic substances	A general category of naturally occurring, biogenic, heterogeneous organic substances that can be characterised as being yellow to black in colour, of high molecular weight, and refractory.
Inorganic ligands	Ions or inorganic (neutral) molecules that bond to a central metal atom or ion.
Intravalvular liquid	The muscles, body and organs of shellfish together with the liquid contained within the shells when the animal is tightly closed out of the water.
In situ	In the original location.
Interstitial	Water that occurs within the pores of sediment (also referred to as pore water)
Macrophytes	Refers to macroscopic forms of aquatic plants and includes of algae and aquatic vascular plants.
Median	Middle value in a list ordered from smallest to largest (also known as 50th %ile).
Mycrocystins	Class of toxins produced by certain cyanobacteria, commonly known as blue-green algae.
Quality targets	A level or concentration of a physical, chemical, or microbiological parameters that, if achieved, would not result in detrimental effects on marine aquatic ecosystems, or uses of marine environments, such as recreation and mariculture.
Pathogen	(Pathogenic) Causing disease.
Percentile value	A measure used in statistics indicating the value below which a given percentage of observations in a set of observations fall, e.g. the 20th %ile is the value below which 20% of observations is found.
Photic zone	see Euphotic zone.
Photometrically	(Photometry) The calculation and measurement of quantities describing light, such as luminous intensity, sometimes taken to include measurement of near-infrared and near-ultraviolet radiation as well as visible light.
Protozoa	A diverse phylum of eukaryotic micro-organisms; the structure varies from a simple uninucleate protoplast to colonial forms. The body is either naked or covered by a cyst. Locomotion is by means of pseudopodia or cilia or flagella.
Sanitary inspection	A field visit that is undertaken to identify and log any potential sources of faecal pollution (particularly human faecal pollution), such as sewage, riverine discharges, contamination form bathers, in order er to grade a recreational area accordingly.
Seasonality	Refers to changes associated with the four seasons of the year.
Site specific	Refers to conditions that are unique or specific to a certain site or location.
Streptococci	A genus of spherical gram-positive bacteria occurring in pairs or chains.
Titrimetrically	A technique where the substance to be determined is allowed to react with an appropriate reagent added as a standard solution, and the volume of solution needed for complete reaction is determined.
Toxic	Containing or being poisonous causing death or serious debilitation.
Toxicants	A chemical that poses detrimental effects to humans or marine life, causing death or serious debilitation.
Toxicity	The quality of a chemical to pose detrimental effects to humans or marine life, causing death or serious debilitation.
Upwelling	The phenomenon by which deep, colder and nutrient-rich ocean waters are introduced into the well-mixed surface layer.
Virus	A typical virus consists of nucleic acid (DNA or RNA) neatly wrapped in a protective protein coat (capsid). The latter carries a receptor site which will attach to matching receptor sites only on certain cells. This matching determines the host specificity of viruses.

Photo: © UNEP – Duck near mangrove forest in Seychelles.

1. INTRODUCTION

1.1 Purpose

The Nairobi Convention is an important regional platform for addressing coastal and marine ecosystems challenges in the Western Indian Ocean (WIO) through catalytic interventions, dialogue, and partnerships. The Contracting Parties to the Nairobi Convention include Kenya, Mozambique, Somalia, South Africa, Tanzania and the island states of Comoros, Mauritius, Madagascar, Reunion (France) and Seychelles. The governments of these countries have agreed, through a highly consultative process, on a suite of national and regional collective actions that are required to address significant stresses on the coastal and marine environment of the region, including:

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In terms of coastal and marine water quality management (C&MWQM), it is expected that through improved capacity and the implementation of the appropriate strategic framework ecosystem integrity can be improved, leading to local socio-economic and environmental benefits, in addition to global environmental benefits. The development of a *regional strategic framework for C&MWQM* could provide a basis for adopting and integrating effective management into national frameworks, acknowledging that countries are at different development stages. Two phases are envisaged:

- Phase 1 – Development of a Strategic Framework for Coastal and Marine Water Quality Management
- Phase 2 – Implementation of the Strategic Framework for Coastal and Marine Water Quality Management at the national and sub-national levels.

Forming part of Phase I, the *Guidelines for Setting Water and Sediment Quality Targets for the Coastal and Marine Environment in the WIO region* (or simply *Target Guidelines*) represent an update of a previous guideline document – UNEP *et al.*, 2009, informed by the *Situation Assessment on Marine Pollution and Coastal and Marine Water Quality Management in the WIO Region* (UNEP *et al.*, 2022a). The Target Guidelines also feeds into the *Strategic Framework for C&MWQM for the WIO Region* (UNEP *et al.*, 2022b).

These *Target Guidelines* aim to **assist responsible authorities and water quality managers in developing site-specific targets for their coastal and marine areas towards the effective implementation of national-level C&MWQM**. For this reason, this document also includes practical guidance on deriving and/or applying water and sediment QTs at the site-specific scale.

1.2 Context of Guidelines

Within the WIO region, as in many other coastal regions, the integrity of coastal and marine ecosystems is increasingly degraded and threatened by an array of natural phenomena (e.g. floods, storms, cyclones) and anthropogenic (human) activities, including:

- Modification of stream flows, e.g. through dams and smaller-scale abstractions for agricultural use
- Destruction and modification of ecosystems and ecotones, e.g. through coastal infrastructure development, mining and inappropriate harvesting practices
- Over-exploitation of living resources
- **Coastal and marine pollution**

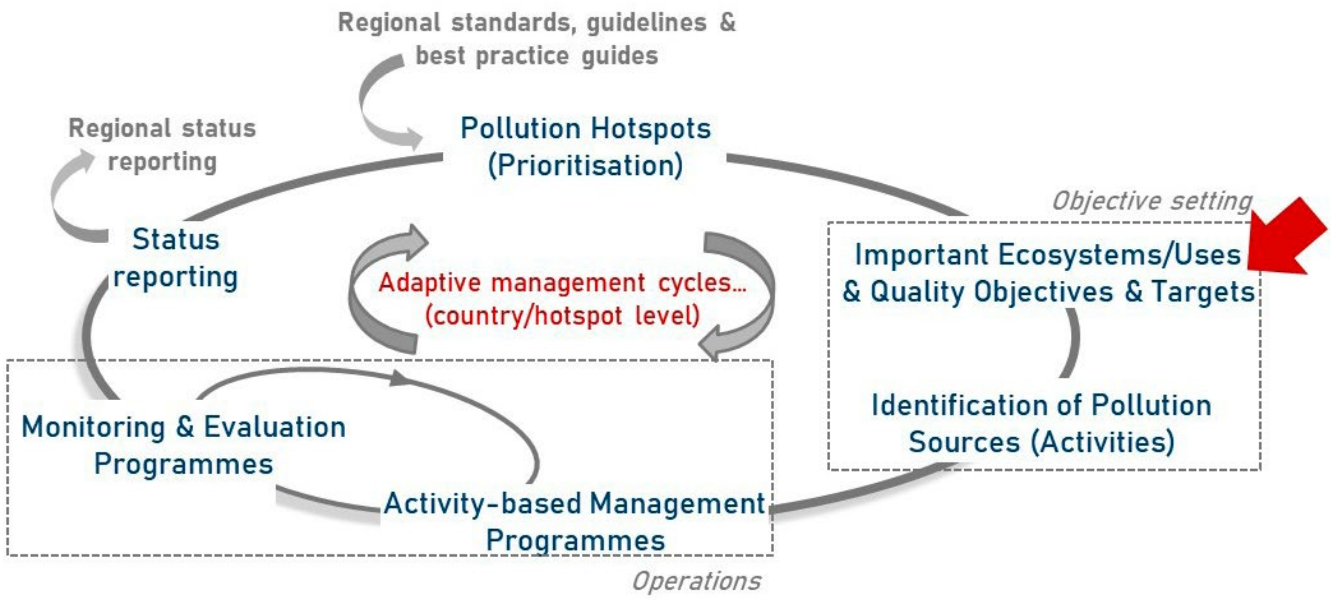
C&MWQM specifically focuses on mitigating coastal and marine pollution, where the ultimate goal is to keep the resource suitable for designated uses – both existing and future uses (this includes the protection of biodiversity and aquatic ecosystem functioning). To achieve this goal, it is important to identify valuable aquatic ecosystems and other beneficial uses of coastal and marine areas that rely on good water and sediment quality. Internationally, these have typically been divided into four broad categories (e.g. ANZECC, 2000; Mauritius Government, 1999), namely:

- Protection of aquatic ecosystems
- Recreational use (including tourism)
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial uses (e.g. intakes for desalination, cooling water intake and seafood processing)

Drawing on an existing model for Integrating Coastal Management (the broader domain within which C&MEQM is nested) *an ecosystem-based Implementation Framework for C&MWQM* has been development for the WIO region (Figure 1.1), as part of the overarching *Strategic Framework for C&MWQM* (UNEP *et al.*, 2022b).

To wisely apply human and financial resources, it may be necessary to tackle C&MWQM in a phased approach. In this regard, the identification of marine pollution **hotspots** or emerging hotspots, provides a transparent mechanism to prioritize study areas where coastal and marine environmental quality is most at risk or impacted by human activities. The identification and mapping of **important ecosystems, and key socio-economic beneficial uses** in a specific area, as well as their environmental quality objectives and associated targets are key components in a C&MWQM programme. Agreement on important aquatic ecosystems and other beneficial uses within a specific coastal management area (or hotspot), as well as associated water and sediment QTs, should be negotiated in a consultative process using appropriate institutional structures, e.g.

Figure 1.1 Ecosystem-based Implementation Framework for C&MWQM in the WIO region, also showing the context of these guidelines.



stakeholder forums. As part of the objective setting phase, another key component is the identification and characterization (including location and quantification) of potential marine pollution sources (both land-based and sea-based) that may alter water and sediment quality within a specific study area, as well as setting limits. **Activity-based management programmes** involve the operational management of specific activities potentially contributing to marine pollution. These types of programmes often show a strong sectoral focus (i.e. activities are managed by different governing authorities through activity-specific statutory systems). The design and implementation of environmental quality **monitoring and evaluation programmes** forms an integral and critical element in the Implementation Framework’s operational phase. **Status reporting** provides for a high-level reflection on progress and transparency on issues of concern which need to be addressed through a cycle of adaptive management. National level status reports, in turn, feed into the overarching regional status assessment processes, such as the WIO State-of-Coast reporting.

The *Target Guidelines align with the Objective setting phase* of the ecosystem-based Implementation Framework for C&MWQM (Figure 1.1). These recommended water and sediment QTs, as propose here, are usually developed on a regional or national scale, either as numerical targets or descriptive statements. To accommodate for natural variability, but still minimize risk of impact, these QTs are usually broad-based and conservative. Therefore, they should be considered as a first phase in setting site-specific QTs. Depending on site-specific conditions (ecological, social and/or economic) they may have to be refined for specific national or local seascapes. As a result, the recommended QTs proposed in these regional guidelines cannot automatically be legally binding (Ragas *et al.*, 2005). However, once water and sediment QTs have been verified and refined to accommodate site-specific needs they can become legally binding standards in themselves (e.g. national water and sediment quality standards) (Ragas 10,5 pt, 2005). Guided by international best-practice, the water and sediment quality constituent types that were selected for inclusion in these guidelines, in relation to the protection of aquatic ecosystems and the other beneficial uses, are indicated in Table 1.1.

Table 1 **Summary of constituent types for which QTs are addressed in these guidelines, as well as relevance to broad categories of beneficial uses.**

Type of constituent		Protection of aquatic ecosystem	Recreation	Marin aquaculture	Industrial use
Water	Objectionable matter	●	●	Similar to Protection of Aquatic Ecosystems	Based on site-specific requirements of industries
	Physico-chemical properties	●	Refer to Drinking water guidelines		
	Nutrients	●			
	Toxicants	●			
	Microbiological indicators		●	●	
	Tainting substances			●	
Sediment	Toxicants	●		Similar to Protection of Aquatic Ecosystems	

It is important to note that the existence of recommended QTs **does not imply that water and sediment quality should or could automatically be degraded to those levels**. A continuous effort should be made to ensure that coastal and marine environment are of the highest attainable quality, taking into account economic and social opportunities and constraints, and considering principles such as:

- Precautionary approach
- Pollution prevention
- Waste minimization
- Recycling and re-use
- Best available or best attainable technologies

1.3 Structure of this Document

Following this introductory chapter (Chapter 1), the following chapters deals with recommended QTs for important aquatic ecosystems and beneficial uses as follows:

CHAPTER 2: PROTECTION OF MARINE AQUATIC ECOSYSTEMS

CHAPTER 3: RECREATIONAL USE

CHAPTER 4: MARINE AQUACULTURE

CHAPTER 5: INDUSTRIAL USE

Each of these chapters follows a similar structure. First the Approach and Methodology that was applied in the selection of water and sediment QTs for the WIO region is discussed to allow for greater transparency. Thereafter the Recommended Quality Targets are presented and information on the selected constituents is provided, including a short description, natural occurrence, interdependencies and fate in the environment, as well as a recommended method and units of measurement. Finally, each Chapter concludes with practical guidance on deriving or applying site-specific QTs to assist practitioners in developing these as part of their own C&MWQM programmes, e.g. at hotspot-level.

Appendix A contains the Background Information to the development of these *Target Guidelines*, which includes a review of international guideline documents, as well as summary tables of the international water and sediment QTs for coastal and marine areas.

Appendix B presents a Summary of International Guidelines for the protection of aquatic systems

Appendix C provides a proposed Template for Pilot Testing Regional Water and Sediment Quality Objectives and Targets as recommended in this document.

Photo: © Matthew Richmond – Plume from a dredger ship off the coast of Dar es Salaam, Tanzania.

2. PROTECTION OF MARINE AQUATIC ECOSYSTEMS

In Protecting Aquatic Ecosystems, the primary environmental quality objective (a narrative statement describing the desired quality for a particular environment) is:

> *The physical, chemical and biological conditions defining the structure of, and processes within a particular coastal ecosystem are maintained*

From a C&MWQM perspective, this broad objective needs to be translated into measurable targets, in this instance water and sediment quality targets (QTs).

Chemicals can be introduced naturally to coastal and marine environments by events such as volcanic activity, forest fires, wind-blown dust and erosion of ore bearing rock. Metals such as zinc, copper and cobalt, and nutrients are essential for biota's functioning and survival. Most contaminants present in coastal and marine ecosystems are introduced by anthropogenic activities that include sewage discharge, industrial and domestic waste disposal, oil spills and solid waste dumping at sea. An excessive amount of can be toxic to biota and severely interfere with aquatic ecosystem functioning (UNEP *et al.*, 2009).

Marine plants such as phytoplankton, seaweed and seagrasses absorb nutrients and toxic chemicals directly from the water column and interstitial water. Macroalgae have large surface areas that can efficiently accumulate excessive pollutants, and trap toxicants within their polysaccharide walls (Ravera, 2001). Polychaetes (marine worms) can absorb contaminants across their soft epidermal layers which are continuously exposed to interstitial water (Rainbow, 1995). These worms have a variety of feeding mechanisms that include sediment ingestion, suspension-feeding and scavenging. Therefore, they can accumulate contaminants from various sources such as the water column, contaminated sediments, as well as by bio-transference of pollutants through the food chain (Rainbow, 1995). This is also the case with other biological assemblages, such as crustaceans that feed on contaminated detritus and detached algae. Suspension feeders such as mussels, oysters and barnacles absorb contaminants from the water column in addition to ingesting contaminated suspended particles. Bivalves such as clams ingest toxic compounds from the overlying water and deposited particulates. Depending on the nature of the pollutant, accumulation takes place in different parts of the affected organism. Heavy metals are usually concentrated in fish bones, molluscan shells, exoskeletons of crustaceans, as well as soft body tissues such as gills and livers of fish and mantle tissue in bivalves (Ravera, 2001).

Exposure to pollution can cause a variety of effects in coastal and marine organisms, including morphological changes such as the greening of oysters that have accumulated extremely high quantities of copper (Bryan, 1971), Fish and crustaceans display histological changes in gill tissue as well as necrosis of kidneys and fatty metamorphosis of the liver. Several marine organisms display behavioural changes as well as biochemical, cytological and physiological responses to pollutants. Changes in population and community structure due to a decline in growth and recruitment rates of marine organisms have been found to be significantly correlated with contaminant exposure (Bryan, 1971). Metals are known to cause sensory alterations in crustacean larvae and disrupt motor and swimming activities in crabs. They cause changes in chemoreception, tactile ability and lateral line sensitivity in marine fishes, as well as physiological and cytological responses in marine molluscs (Bryan, 1971). Persistent organic pollutants such as polychlorinated biphenyls (PCBs) and pesticides affect sensory functions in crustaceans, physiological rates in molluscs as well as locomotor activities in fishes. These pollutants also disrupt reproduction in marine organisms (Bryan, 1971; Eisler *et al.*, 1979). Petroleum has been found to have similar effects as other organic pollutants on molluscs, crustaceans and fishes (Eisler *et al.*, 1979). PCBs, poly-aromatic hydrocarbons (PAHs) and pesticides are lipid-soluble and accumulate in the fatty tissue of marine organisms (Bryan, 1971). Predatory organisms may accumulate toxicants from their food sources in a process called bio-magnification, ultimately leading to very high concentrations in apex predators.

Therefore, water and sediment quality-related problems or impacts on the coastal and marine aquatic ecosystems typically manifest in:

- Abnormal growth stimulation (e.g. excessive nutrients)

- Biological health (e.g. toxic compounds affecting, for example, the reproductive rate of organisms)

- External behaviour responses (e.g. pollutant affecting movement and burrowing habits of organisms or entanglement).

Types of constituents (key indicators) that are typically used to set QTs for the protection of aquatic ecosystems in coastal and marine areas, and their relevance to various impacts, are indicated in Table 2.1.

Table 2.1 **Type of constituents (key indicators) typically used to set QTs for the protection of aquatic ecosystems in coastal and marine areas, as well as potential associated impacts.**

Type of constituent	Growth stimulation	Biological health	External behaviour response
Objectionable matter		●	●
Physico-chemical properties		●	●
Nutrients	●		
Toxicants		●	●

Grow stimulation, primarily relates to excessive eutrophication associated with nutrient pollution. Biological health mainly relates to the impact of chemical on one of more life stages of marine organism, either chronic or acute, while objectionable matter and high levels of pollutants (e.g. suspended solids), for example can impact on the natural migration of marine organisms.

2.1 Approach and Methodology

2.1.1 Objectionable substances

Recommended QTs related to objectionable substances are usually presented as a narrative, requiring coastal and marine areas be free from:

- Solid waste, i ncluding macroplastics that may be floating, submerged and/or settleable matter (smothering, ingestion and entanglement of marine organisms)

- Oil and greasy films (ingestion and organism behavioural patterns)

- Microplastics (ingestion by marine organisms)

Note: Microplastics (small particles of plastics) are emerging as a serious threat to marine ecosystems and research on their impacts is being undertaken worldwide (see Barnardo and Ribbink, 2020). Specific QTs for these particles should be set once more quantitative data becomes available.

In alignment with international trends, a similar approach is adopted for the WIO region, i.e. providing descriptive (or narrative) targets for matters related to objectionable substances.

2.1.2 Physico-chemical properties and Inorganic Nutrients

Large variability exists in the physico-chemical properties and inorganic nutrient levels in the WIO region coastal and marine environment, with different aquatic ecosystems being well adapted to the ambient conditions within their particular area. It is therefore considered inappropriate to recommend a single value QTs for physico-chemical properties and inorganic nutrients across the WIO region, but rather to recommend an approach that could be applied to derive site-specific QTs. Ideally, QTs should be derived from a representative set of site-specific field and/or laboratory tests using local species (for more information, refer to Appendix A). However, this level of data may not be available for countries in the region, and it is, therefore, recommended that a Reference Data Approach be adopted (similar to previous guidelines – UNEP *et al.*, 2009). This approach uses an appropriate percentile (e.g. 20th and/or 80th %ile) of the physico-chemical data collected from a specific site prior to modification (or an appropriate Reference site) to derive QTs.

A caution in setting QTs for inorganic nutrients based on reference data is that impact or disturbance caused by inorganic nutrients in coastal and marine ecosystems generally occurs through transformation. Therefore, there may not always be a direct relationship between the ambient nutrient concentration and the biological response measured at a specific time. To address this shortfall, predictive modelling approaches are becoming an increasingly popular tool for deriving site-specific nutrient QTs. However, implementing predictive modelling approaches throughout the region may prove to be difficult (e.g. modelling technologies are not available) and the Reference Data Approach is probably more appropriate.

2.1.3 Toxicants

Ideally, QTs for toxicants should be derived from a representative set of site-specific field and/or laboratory tests using local species, and typically following a Species Sensitivity Distribution (SSD) Approach. This cumulative distribution function describes the variation in the sensitivity of species to a chemical. Following a risk-based approach, a specific level of protection is decided upon in setting the QT (e.g. 95% of species should be protected), as recommended by Warne *et al.* (2018) and illustrated in Figure 2.1. However, it is unlikely that these types of comprehensive data sets will be available in countries across the WIO region—at least not in the short-term.

Although there may be variability in the responses of coastal and marine ecosystems (and different trophic levels) to toxicants, these are generally considered to be less variable than, for example for physico-chemical parameters and inorganic nutrients. Therefore, the common approach adopted in areas where site-specific data are insufficient is to interrogate large international databases to derive recommended QTs (for more information, refer to Appendix A).

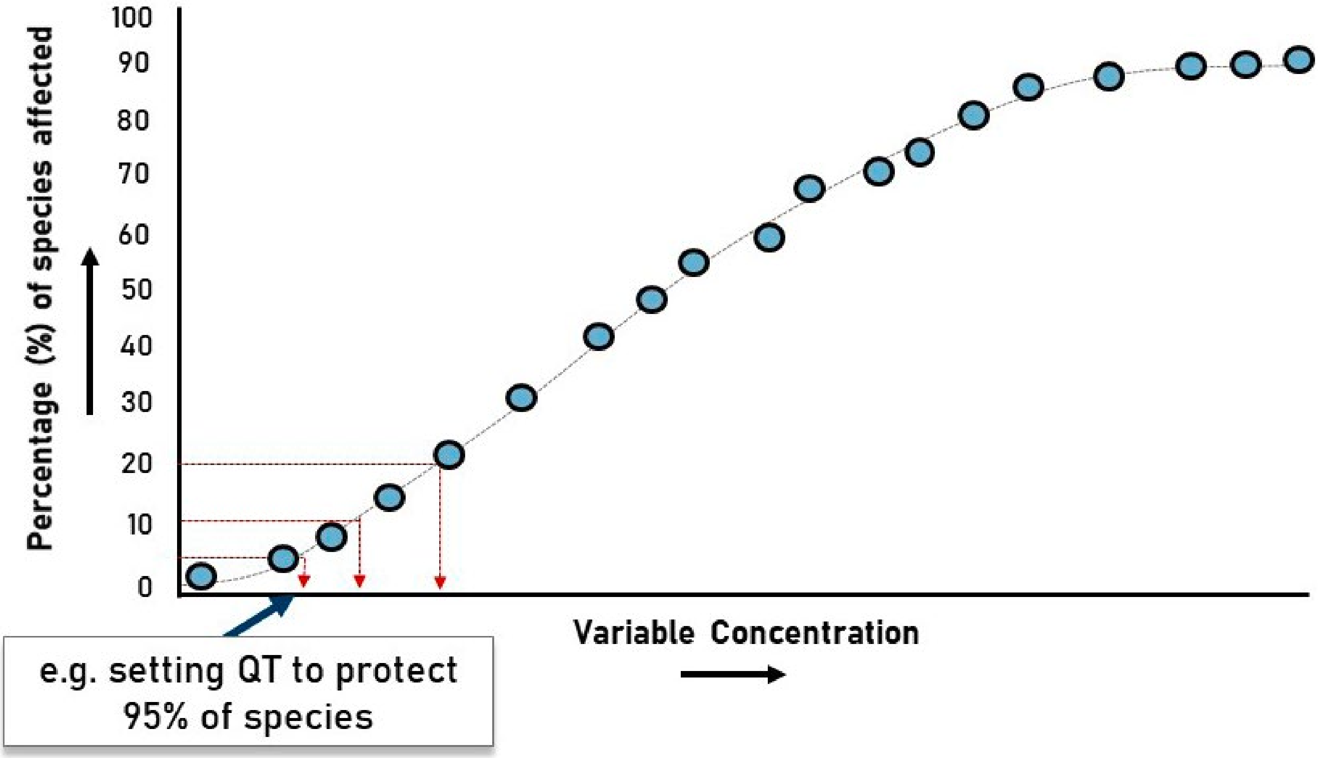
The most recent international review of **QTs for toxicants in water**, linked to the protection of aquatic ecosystems, was carried out by Australia and New Zealand (Australia and New Zealand Government, 2018) as part of their review of the 2000 guidelines for these nations (ANZECC, 2000) (for more information, refer to Appendix A). As it is unlikely that there will be sufficient (and appropriate) toxicological data within the WIO region to derive QTs for toxicants, the Australian and New Zealand QTs for toxicants in water were adopted as recommended QTs for the WIO region (Australia and New Zealand Government, 2018) unless otherwise indicated. The motivation here is three-fold, namely:

- These recommended QTs were based on most recent international review
- They were derived from both southern and northern hemisphere data sets (Warne *et al.*, 2018) (WIO region stretches across both hemispheres)
- Their application followed a transparent and conservative approach, aimed at protecting 95% or 99% of aquatic species

Note: For most toxicants in water a 95% protection level and 99% protection level QT is posed. Where these are provided it is recommended that, as a general rule, these be applied as follows:

- 99% of species protected, apply to pristine areas, conservation areas and areas of high ecosystem value
- 95% of species protected, apply to other coastal and marine waters.

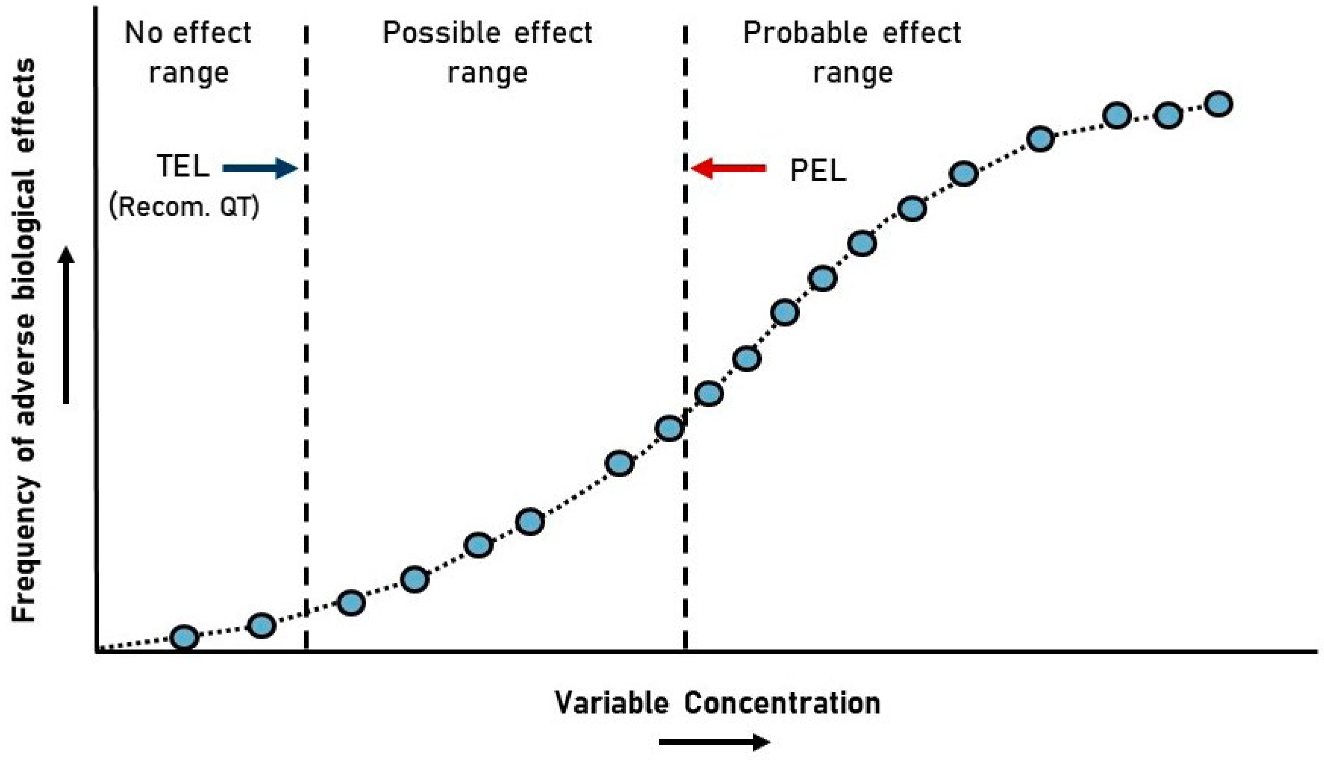
Figure 2.1 **Conceptualizing the SSD Approach typically adopted in deriving QTs for toxicants** (Source: adapted from Warne *et al.*, 2018).



This builds on the previous WIO guidelines (UNEP *et al.*, 2009) that also adopted the then Australian and New Zealand QTs for toxicants in water (as per ANZECC, 2000), which at the time represented the most recent international review and which interrogated both southern and northern hemisphere data sets.

QTs for toxicants in sediments should also ideally be derived from a representative set of site-specific field and/or laboratory tests using local species. However, as for toxicants in water, it is not likely that countries in the WIO region will have sufficient locally relevant data—at least not in the short-term. Indeed, even Australia and New Zealand considered their own effects data sets for sediments to be insufficient for the derivation of such QTs (Simpson *et al.*, 2013). Their recommended QTs for toxicants in sediments, therefore, are adopted from international best practice (Australia and New Zealand Government, 2018) that originally stems from an approach adopted in the National Status and Trends Program by the US National Oceanic and Atmospheric Administration (NOAA) (Long and Morgan, 1990; Long *et al.*, 1995). MacDonald et al. (1996) expanded on the original studies and developed recommended saltwater sediment QTs, by expanding the saltwater database, developing so-called threshold effect level (TEL) and a probable effect level (PEL) concentration as illustrated in Figure 2.2 (for more information, refer to Appendix A). The latter was also adopted for the Canadian sediment QTs (CCME, 2002). The cut-off between the "No effect range" and the "Possible effect range" ("TEL value") was considered as the most appropriate value to set as a target for the protection of aquatic ecosystems. Therefore, as per the previous WIO guidelines (UNEP *et al.*, 2009), it is proposed that the TEL (MacDonald et al., 1996) be adopted as the recommended sediment QT for the WIO region.

Figure 2.2 **Illustration of derivation of threshold effect level (TEL) and probable effect level (PEL) for sediment QTs** (Source: adapted from MacDonald *et al.*, 1996).



For the purpose of these guidelines, toxicants have been categorized as follows:

- Non-metallic inorganics
- Metals (including tributyltin)
- Petrochemicals (mono- and poly-cyclic aromatic hydrocarbons)
- Agrochemicals (pesticides and herbicides)
- Pharmaceuticals
- Other organic toxicants.

Note: Endocrine disrupting chemicals (EDCs) are defined as "… *an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub) populations*" (UNEP and WHO, 2013). These substances interfere with hormone action, and in doing so can produce adverse effects on human and wildlife health.

What is known about EDCs is that they are chemically diverse, primarily include human-made chemicals, and are used in a wide range of materials and goods. They include an array of chemicals, such as metal compounds (e.g. tributyltin), agrochemicals (e.g. pesticides and herbicides) and other organic toxicants (e.g. PCBs). However, only a fraction of the potential EDCs in the environment are currently understood and there is a lack of data on the endocrine effects of these types of compounds.

Therefore, while these guidelines do recommend QTs for some constituents known to be EDCs, the ecotoxicological databases from where these QTs were derived may not have included endocrine-related effects (UNEP and WHO, 2013).

The current knowledge on EDCs is insufficient to make recommendations on QTs specifically pertaining to endocrine effects. This will need to be considered in future revisions of the guidelines when such data becomes available.

2.2 Recommended Quality Targets for Protecting Marine Aquatic Ecosystems

This section provides the recommended QTs for the four constituent types considered most appropriate for the protection of aquatic ecosystems (e.g. Table 1.1), and provide information on the selected constituents, including a short description, their natural occurrence, interdependencies and fate in the environment, as well as recommended methods and units of measurement. Common sources of these pollutants are discussed in the *Strategic Framework for C&MWQM for the WIO Region* (UNEP *et al.*, 2022b).

2.2.1 Objectionable substances

Recommended target	• **Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance.** • **Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits.** • **Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins, and which would be a danger, cause nuisance or interfere with any designated/recognized use.**
Description	Objectionable substances refer to visible non-natural particles, debris, oil, grease, wax, scum, foam, submerged (just below water surface) objects or any other visible substances, including plastics.
Natural occurrence	Objectionable substances typically do not occur naturally, although nutrient enrichment often results in nuisance algal growth that then becomes an “objectionable substance”.
Interdependence & Fate in the environment	Objectionable substances are transported by sea currents and tend to accumulate in areas where sea currents converge, are deposited in areas of low turbulence (“depositional areas”), or are washed onto seashores.
Method	Objectionable substances can be measured quantitatively in marine waters (see Barnardo and Ribbink, 2020).
Impacts & Thresholds	
Typical impacts which may be associated with the presence of objectionable substances include smothering, ingestion entanglement or physical injury to marine life (e.g. benthic communities, sea birds and seals). Objectionable matter may end up on beaches and make these unpleasant for bathing and negatively affect tourism.	

2.2.2 Physico-chemical properties

Temperature

Recommended target	**Temperature range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Temperature is a basic property of water and is important in the regulation or triggering of many physiological processes in marine organisms.
Natural occurrence	In the WIO region, mostly situated in tropical regions, seawater temperature typically varies between 20–30 °C, but is lower along the south and west coasts of South Africa. Upwelling is a seasonal phenomenon in some parts of the region, when warmer surface waters are replaced by cooler bottom water (Bakun *et al.*, 1998; Kanagev *et al.*, 2009).
Interdependence & Fate in the environment	Generally, temperature is not interdependent on other water quality properties or constituents, but is primarily driven by atmospheric temperatures and oceanic processes although excessive suspended solids can lead to increase in temperature due to insolation.
Method	Temperature is best measured using a calibrated *in situ* probe, but a thermometer can also be used. Unit: °C

Impacts & Thresholds

Biota	Range (°C)	Effect	Reference
Seagrass	<9	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl and McRoy (1971)
	> 30	*Zostera marina* displays decrease in photosynthesis rates	Biebl and McRoy (1971)
	> 34	*Zostera marina* tissue death within 12 hrs	Biebl and McRoy (1971)
	38	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl and McRoy (1971)
	11.5–26	Optimal growth for temperate species	Lee *et al.* (2007)
	23–32	Optimal growth for tropical/subtropical species	Lee *et al.* (2007)
Shrimp	11–39	Optimum temperature range for the shrimp *Penaeus indicus* (adults)	McClurg (1974)
	24–34	Optimum temperature range for the shrimp *Penaeus monodon* (adults)	Kungvankij *et al.* (1986 a,b)
	26–31	Optimum temperature range for shrimp larvae, but sudden changes should not exceed 2oC	Kungvankij *et al.* (1986 a,b)
	27.9	Optimum range for maturation of brood stock of Penaeid prawns	Shrimp Farming Short Course (1990)
	26–30	Optimum temperature range for Penaeid prawns larvae	Lee and Wickens (1992)

Coral	29	Loss of zooxanthellae and coral tissue protein in *Pocillopora damicornis*	Glynn and D'Croz (1990)
	30	Severe bleaching in *Pocillopora damicornis*, and death within 9 weeks	Glynn and D'Croz (1990)
	32	Severe bleaching in *Pocillopora damicornis*, and death within 4 weeks	Glynn and D'Croz (1990)
Coral fish	<20	Spawning ceased in angelfish (*Centropyge argi*) and Bluehead wrasse (*Thalassoma bifasciatum*)	Holt and Riley (unpublished report)
	<22	Spawning ceased in Clown wrasse (*Halichoeres maculipinna*)	Holt and Riley (unpublished report)
	23–25.5	Temperature range for optimal egg production in angelfish (*Centropyge argi*)	Holt and Riley (unpublished report)
	27–30	Temperature range for optimal egg production in Bluehead wrasse (*Thalassoma bifasciatum*)	Holt and Riley (unpublished report)
	24–29	Temperature range for optimal egg production in Clown wrasse (*Halichoeres maculipinna*)	Holt and Riley (unpublished report)
	>28	Spawning ceased in angelfish (*Centropyge argi*)	Holt and Riley (unpublished report)

Salinity

Recommended target	**Salinity range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Salinity refers to the dissolved salt content in seawater. The major constituents in 1 kg of seawater with a salinity of 35 parts per thousand (ppt) are: Na^+ – 10.78 g; Mg^{2+} – 1.28 g; Ca^{2+} – 0.41 g; K^+ – 0.40 g; $Sr2^+$ – 0.01 g; Cl^- – 19.35 g – SO_4^{2-} – 2.71 g; HCO_3^- – 0.11 g; Br^- – 0.07 g; CO_3^- – 0.01 g; $B(OH)_4^-$ – 0.001 g; $B(OH)_3^-$ – 0.02 g (Millero and Sohn 1992). The practical salinity of a sample of seawater is defined in terms of the conductivity ratio, K15, defined by (Open University, 1989): Conductivity of seawater sample (at 15 °C, 1 atm pressure) ÷ Conductivity of standard KCl solution (32.4356 g/kg)
Natural occurrence	Salinity in the WIO region shows large variations as a result of high seasonal and annual variability in rainfall and evaporation rates. Sea surface salinity is also affected by anomalous anticyclonic winds blowing in the Southeast Indian Ocean and preventing the export of saltier water from the WIO region. Overall, the salinity ranges between 32 and 37 ppt, but with large local differences (Kanagev *et al.*, 2009).
Interdependence & Fate in the environment	Salinity is not dependent on other water quality properties or constituents.
Method	Salinity is best measured using a calibrated *in situ* probe. Where the ionic strength ("salt content") of seawater has been measured as Electrical Conductivity (EC in mS/m) conversion factors can be used (Riley and Skirrow 1975). Where the salt content has been measured as mg/ℓ Total Dissolved Solids (TDS), it can be converted to salinity by dividing the TDS value by 1000. Unit: According to The International System of Units (SI) salinity is unitless, being the ratio between two electrical conductivities.

Impacts & Thresholds			
Biota	**Range (°C)**	**Effect**	**Reference**
Phytoplankton	<15	Significant growth changes in *Skletonema costatum*	Su *et al.* (1990)
	>30	Significant growth changes in *Skletonema costatum*	Su *et al.* (1990)
Green algae	Hyposalinity	*Ulva* and *Enteromorpha* are vulnerable to changes in salinity – flush of algal growth	Branch *et al.* (1990)
	Declining salinity	*Cladophara* sp. Shows inhibited photosynthesis and increase in osmotic stress	Wieche and Davenport (1987)
Seagrass	15–35	Maximum growth of *Zostera capensis*	Adams and Bate (1994)
	40	*Zostera capensis* Setchell displays tissue alteration	Iyer and Barnabas (1993)
	60	*Zostera capensis* Setchell leaf blade cells damaged	Iyer and Barnabas (1993)
	>20	inhibition of seed germination and seedling survival of *Zostera marina*.	Kamermans *et al.* (1999)
	>32	Decrease in shoot and leaf production in mature *Zostera marina*	Kamermans *et al.* (1999)
	<30	Significant decrease in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
	>40	Significant decrease in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
	0 and 70	100% mortality in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
Shrimp	1–75	*Penaeus indicus* can tolerate such a wide salinity range if acclimation time is at least 48 hrs (adults)	McClurg (1974)
	15–30	Tolerant salinity range, above and below which *Penaeus monodon* displays physiological stress (adults)	Kungvankij *et al.* (1986 a,b)
	18	Salinity limit for *Penaeus semisulcatus*, above which respiration decreased and mortality occurs (adults)	Clark (1992)
	25–40	Tolerant salinity range, above and below which *P. indicus* displays physiological stress (adults)	Kungvankij *et al.* (1986 a,b)
	27–32	Tolerant salinity range, above and below which *P. japonicus* displays physiological stress (adults)	Kungvankij *et al.* (1986 a,b)
	30–32	*P. monodon* larval tolerant range (larvae)	Kungvankij *et al.* (1986a,b)
	33.5	Maturation of *P. monodon* broodstock (larvae)	Lee and Wickens (1992)

Crabs	<5	*Scylla serrata* zoeae mortality within 4 months	Hill (1974)
	<10	*S. serrata* female crabs do not release their eggs	Hill (1974)
	<10	*S. serrata* larvae inactive	Hill (1974)
	<17,5	*S. serrata* significant larval mortality	Hill (1974)
	15–25	*S. serrata* oxygen uptake of adult crabs decreased significantly at 22, 27, and 32 °C	Hill (1974)
	23–25	*S. serrata* 46% survival of first stage zoeae	Hill (1974)
	21–24	*S. serrata* faster growth rate of postlarvae	Hill (1974)
	>25	*S. serrata* 100% zoeae mortality and significant growth rate reduction of postlarvae	Hill (1974)
Bivalve Molluscs	7	*Macoma litoralis* lowest salinity tolerance	Matthews and Fairweather (2004)
	13–45	Optimum salinity range for *Solen cylindraceus*, above which physiological functioning is impaired	De Villiers and Allanson (1989)

Dissolved oxygen

Recommended target	**Dissolved oxygen concentration defined by the 20%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	This property refers to the amount of dissolved oxygen present in water and is an essential requirement for most heterotrophic marine life.
Natural occurrence	Dissolved oxygen is a non-conservative property of seawater and its natural concentrations in surface waters are largely governed by local temperature/salinity regimes, organic content and extent of primary productivity (Grasshoff *et al.*, 1999). For example, then saturated concentration at salinity 35 and temperature 20 °C is 7.4 mg/ℓ, while at 30 °C it drops to 6.2 mg/ℓ. Dissolved oxygen concentrations in seawater below thermo- or haloclines can be naturally low, owing to biological demand and limited replenishment from the atmosphere.
Interdependence & Fate in the environment	Generally, the distribution of dissolved oxygen in the ocean is the net result of near equilibrium of atmospheric oxygen in the surface mixed layer and *in situ* biological processes. In oxygenated surface waters the dissolved oxygen saturation levels are dependent on water temperature and salinity (Grasshoff *et al.*, 1999). *In situ* primary production may result in a diurnal signal in dissolved oxygen—during daytime photosynthesis increases concentrations while at night respiration decreases concentrations (Baumann and Smith, 2018). Often wastewater's oxygen-related characteristics are presented, for example as a five-day biochemical oxygen demand (BOD) or chemical oxygen demand (COD). These parameters give an indication of the amount of oxygen which might be consumed by a wastewater plume when discharged into a receiving water body. However, in receiving marine waters it is more appropriate to measure the actual amount of oxygen in solution, expressed as dissolved oxygen (DO) (Lusher, 1984).

<table>
<tr><td>Method</td><td colspan="3">Dissolved oxygen is best measured using a calibrated <i>in situ</i> probe. Water samples can be taken to conduct a Winkler titration. However, care should be taken when sampling sub-surface waters to prevent aeration (e.g. use flow through system to collect sample) (Strickland and Parsons, 1972).
Unit: mg/ℓ (where DO is recorded in mℓ/ℓ it can be converted to mg/ℓ by multiplying by 1.4290 then divided by the density of seawater at the specific temperature).</td></tr>
<tr><th colspan="4">Impacts & Thresholds</th></tr>
<tr><th>Biota</th><th>Range (mg/ℓ)</th><th>Effects</th><th>Reference</th></tr>
<tr><td>Coral</td><td>4.0–4.5</td><td>Optimum range for coral productivity</td><td>Edwards <i>et al.</i> (1987)</td></tr>
<tr><td rowspan="6">Shrimp</td><td>0.5–1.2</td><td>Lethal range from <i>Penaeid</i> adults</td><td>Allan and Maguire (1991), Chamberlain (1988)</td></tr>
<tr><td>3.7</td><td>Level necessary for normal biological functioning in <i>Penaeus monodon</i> (adult)</td><td>Chamberlain (1988)</td></tr>
<tr><td>>4</td><td>Tolerable range for adults of Penaeid family (adult)</td><td>Evans (1993)</td></tr>
<tr><td>0.74</td><td>Lethal concentration for <i>Penaeus chinensis</i> juveniles</td><td>Chen and Nan (1992)</td></tr>
<tr><td>0.9</td><td>LC_{50} (96hrs) concentration for <i>P. monodon</i> juveniles</td><td>Allan and Maguire (1991)</td></tr>
<tr><td>2.2</td><td>Critical concentration for <i>P. monodon</i> juveniles</td><td>Chamberlain (1988)</td></tr>
<tr><td rowspan="3">Abalone</td><td><4</td><td>Mortality of abalone adults</td><td>Hahn (1989)</td></tr>
<tr><td>>110</td><td>Adults display abnormal behaviour</td><td>Hahn (1989)</td></tr>
<tr><td>>150</td><td>Prolonged exposure results in death</td><td>Hahn (1989)</td></tr>
<tr><td rowspan="2">Rock Lobster</td><td>0.4</td><td>Critical limit for <i>Palinurus</i> sp.</td><td>Harvey and Przybylak (1985), Wessels (1993)</td></tr>
<tr><td>2</td><td>Significant mortality in <i>Palinurus</i> sp.</td><td>Harvey and Przybylak (1985), Wessels (1993)</td></tr>
</table>

pH

Recommended target	**pH range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	pH is a measure of the concentration of hydrogen ions in solution, according to the expression: $pH = -\log_{10}[H^+]$, where H^+ is the hydrogen ion concentration. At a pH less than seven, water is acidic, while at a pH greater than seven, water is alkaline.
Natural occurrence	The pH of seawater typically ranges between 7.9 and 8.2 (Huguenin and Colt, 1989). Seawater in equilibrium with atmospheric CO_2 is slightly alkaline, with a pH of about 8.1–8.3. The pH may rise through rapid uptake of CO_2 during photosynthesis (Open University, 1989). *In situ* primary production, therefore, may result in a diurnal signal in pH where during daytime photosynthesis increases levels, while at night respiration decreases levels in water (Baumann and Smith, 2018).

Interdependence & Fate in the environment	Aqueous solutions containing salts of weak acids or bases, such as seawater, show a resistance to pH change (known as buffering) (Riley and Skirrow, 1975). The pH of water can be affected by algal photosynthesis—algae extract CO_2 from the water, decreasing the carbonic acid concentration and increasing the pH in the process.
Method	pH is best measured using a calibrated *in situ* probe, but can also be measured using a probe in the laboratory. Unit: Unitless ($\log_{10}$ of the hydrogen ion concentration)

Impacts & Thresholds

Biota	Range	Effects	References
Coral	7.2	Decreased calcification rate in *Stylophora pistillata*	Venn *et al.* (2013)
	7.3	Shift in associated bacterial community in *Acropora eurystoma* towards pathogenic-type bacteria	Meron *et al.* (2011)
	6.2	Shift in associated bacterial community in *Porites compressa* towards pathogenic-type bacteria	Vega-Thurber *et al.* (2009)
Molluscs	7.1–7.8	Reduction in settlement of benthic molluscs	Cigliano *et al.* (2010)

Total Suspended solids (TSS)

Recommended target	**Total suspended solid (TSS) defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	TSS is a measure of water clarity and refers to particulate inorganic and organic matter that is in suspension in the water column.
Natural occurrence	Naturally occurring suspended materials include fine inorganic (e.g. silt and clays) and organic matter (e.g. plankton and other microscopic organisms). These are usually more evident during stormy conditions, plankton blooms and periods of high river runoff. TSS may also be introduced to the water column through resuspension of natural bottom debris and sediment during turbulent conditions, usually because of strong wind and wave action, and river runoff. Concentrations in coastal water typically are less than 5 mg/ℓ, but can vary naturally depending, for example on river runoff and weather conditions.
Interdependence & Fate in the environment	Suspended solids are usually kept in suspension as their density is like that of the water. However, suspended solids may settle from the water column and be deposited onto sediments under calmer conditions.
Method	Suspended solids are determined gravimetrically by collecting the suspended matter from a known volume of seawater (usually one litre) onto GF/C glass fibre filter paper (Standard Methods 1989). It is critically important to rinse the filter with deionized water prior to drying to wash out salts that may crystalize on the filter, resulting in an over-estimation of the suspended solids concentration. Remote sensing technologies have also been used to measure TSS in coastal and marine waters (e.g. Jiang *et al.*, 2021). Unit: mg/ℓ

Impacts & Thresholds

Suspended solids (e.g. clay, silt and organic matter, plankton and other microscopic organisms) interfere with light penetration and thus cause turbidity. When light penetration is blocked, photosynthesis can be reduced, affecting the productivity of marine flora such as seagrasses. Suspended solids also can smother aquatic organisms, and carry contaminants, such as metal and toxic organic compounds. High suspended solids concentrations may also contribute to increased water temperature through greater adsorption of heat. Further, lower visibility can affect predator–prey interactions, affecting foraging efficiency and prey escape behaviour.

Turbidity

Recommended target	**Turbidity is defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), considering possible differentiation between seasons or episodic events.**
Description	Turbidity is another measure of water clarity and is caused by colloidal suspensions (particle size between 0.001 µm and 0.1 µm) giving water a “murky” appearance.
Natural occurrence	Natural turbidity in water is caused by colloidal suspension (particle size between 0,001 µm and 0,1 µm) of, for example, clays and silt, usually introduced through river run-off. Turbidity may also be introduced to the water column through re-suspension of natural sediment deposits during turbulent conditions caused by strong wind and wave action. Concentrations in tropical waters were found to average 3 FTU, but can vary naturally depending, for example on river runoff and weather conditions.
Interdependence & Fate in the environment	Owing to the high salt content of seawater, natural colloidal suspensions (causing turbidity) usually coagulate with specific ions and precipitate out.
Method	Turbidity is best measured using a calibrated *in situ* probe, but can also be measured using a turbidimeter in the laboratory. Remote sensing technologies have also been used to measure turbidity in coastal and marine waters (e.g. Ouillon *et al.*, 2008; Ha and Koike, 2011). Unit: NTU (Nephelometric turbidity units) or Formazin Nephelometric Unit (FNU), which are similar in that both measures scattered light at 90 degrees from the incident light beam, but FNU is measured with an infrared light source method whereas NTU is measured with a white light.
Impacts & Thresholds	
High turbidity reduces light penetration, which may reduce photosynthesis, and affect the productivity of marine flora such as seagrasses. Associated colloidal matter also can smother aquatic organisms, and carry contaminants, such as metal and toxic organic compounds. Such matter may also contribute to increased water temperature through greater adsorption of heat. Further, lower visibility can affect predator–prey interactions, affecting foraging efficiency and prey escape behaviour.	

2.2.3 Inorganic nutrients

Dissolved Nitrite

Recommended target	**The nitrite (NO_2^-) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Nitrite (NO_2^-) occurs in seawater as an intermediate compound in the microbial reduction of nitrate, or in the oxidation of ammonia (Grasshoff *et al.*, 1976): $NO_3^- \leftrightarrow \mathbf{NO_2^-} \leftrightarrow NO \leftrightarrow N_2O \leftrightarrow N_2$ or $NH_4^+ \leftrightarrow \mathbf{NO_2^-} \leftrightarrow NO_3^-$
Natural occurrence	The natural concentration of NO_2^-N in seawater is usually very low at < 1.4 µg/ℓ. However, in zones where dissolved oxygen concentrations are low, higher NO_2^-N concentrations may occur. Following upwelling, concentrations can also increase, indicative of higher primary production (Grasshoff *et al.*, 1976).
Interdependence & Fate in the environment	Low dissolved oxygen concentrations favour the formation of nitrite (Riley and Chester, 1983).

Method	NO_2^- in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff *et al.*, 1983). Unit: µg/ℓ NO_2^-N or µmol/ℓ NO_2^-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).		
Impacts & Thresholds			
Biota	**Range (µg/ℓ as N)**	**Effects**	**References**
Coral	14 000 (Total Dissolved inorganic nitrogen (DIN))	Maximum limit for coral productivity	Lapointe *et al.* (1992)
Shrimp	100–250	Safe level of nitrite for Penaeid adults	Chamberlain (1988), Lee and Wickens (1992)
	100–300	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course (1990)
	110	Safe level for *Penaeus monodon* larvae	Chen and Chin (1988)
	1,360	Safe level for *P. monodon* post-larvae	Chen and Chin (1988)
	2,300	Safe concentration for *Penaeus chinensis* juveniles	Chen *et al.* (1990a)
	3,800	Safe concentration for *P. monodon* juveniles	Chen and Lei (1990)
	10,600	Safe concentration for *P. monodon* adolescents	Chen *et al.* (1990a)
	171,000	LC_{50} value (over 96 hrs) for *P. monodon* adolescents	Chen *et al.* (1990a)
Rock Lobster	5,000	Favourable concentration for *Palinurus* sp.	Wessels (1993)
The toxicity of nitrite, while still formidable, is significantly reduced in seawater due to the high concentration of chloride and calcium (Huguenin and Colt, 1989).			

Dissolved Nitrate

Recommended target	**The nitrate (NO_3^-) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Nitrate (NO_3^-) is the final oxidation product of inorganic nitrogen compounds in water and is the only thermodynamically stable oxidation level of nitrogen in water in the presence of oxygen (Grasshoff *et al.*, 1976): $N_2 \leftrightarrow NO_2^- \leftrightarrow NO \leftrightarrow N_2O \leftrightarrow \mathbf{NO_3^-}$ **or** $NH_4^+ \leftrightarrow NO_2^- \leftrightarrow \mathbf{NO_3^-}$

Natural occurrence	Natural concentrations of NO_3^-N in oxygenated seawater range between 1.4–630 µg/ℓ. Concentrations usually increase with depth, i.e. surface depletion versus enrichment at depth (Grasshoff *et al.*, 1983). Nitrate is depleted in surface waters where biological production is high. It is usually the limiting nutrient in seawater (i.e. when this nutrient is exhausted, production ceases) (Open University 1989). In upwelling areas, the supply rate of NO_3^-N is considerably higher than uptake rates, resulting in high net concentrations. For this reason, the NO_3^- concentration can be applied as an indicator for upwelling, together with temperature measurements (Grasshoff *et al.*, 1976).
Interdependence & Fate in the environment	In many marine waters, nitrate is considered the micronutrient controlling primary production in the euphotic surface layers. The concentration of nitrate in these layers is governed by the advective transport of nitrate into surface layers, the microbial oxidation of ammonia and the uptake by primary producers. If light penetration is sufficient the uptake rate is usually much faster than the processes transporting the nitrate into the surface layers. Therefore, the nitrate concentration in most ocean surface waters is close to zero (Grasshoff *et al.*, 1976).
Method	NO_3^-N in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff *et al.*, 1983). Unit: µg/ℓ NO_3^-N or µmol/ℓ NO_3^-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts & Thresholds

Biota	Range (µg/ℓ as N)	Effects	References
Coral	14,000 (Total DIN)	Maximum limit for coral productivity	Lapointe *et al.* (1992)
Shrimp	1,000–2,000	Favourable range for Penaeid adults	Lee and Wickens (1992)
	10–40	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course (1990)
	1,000	High mortality rate of *Penaeus monodon* larvae within 40 hrs	Muir *et al.* (1991)

Dissolved total ammonia

Recommended target	**The total ammonia (NH_3 plus NH_4^+) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**	
Potential interim targets for WIO (Total inorganic N)	**Seagrass**	**500 µg/ℓ**
	Mangroves	**1 000 µg/ℓ**
	Coral reefs	**15 µg/ℓ**
Description	In aqueous solutions ammonia is present in two forms, ionized (NH_4^+) and unionized (NH_3) (Bower and Bidwell, 1978): $NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$ NH3 is regarded as the toxic form of ammonia because it is uncharged and lipid soluble, whereas hydrated ammonium ions (NH_4^+) are non-toxic and act as a nutrient to primary producers.	

Natural occurrence	Ammonia is excreted directly by animals together with urea and peptides. The concentration of ammonia in seawater shows considerable variations and can change rapidly. In unpolluted oxygenated seawater, Total ammonia-N concentrations are usually low, but in deeper anoxic water, concentrations can be naturally high (Grasshoff *et al.*, 1976).
Interdependence & Fate in the environment	Soluble and particulate organic nitrogen compounds, resulting from decaying organisms together with those excreted by plants and animals, are rapidly broken down to NH_3 by various species of proteolytic bacteria. The relative proportions of NH_3 and NH_4^+ in solutions depend on temperature, pH, and to a lesser extent salinity. The concentration of NH_3 increases with elevated temperatures and pH values, and decreases with higher salinities. At salinities common in seawater (~35 ppt) there is up to one fifth less unionized ammonia (NH_3) than in freshwater at the same temperature and pH. Thus, in seawater Total Ammonia-N is primarily present as NH_4^+ (Bower and Bidwell, 1978).
Method	Total ammonia-N (NH_3-N plus NH_4^+-N) in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et *al.*, 1983). Unit: µg/ℓ Total Ammonia-N or µmol/ℓ Total Ammonia-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts & Thresholds			
Biota	**Range (µg/ℓ as N)**	**Effects**	**References**
Coral	14,000 (Total DIN)	Maximum limit for coral productivity	Lapointe *et al.* (1992)

Dissolved reactive phosphate

Recommended target	**The reactive phosphate (PO_4^{2-}) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events**
Description	Reactive phosphate (or inorganic phosphate) is the most common form of phosphorous (P) used by primary producers, and therefore provides a good indication of the amount of available P for photosynthesis. The most probable reactive phosphate (PO_4^{2}) species in oxygenated seawater are H_2PO_4, $NaHPO_4$ and $MgHPO_4$ (Riley and Skirrow, 1975).
Natural occurrence	Phosphorus (P) occurs naturally and abundantly in rocks and other mineral deposits and is gradually released by the weathering rocks and mineral deposits forming ions soluble in water. In seawater, P is typically found as inorganic phosphorus (referred to as inorganic phosphate or reactive phosphate), but also as particulate and dissolved organic forms (Grasshoff *et al.*, 1976). Natural concentrations of PO_4^{2-}–P in seawater can vary greatly, but have been found to range between 31 and 109 µg/ℓ, usually depleted in surface waters with bottom waters more enriched (Riley and Chester, 1983). Upwelling also introduces higher PO_4^{2-}–P concentrations into surface waters.
Interdependence & Fate in the environment	PO_4^{2-} is taken up by primary producers in the euphotic zone, contributing to the removal of this nutrient in surface waters. In turn, phytoplankton is consumed by zooplankton and other animals that package most of their waste products into faecal pellets. On the decomposition of organic matter, this nutrient is returned to the water column. Under anoxic conditions, precipitated P can be re-solubilized from sediments.

<table>
<tr><td>Method</td><td colspan="3">PO_4^{2-}–P in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff <i>et al.</i>, 1983).
Unit: µg/ℓ PO_4^{2-}–P or µmol/ℓ PO_4^{2-}–P (the latter can be converted to µg/ℓ by multiplying with atomic mass of P, i.e. 31).</td></tr>
<tr><td colspan="4">Impacts & Thresholds</td></tr>
<tr><td>Biota</td><td>Range (µg/ℓ as P)</td><td>Effects</td><td>References</td></tr>
<tr><td>Coral</td><td>6.7–45.3</td><td>Concentration for normal growth in <i>Ulva lactuca</i>, sublethal concentration and effects unknown.</td><td>Ho (1987)</td></tr>
<tr><td>Coral</td><td>1,400</td><td>Maximum limit for coral productivity</td><td>Lapointe <i>et al.</i> (1992)</td></tr>
</table>

2.2.4 Non-metallic inorganic toxicants

Total ammonia (as toxicant)

<table>
<tr><td>Recommended target</td><td colspan="3">Total ammonia-N (NH_3-N plus NH_4^+-N) concentration should not exceed 500 µg/ℓ (99% protection) or 910 µg/ℓ (95% protection)</td></tr>
<tr><td>Description</td><td colspan="3">In aqueous solution ammonia is present in two forms, ionized (NH_4^+) and unionized (NH_3) (Bower and Bidwell, 1978): $NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$
NH_3 is regarded as the toxic form of ammonia because it is uncharged and lipid soluble, whereas hydrated ammonium ions (NH_4^+) are non-toxic and acts as a nutrient to primary producers.</td></tr>
<tr><td>Natural occurrence</td><td colspan="3">Ammonia is excreted directly by animals together with urea and peptides. The concentration of ammonia in seawater shows considerable variations and can change rapidly. In oxygenated unpolluted seawater, Total ammonia-N concentrations are usually low, but in deeper anoxic water, concentrations can be naturally high (Grasshoff <i>et al.</i>, 1976).</td></tr>
<tr><td>Interdependence & Fate in the environment</td><td colspan="3">Soluble and particulate organic nitrogen compounds, resulting from decaying organisms together with those excreted by plants and animals, are rapidly broken down to NH_3 by various species of proteolytic bacteria. The relative proportions of NH_3 and NH_4^+ in solutions depend on temperature, pH, and to a lesser extent salinity. The concentration of NH_3 increases with elevated temperatures and pH values, and decreases with higher salinities. At salinities common in seawater (~35 ppt) there is up to one fifth less unionized ammonia (NH_3) than in freshwater at the same temperature and pH. Thus, in seawater Total ammonia-N is primarily present as NH_4^+ (Bower and Bidwell, 1978).</td></tr>
<tr><td>Method</td><td colspan="3">Total ammonia-N (NH_3-N plus NH_4^+-N) in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff <i>et al.</i>, 1983).
Unit: µg/ℓ Total Ammonia-N or µmol/ℓ Total Ammonia-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).</td></tr>
<tr><td colspan="4">Impacts & Thresholds</td></tr>
<tr><td>Biota</td><td>Range (µg/ℓ as N)</td><td>Effect</td><td>Reference</td></tr>
<tr><td>Amphipoda</td><td>49,000</td><td>LC_{50} value (96 hrs) for <i>Ampelisca abdita</i></td><td>Kohn <i>et al.</i> (1994)</td></tr>
</table>

Shrimp	<20	Tolerable range for Penaeid adults in the presence of nitrite	Lee and Wickens (1992)
	80	Safe level for *Penaeus monodon* adults	Chen *et al.* (1990a)
	90–110	Safe level for Penaeid adults	Lega *et al.* (1992)
	110	Maximum level for Penaeid adults over 40 days	Chen and Lin (1992)
	450	Growth rate of Penaeid shrimps drastically declined by 50%	Kungvankij *et al.* (1986a)
	12,900	LC_{50} value (24 hrs) for *Palaemonetes pugio*	Burton and Fisher (1990)
	6,100–8,100	LC_{50} value (96 hrs) for *Penaeus japonicus* zoeae	Lin *et al.* (1993)
	10	Safe level for *Penaeus monodon* nauplii	Chin and Chen (1987)
	20–40	Concentration required for maturation of brood-stock in Penaeid larvae	Shrimp Farming Short Course (1990)
	32	Maximum limit for ammonia to *P. monodon* post-larvae	Chen and Tu (1991)
	52,700	LC_{50} value (96 hrs) for *P. japonicus* juveniles	Lin *et al.* (1993)
	60–183	*P. monodon* post-larvae displayed a 5% decline in growth and body condition	Chen *et al.* (1990b)
	100	Safe level for *P. monodon* juveniles	Chen and Lei (1990)
	>210	*P. monodon* displays a 5% reduction of growth rates over 3 weeks	Evans (1993)
	350	Maximum limit of ammonia to *P. japonicus* juveniles	Chen and Kou (1992)
	1,040	LC_{50} value (96hrs) for *P. monodon* post-larvae	Chin and Chen (1987)
	1,200–2,570	LC_{50} value (48hrs) for *P. pugio* juveniles	Burton and Fisher (1990)
	4,050	LC_{50} value (24 hrs) for *Scylla serrata* zoeae	Neil *et al.* (2005)
	6,540	100% mortality of *S. serrata* larvae	Neil *et al.* (2005)
	320–512	Safe ammonia level for *Homarus americanus* adult	Young-Lai *et al.* (1991)
	720–3,250	LC_{50} value (96 hrs) for *H. americanus* larvae	Young-Lai *et al.* (1991)
	3,500	Tolerable level for *Palinurus* sp.	Wessels (1993)
Molluscs	100	Favoured level for molluscan growth, above which severe physiological functioning is altered	Barnabe (1989)
Abalone	500	Growth inhibition in abalone	Hahn (1989)
Fish	>100	Growth inhibition of finfish	Morimura (1993), Tarazona *et al.* (1991)

Free Chlorine (Total Bromine)

Recommended target	**Total free chlorine should not exceed 0.5 µg/ℓ***
Description	Chlorine (Cl_2) is a chemical which is used as a disinfectant. Reactive oxygen species that are formed during the chlorination of seawater include hypobromous acid, hypobromite ion and bromamines.
Natural occurrence	Chlorine does not occur naturally in seawater. However, compounds such as chloroform and bromoform, as well as other halogenated compounds are produced naturally in the marine environment, for example by algae (Abarnou and Moissec, 1992).
Interdependence & Fate in the environment	Seawater chlorination differs greatly from that of freshwater primarily due to the high bromide concentration of seawater (~67 mg/ℓ). In the presence of bromide, free chlorine cannot exist in seawater as it instantaneously oxidizes bromide into bromine (which also acts as disinfectant harmful to marine organisms). Under typical seawater conditions (pH between 7.8 and 8.2), the un-dissociated form (HOBr) predominates with consequently higher reactivity and biocidal activity (Abarnou and Moissec, 1992). In coastal waters, ammonia concentrations are usually lower (typically < 28 µg N/ℓ) N) and therefore bromine remains as hypobromous acid. When ammonia increases, bromamines may be formed. At pH 8.1, ammonia and bromine react with chlorine at comparable rates. Monochloramine, the more persistent species among the various oxidized chlorine-produced oxidants, may be found when ammonia concentrations increase or in lower pH conditions (Abarnou and Moissec, 1992). Hypobromous acid can also disproportionate into bromide and bromate. Bromate is formed during seawater chlorination and this reaction is accelerated by sunlight (Abarnou and Moissec, 1992). Chlorine can also combine with phenolic compounds to form chlorophenols, some of which can taint fish flesh at concentrations as low as 0,001 mg/ℓ (Hawkins, 1981). Paradoxically, free chlorine is therefore not found in seawater because of instantaneous bromide oxidation or combination with phenolic compounds to form chlorophenols.
Method	Because free chlorine cannot exist in seawater as it instantaneously oxidizes bromide into bromine, when measuring "free chlorine" in seawater, total bromine should be measured (which can be converted to chlorine equivalents using an appropriate *in situ* probe (Process Instruments, 2017). Unit: ug/ℓ as total bromine translated into free chlorine equivalent

** No QT provided for Australia and New Zealand, recommend Canadian QT (CCME, 1999, as revised 2002)*

Impacts & Thresholds

Biota	Range (µg/ℓ as ~N)	Effect	Reference
Phytoplankton	>400	Growth inhibition in *Skeletonema costatum*	Carpenter *et al.* (1972)
	1,500–2,300	Lethal range for *S. costatum*	Carpenter *et al.* (1972)
	2,0000	Lethal range for *Chlamydomonas* spp.	Carpenter *et al.* (1972)
Molluscs	<300	Valve closure for 6 hrs in *Donax serra*	Hill (1977)
	>600	Immediate valve closure for 8 days in *D. serra*	Hill (1977)
	600–1,200	>90% mortality of *D. serra* after 14 days of exposure	Hill (1977)
Shrimp	37	LC_{50} value (48 hrs) for *Palaemonetes pugio* (adults)	Roberts and Gleeson (1978)
Rock lobster	410–2,900	LC_{50} value (over 48 hrs) for *Homarus americanus* larvae	Capuzzo (1979)

Free Cyanide

Recommended target	**Free cyanide concentration should not exceed 2 µg/ℓ (99% protection) or 4 µg/ℓ (95% protection)**
Description	Free cyanide is bioavailable and refers to either molecular hydrogen cyanide (HCN) or ionic cyanide (CN^-), with HCN being the most toxic form (WHO, 1982). At a pH <7 free cyanide is present entirely as HCN. Above pH 11, free cyanide exists entirely as CN^-. In seawater the equilibrium species are HCN (90 %) and CN^- (10%).
Natural occurrence	No information could be obtained on natural occurrence of cyanide in marine waters.
Interdependence & Fate in the environment	The form of cyanide is dependent on pH, but is also influenced by temperature, as well as other properties such as constituents dissolved oxygen, salinity, sunlight and complexing agents. There is therefore a possibility of a multitude of complex metallo-cyanides existing in aquatic environments, each with its own physical and chemical properties. The toxicity of cyanide increases if the pH levels decreases, forming extremely toxic HCN (WHO, 1982).
Method	Common methods for measuring cyanide include colorimetry, titrimetry and potentiometry (ANZECC, 2000). Unit: µg/ℓ as CN^-
Impacts & Thresholds	
Cyanide interferes with cellular respiration. Chronic effects of cyanide include developmental abnormalities and lower reproductive potential, and negatively affect endocrine function. However, no specific data relevant to WIO region could be obtained.	

Fluoride

Recommended target	**Fluoride concentration should not exceed 5 000 µg/ℓ***
Description	Fluoride (F^-) is the stable form of fluorine, a very reactive element.
Natural occurrence	Fluoride occurs at a relatively high concentration in seawater, where concentrations of 1,300 µg/ℓ have been reported (Slooff *et al.*, 1988).
Interdependence & Fate in the environment	Fluoride shows a conservative type distribution in seawater, i.e. it shows a constant concentration relative to salinity (or chlorinity) as a result of its low reactivity in seawater, with a fluoride/chlorinity ratio (in parts per thousand) of $6.7 \pm 0.1 \times 10^{-5}$. However, in some localized bottom waters the ratio may reach 9.5×10^{-5} (Riley and Chester, 1983). Deviations from this narrow fluoride/chlorinity ratio generally indicate that man-made pollution is occurring or that seawater is mixing with freshwater in estuarine areas.
Method	In seawater, fluoride can be determined by molecular absorption spectrophotometry (Gomez *et al.*, 1988) or using an ion-selective electrode. Unit: µg/ℓ
** No QT provided for Australia and New Zealand, recommend limit provided by Slooff et al. (1988)*	
Impacts & Thresholds	
Concentrations below 5 000 µg/ℓ are not expected to have detrimental effects on marine organisms (Slooff *et al.*, 1988)	

Hydrogen sulphide

Recommended target	**Hydrogen sulphide concentration should not exceed 2 µg/ℓ***
Description	Hydrogen sulphide is a poisonous gas that readily dissolves in water. No heterotrophic life can exist in water containing hydrogen sulphide and affected areas are, therefore, transformed into oceanic “deserts” (Grasshoff *et al.*, 1976). The speciation of H_2S in seawater at 25 °C, pH of 8.1 and salinity of 35 ppt is H_2S (3.07 %), HS^- (96.93 %) and S^{2-} (1.9×10^{-4} %) (Millero, 1976).
Natural occurrence	Hydrogen sulphide is a frequent anoxic water component, attaining concentrations as high as 70 mg/ℓ under extreme conditions (Hutzinger, 1980).
Interdependence & Fate in the environment	Hydrogen sulphide behaves as a weak acid and is present in natural waters as both the un-dissociated compound and the HS^- ion (below a pH of 12 the concentration of S^{2-} ion is negligible). Hydrogen sulphide is very volatile and reacts rapidly with oxygen. Hydrogen sulphide is produced in anaerobic environments by the activities of sulphate-reducing bacteria, which derive energy from a process of anaerobic respiration: $2\,CH_2O + SO_4^{2-}\ _{\text{desulfovibrio}}\ 2\,HCO_3^- + H_2S$ The solubility of hydrogen sulphide in seawater is dependent on temperature and salinity (Douabul and Riley, 1979). In contact with oxygen, hydrogen sulphide is rapidly oxidized to sulphur in an acid medium, but slowly to sulphate in more neutral solutions like seawater (Grasshoff *et al.*, 1976).
Method	Hydrogen sulphide in seawater can be measured photometrically or titrimetrically, with the photometric method being most sensitive and accurate (Grasshoff *et al.*, 1983). Unit: µg/ℓ

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (US-EPA 2002)*

Impacts & Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Shrimp	<0.002	Favoured level for Penaeid adults	Lee and Wickens (1992)
	0.033	Safe level for *Penaeus monodon* (adults)	Chamberlain (1988)
	4	Severe mortality in Penaeid adults	Chamberlain (1988), Lee and Wickens (1992), Clark and Griffiths (1990)
	0.117	LC_{50} value (96 hrs) for *Penaeus indicus* juveniles at pH 6 - 6.3	Gopakumar and Kuttyamma (1996)
	0.189	LC_{50} value (96 hrs) for *P. indicus* juveniles at pH 7–7.3	Gopakumar and Kuttyamma (1996)
	4,000	100% mortality in *Penaeus japonicus*	Gopakumar and Kuttyamma (1996)
	5,900	No effect on growth or survival of *Penaeus indicus*	Hemens *et al.* (1975)
Crab	5,900	No effect on growth or survival of *Tylodiplax blephariskios*	Hemens *et al.* (1975)
Bivalve	2,400	No lethal effects in *Mytilus edulis* after 42 days	Wright and Davidson (1975)
	10,000	75% mortality in in *Mytilus edulis* after 14 days	Wright and Davidson (1975)
	30,000	100% mortality in in *Mytilus edulis* after 21 days	Wright and Davidson (1975)

Abalone	50	Growth inhibition in abalone	Hahn (1989)
	500	Mortalities in abalone	Hahn (1989)

2.2.5 Metals

Arsenic (As)

Recommended target	**Water**	**Total As [III] concentration should not exceed 2.3 µg/ℓ***	
		Total As [VI] concentration should not exceed 4.5 µg/ℓ*	
	Sediment	**As concentration should not exceed Threshold Effect Level = 7.24 µg/g (dry weight)**	
		Probable Effect Level = 41.6 µg/g (dry weight)	
Description	The dominant forms of inorganic As in seawater are arsenite (As [III]) (regarded as the most toxic and the predominant form under anaerobic conditions) and arsenate (As [V]) (the stable form in aerobic conditions). At typical pH of surface seawater (~8.2) As [III] exists mainly as an uncharged species, e.g. As (OH) and As (V) as the ion HAsO, the latter should be the predominant form at equilibrium (Hutzinger, 1982; Riley and Chester, 1983).		
Natural occurrence	The main natural pathways through which arsenic enters the marine environment from land are through weathering, including solubilization and transport of sediment, and vulcanism (WHO, 1982). The concentration of total arsenic in clean coastal and ocean waters is 1,000–3,000 µg/ℓ, with a mean of about 1,700 µg/ℓ (Andreae, 1979; Andreae and Andreae, 1989; Li, 1991). Lowest As concentrations occur in the spring when dissolved arsenate is scavenged by phytoplankton and suspended particles; concentrations increase in winter due to the remobilization of arsenic from sediments. The behaviour of arsenate resembles that of phosphate (Open University, 1989], which is known to undergo seasonal remineralization and mobilization, with peak remobilization often in late summer (Bower and Bidwell, 1978). A good correlation usually exists between concentrations of arsenate and phosphate in ocean water, suggesting that the vertical distribution of arsenic in the ocean is controlled by biological activity.		
Interdependence & Fate in the environment	In oxygenated seawater, arsenic usually present as arsenate (As[V]), but under reducing conditions arsenite (As [III]) predominates.		
Method	Arsenic in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), ICP/mass spectrometry (MS), and LC/MS/MS. The strength of acids used to digest sediment will influence the concentration determined. Unit: Total As – µg/ℓ (water) and µg/g dry weight (sediment)		
** Not sufficient data to derive a reliable QT (Australia and New Zealand Government, 2018), these should be treated as low reliability QT*			
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Phytoplankton	75	Phytoplankton biomass reduced	Eisler (1988)
	130	Growth inhibition in *Skletonema costatum*	Eisler (1988)
	1,000	*Tetraselmis chui* and *Hymenomonas carterae* are not affected	Bottino *et al.* (1978)

Algae	19–20	Reduced growth in algae	Eisler (1988)
	75	Reduction of chlorophyll-a in *Thalassiosira aestivalis*	Eisler (1988)
	300	Death of red algae species (*Champia parvula*)	Eisler (1988)
	580	Spore development of red algae *Plumaria elegans* stopped	Eisler (1988)
	27,300	LC_{50} value (96 hrs) for mullet species (*Chelon labrosus*)	Eisler (1988)
	60,000	LC_{50} value (192 hrs) for *Macoma balthica*	Eisler (1988)
Molluscs	2,000	Reduction of oxygen consumption in mud snail *Nassarius absoleus*	Eisler (1988)
	3,490	LC_{50} value (96 hr) for juvenile scallops *Argopecten irradians*	Nelson *et al.* (1976)
Crustacea	232	LC_{50} value (96 hr) for *Cancer* magister larvae	Martin *et al.* (1981)
	1,100 2,750	Acute toxicity to amphipods *Corophium insidiosum* and *Elasmopus bampo*	Reish (1993)
	7,500	Highest concentration tolerated by crab *Scylla serrata* for 96 hr without mortalities	Krishnaja *et al.* (1987)
	17,000	LC_{50} value (96 hr) for crab *S. serrata*	Krishnaja *et al.* (1987)
	2,319	Acutely lethal concentration for mysid *Mysidopsis bahia*	US-EPA (1984)
	25,000	Concentrations in excess required to affect survival of shrimp *Crangon crangon* (adult)	Madsen (1992)

Cadmium (Cd)

Recommended target	**Water**	**Total Cd concentration should not exceed 0.7 µg/ℓ (99% protection) or 5.5 µg/ℓ (95% protection)**
	Sediment	**Cd concentration should not exceed Threshold Effect Level = 0.68 µg/g (dry weight)**
		Probable Effect Level = 4.21 µg/g (dry weight)
Description	The most probable main species of cadmium in oxygenated seawater is $CdCl^+$, $CdCl_2$ and $CdCl_3^{-1}$ (Neff, 2002).	
Natural occurrence	Weathering and erosion result in rivers transporting large quantities of cadmium to the world's oceans. Deep sea vulcanism is also a source of cadmium. Concentrations ranging between 0.11 x 10^{-3} and 0.6 µg/ℓ have been reported for the most probable species ($CdCl^2$) in oxygenated seawater with a salinity of 35 ppt, while reported levels in marine sediment porewater range between 30 and 1,000 µg/ℓ (Riley and Chester, 1983; WHO, 1992a).	

Interdependence & Fate in the environment	Up to about 80 %, but usually less, of the cadmium in coastal seawater is complexed with dissolved or colloidal organic matter (Muller, 1996, 1998). The relative amounts of dissolved cadmium in the different cadmium complexes vary with seawater salinity (Neff, 2002). Increasing temperature increases the uptake and toxic impact of Cd. A decrease in Cd toxicity with increased salinities has been attributed to chloride complexation. The solubility of cadmium decreases in anoxic waters due to the presence of hydrogen sulphide (CdS is very insoluble). The organic content of seawater generally decreases the uptake and toxicity of Cd by binding and reducing its availability to organisms (WHO, 1992a, de Baar *et al.*, 1994, Yeats *et al.*, 1995). The vertical distribution of Cd in ocean waters is characterized by surface depletion and deep-water enrichment as a result of absorption of cadmium by phytoplankton in surface waters, which then settles to bottom sediments from where it is subsequently released. In contrast, cadmium is enriched in the surface waters of upwelling areas (not linked to pollution sources), which also leads to elevated levels of cadmium in plankton and shellfish (WHO, 1992a).
Method	Cadmium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cd – µg/ℓ (water) and µg/g dry weight (sediment)

Impacts & Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Diatoms	60	Growth inhibition in Chaetoceros species	Ismail *et al.* (2002)
Coral	5,000	Reduction of fertilization in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
Copepod	1,370	LC_{50} value (over 24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)
Polychaete	2,800	LC_{50} value (96 hrs) for *Sabellaria clandestinus* (adult)	Mohan *et al.* (1984)
Amphipod	1,320	LC_{50} value (96 hrs) for *Ampelisca abdita*	Kohn *et al.* (1994)
Molluscs	170–250	LC_{50} value (over 96 hrs) for *Donax faba*	Ong and Din (2001)
	>1,000	Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
	530	LC_{50} value for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Pesch and Stewart (1980)
	1,010	LC value for estuarine clams (species not reported)	Bonifacio and Montaño (1998)

Shrimp	1,850	LC$_{50}$ value (over 168 hrs) for *Palaemon* sp. (adult)	Ahsanullah (1976)
	200–400	LC$_{50}$ value for *Palaemon pugio* (adult)	Pesch and Stewart (1980)
	420–760	LC$_{50}$ (over 48 hrs) for *Palaemon pugio* (adult)	Burton and Fisher (1990)
	200	Severe growth and survival of *Penaeus japonicus* larvae	Brown and Mclachlan (1990)
	490	LC$_{50}$ value (14 days) for *Callianassa australiensis*	Ahsanullah and Arnott (1978)
	800	LC$_{50}$ value (48 hrs) for *Palaemontes vulgaris* juveniles	Burton and Fisher (1990)
	1,300	LC$_{50}$ value (48 hrs) for *Palaemontes pugio* juveniles	Burton and Fisher (1990)
	3,100	LC$_{50}$ value for *Penaeus indicus* postlarvae	Chinni and Yallapragda (2000)
Mollusc	1,800	LC$_{50}$ value (96 hrs) for *Donax spiculum* (adult)	Mohan *et al.* (1984)
	2,500	LC$_{50}$ value (96 hrs) for *Perna viridis* (adult)	Mohan *et al.* (1984)
	5,600	LC$_{50}$ value (96 hrs) for *Modiolus carvalhoi* (adult)	Mohan *et al.* (1984)
Echinoderms	95	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison (2005)
	>100	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison (2005)
Crab	1,350	LC$_{50}$ value (96 hrs) for *Emerita* sp. (adult)	Mohan *et al.* (1984)
Fish	27,300	LC$_{50}$ value for milkfish (species not reported)	Bonifacio and Montaño (1998)

Chromium (Cr)

Recommended target	**Water**	**Total C r[III] concentration should not exceed 7.7 µg/ℓ (99% protection) or 27 µg/ℓ (95% protection)**
		Total Cr [VI] concentration should not exceed 0.14 µg/ℓ (99% protection) or 4.4 µg/ℓ (95% protection)
	Sediment	**Cr concentration should not exceed Threshold Effect Level = 52.3 µg/g (dry weight)**
		Probable Effect Level = 160 µg/g (dry weight)
Description	Cr occurs naturally in the elemental state (Cr [0]) or in the trivalent oxidation (Cr [III]) state. Almost all the hexavalent chromium (Cr [VI]) in the environment arises from human activities, the most probable species being CrO$_4^{2-}$ and NaCrO$_4^-$. Cr [III] is an essential element, while Cr [VI] is extremely toxic. These two oxidation states have very different properties and biological effects on living organisms and should therefore be examined separately (a generalization of biological effects of Cr as an element cannot be made (WHO, 1988).	
Natural occurrence	Concentrations ranging between 0.1 and 2 µg/ℓ have been reported for the most probable species (CrO$_4^{2-}$ and NaCrO$_4^-$) in oxygenated seawater with a salinity of 35 ppt (Riley and Chester, 1983; Riley and Skirrow, 1975).	

Interdependence & Fate in the environment	The toxicity of Cr decreases with increasing pH (Riley and Skirrow, 1975). The oxygen content influences the ionic state of Cr. In oxygenated seawaters, Cr should exist entirely as CrO_4^{2-}, while under anoxic conditions it is stable as Cr [III] (Riley and Chester, 1983). As Cr [III] it forms insoluble compounds unless protected by complex formation. In theory Cr [VI] is reduced to Cr [III] when its settles to the ocean bed. Substantial energy is needed to oxidize Cr [III] back to Cr [VI]. Where the organic content of water is low, Cr should persist as Cr [VI] (WHO, 1982; Riley and Skirrow, 1975).		
Method	Chromium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cr [III] or Cr [VI] – µg/ℓ (water) and µg/g dry weight (sediment)		
Impacts & Thresholds			
Biota	**Range (µg/ℓ) Cr(III)**	**Effect**	**Reference**
Diatoms	>5	LC_{50} value (72 hr) for *Nitzschia closterium*	Florence and Stauber 1991
Amphipod	5,560	LC_{50} value (96 hr) for *Allorchestes compressa*	Ahsanullah (1982)
Copepod	5,900	LC_{50} value (96 hr) for *Tisbe battagliai* (adult)	Hutchinson *et al.* (1994)
	1,600	LC_{50} value (96 hr) for *Tisbe battagliai* (nauplii)	Hutchinson *et al.* (1994)
	19,300	LC_{50} value (48 hr) for *Acartia clausi*	Moraitou-Apostolopoulou and Verriopoulos (1982)
Polychaete	12,500	LC_{50} value (96 hr) for *Neanthes arenaceodentata* (juveniles)	Mearns *et al.* (1976)
Mollusc	10,300	LC_{50} value (96 hr) for oyster *Crassostrea virginica* (embryos)	Calabrese *et al.* (1973)
	2	LC_{50} – decreased filtering rate in mussel *Perna perna*	Watling and Watling (1982)
Fish	53,000	LC_{50} value (96 hr) for *Aldrichetta forsteri* (juvenile)	Negilski (1976)
	5	Sperm damage to marine *Oncorhyncus mykiss*	Billard and Robaud, (1985)

Copper (Cu)

Recommended target	**Water**	**Total Cu concentration should not exceed 0.3 µg/ℓ (99% protection) or 1.3 µg/ℓ (95% protection)**
	Sediment	**Cu concentration should not exceed Threshold Effect Level = 18.7 µg/g (dry weight)**
		Probable Effect Level = 108 µg/g (dry weight)
Description	The most probable main species of Cu in oxygenated seawater are $CuCO_3$, CuOH+ and Cu_2^+ (Riley and Chester, 1983).	
Natural occurrence	A range between 0.03 and 2 µg/ℓ has been reported for the most probable species in oxygenated seawater with a salinity of 35 ppt (Riley and Chester, 1983). Naturally, the concentration of copper in surface waters is lower than in deep waters, referred to as a nutrient type distribution (Riley and Chester, 1983).	

Interdependence & Fate in the environment	Seawater can retain a maximum of 50 µg/ℓ of Cu, but at high concentrations is usually present in a colloidal form (Riley and Skirrow, 1975). A significant fraction of Cu_2^+ may exist as complexes with dissolved organic compounds which on degradation can result on the increase of free Cu (Riley and Skirrow, 1975). Anoxic near-shore sediments represent a significant sink for Cu when compared with the accumulation rates for pelagic sediments (Riley and Skirrow, 1975). Cu_2^+ can also be adsorbed onto dead or living bacteria. In addition to adsorption processes, active uptake of copper by phytoplankton in the photic zone can also be important, playing an important role in metal requiring and metal-activated enzyme systems (Riley and Chester, 1983).		
Method	Copper in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cu – µg/ℓ (water) and µg/g dry weight (sediment)		
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Phytoplankton	>50–80	Inhibits 50% growth after 96 hrs in *Chaetoceros calcitrans*	Ismail *et al.* (2002)
	250	Growth inhibited over 10–14 days in *Phaeodactylum tricornutum*	Braek and Jensen (1976)
Diatoms	70	Growth inhibition in *Chaetoceros* sp.	Ismail *et al.* (2002)
Macroalgae	>10	Reduced growth rates of *Sargassum* seaweed	Joshi *et al.* (1982)
Copepod	200	LC_{50} (24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)

Shrimp	35,900	LC_{50} (48 hrs) for adult *Palaemonetes pugio*	Burton and Fisher (1990)
	50	Lethal level for Penaeid post-larvae	Shrimp Farming Short Course (1990)
	190	LC_{50} (over 14 days) for *Callianassa australiensis*	Ahsanullah *et al.* (1981)
	2,100	LC_{50} (48 hrs) for *Palaemonetes pugio* juveniles	Burton and Fisher (1990)
	2,500	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
	3,130	LC_{50} (96 hrs) for juveniles of *Penaeus monodon* (salinity 15 ppt)	Chen and Lin, 1999
	7,730	LC_{50} (96 hrs) for juveniles of *Penaeus monodon* (salinity 25 ppt)	Chen and Lin, 1999
	2,820	EC_{50} (30 days) (50% reduced weight gain for juveniles of *P. monodon*)	Chen and Lin, 1999
	1,890	EC_{50} (60 days) (50% reduced weight gain for juveniles of *P. monodon*)	Chen and Lin, 1999
	5,000	Decreased feeding patterns in *P. monodon* juveniles	Chen and Lin, 1999
	900	Shortened time to first molt and decreased growth and moulting frequency in *P. monodon* juveniles	Chen and Lin, 1999
	29	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al. (1976)
	51	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson *et al.* (1976)
	750–1,240	LC_{50} value (96 hrs) for *Donax faba*	Ong and Din (2001)
Coral	14.5–18.5	Reduction of fertilization rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)
	15.2	Reduction of fertilization rate by 50% in *Acropora longicyathus*	Reichelt-Brushett and Harrison (2005)
	17.4	Reduction of fertilization rate by 50% in *Acropora millepora*	Reichelt-Brushett and Harrison (2005)
	17.4	Reduction of fertilization rate by 50% in *Acropora corporamillepora*	Reichelt-Brushett and Harrison (2005)
	24.9	Reduction of fertilization rate by 50% in *Goniastrea retiformis*	Reichelt-Brushett and Harrison (2005)
	39.7	Reduction of fertilization rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
	48	LC_{50} value (96 hrs) of adult *Montipora verrucosa*	Reichelt-Brushett and Harrison (2005)

Abalone	40	100% mortality (within 48 hrs) of *Haliotis discus* larvae	Chamberlain (1988)
	50	LC$_{50}$ value (96 hrs) for *Haliotis cracherodii* adults	Hahn (1989)
	65	LC$_{50}$ value (96 hrs) for *Haliotis rufescens* adults	Hahn (1989)
	80	Mortalities in abalone larvae	Hahn (1989)
Rock lobster	95.5	LC$_{50}$ value (24 hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran (2004)
	158.5	LC$_{50}$ value (96 hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran (2004)
Echinoderms	7	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison (2005)
	14	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison (2005)

Lead (Pb)

Recommended target	**Water**	**Total Pb concentration should not exceed 2.2 µg/ℓ (99% protection) or 4.4 µg/ℓ (95% protection)**	
	Sediment	**Pb concentration should not exceed Threshold Effect Level = 30.2 µg/g (dry weight)**	
		Probable Effect Level = 112 µg/g (dry weight)	
Description	Pb is not known to be an essential trace element, with most probable species in marine waters being PbCO$_3$, (PbCO$_3$)$^{2-}$ and PbCl$^+$ (Riley and Chester, 1983).		
Natural occurrence	Natural sources of Pb include weathering of rocks, vulcanism and forest fires. In deep marine waters, reported Pb concentrations range between 0.0004 and 3 µg/ℓ (Riley and Chester, 1983; Riley and Skirrow, 1975).		
Interdependence & Fate in the environment	The precipitation of sparingly soluble species, the formation of stable organic complexes and the adsorption of lead to particulate matter are the main routes for environmental cycling of Pb. In anaerobic sediments, most of the Pb is present as PbS (Hutzinger, 1980).		
Method	Lead in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Pb – µg/ℓ (water) and µg/g dry weight (sediment)		
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**

Phytoplankton	>5,000	LC_{50} value (96 hrs) for *Phaeodactylum tricornutum*	Eisler (1988)
	5.1	Growth reduced by 50% (over 12 days) in *Skeletonema costatum*	Eisler (1988)
	10	100% growth retardation in *Skeletonema costatum*	Eisler (1988)
Amphipod	0.547	LC_{50} value (96 hrs) for amphipods from the genus *Ampelisca*	Eisler (1988)
Molluscs	8.6	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson *et al.* (1976)
	5.4	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima* (belonging to the family Mactridea)	Nelson *et al.* (1976)
Shrimp	7,200	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda (2000)
Coral	1,453	Reduction of fertilization rate by 50% in *Acropora longicyathus*	Reichelt-Brushett and Harrison (2005)
	1,801	Reduction of fertilization rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
	2,467	Reduction of fertilization rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)
Rock Lobster	50	Alteration of enzyme activity and biochemical functions in *Homarus americanus*	Eisler (1988)

Mercury (Hg)

Recommended target	**Water**	**Total Hg (as methyl mercury) concentration should not exceed 0.1 µg/ℓ (99% protection) or 0.4 µg/ℓ (95% protection)**
	Sediment	**Hg concentration should not exceed Threshold Effect Level = 0.13 µg/g (dry weight)**
		Probable Effect Level = 0.7 µg/g (dry weight)
Description	Mercury is a metal which is liquid at normal temperatures and pressures. It forms salts in two ionic states, namely Hg [I] and Hg [II], the latter being the most common form with most probable form in seawater being $HgCl_4^{2-}$. Hg [II] also forms organometallic compounds (e.g. methylmercury), some of which are generally more toxic to aquatic organisms than inorganic forms because the carbon-mercury bond is chemically stable (WHO, 1989; Neff, 2002).	
Natural occurrence	Concentrations of Hg in coastal waters and estuaries generally are much higher than those in the open ocean. Concentrations in relatively uncontaminated coastal and estuarine waters may be as high as 0.02 µg/ℓ (Neff, 2002). Hg concentrations in ocean waters range between 0.0005–0.003 µg/ℓ. Local variations from these values are considerable, especially in coastal seawater where mercury associated with suspended material may also contribute to the total load (WHO, 1989; Neff, 2002).	

Interdependence & Fate in the environment	The solubility of mercury decreases in anoxic waters due to hydrogen sulphide formation, leading to the formation of mercury sulphide which is very insoluble. pH increases the uptake of mercury by fish, particularly methylmercury. The toxicity of mercury is reduced in the presence of high salt content but increase for invertebrates with an increase in temperature (WHO, 1989). Mercury salts, and to a much greater extent, organic (methyl) mercury, are readily taken up by marine organisms and there is a strong indication that bacterial action leads to methylation of short-chain alkyl mercurials, e.g. methyl-, ethyl- or propyl-mercury (WHO, 1989).
Method	Mercury in seawater and sediment can be measured using a direct mercury analyser (DMA), atomic absorption spectroscopy (AAS), atomic fluorescence spectrometry, inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). Unit: Total Hg – µg/ℓ (water) and µg/g dry weight (sediment)

Impacts & Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	50	Growth retardation in *Dunaliella minuta*	Gotsis (1982)
Shrimp	16	Threshold level for *Penaeus monodon*	Das and Sahu (2002)
	24	Threshold level for *Penaeus indicus*	Das and Sahu (2002)
	36	LC_{50} value (96 hrs) for *Penaeus monodon*	Das and Sahu (2002)
	42	LC_{50} value (96 hrs for *Penaeus indicus*	Das and Sahu (2002)
	<56	Reduced survival of *Penaeus vulgaris* postlarvae after 48 hrs	Shealy and Sandifer (1975)
	56	Critical limit for *Penaeus vulgaris* postlarvae within 24 hrs	Shealy and Sandifer (1975)
Molluscs	>1,000	Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
Fish	380	LC value for milkfish (species not reported)	Bonifacio and Montaño (1998)

Nickel (Ni)

Recommended target	**Water**	**Total Ni concentration should not exceed 7 µg/ℓ (99% protection) or 70 µg/ℓ (95% protection)**
	Sediment	**Ni concentration should not exceed Threshold Effect Level = 15.9 µg/g (dry weight)**
		Probable Effect Level = 42.8 µg/g (dry weight)
Description	Nickel occurs in abundance in nature with the most probable species in marine waters being $NiCO_3$, Ni^{2+} and $NiCl^+$ (Riley and Cheser, 1983). Ni and Vanadium (V) are the two most abundant metals in petroleum (Schlesinger *et al.,* 2017).	
Natural occurrence	Natural sources of Ni in marine waters include volcanoes, forest fires and natural erosion of soils transported via rivers (WHO, 1991). In natural waters, at a pH range of 5–9, the divalent ion Ni^{2+} is the dominant form. In this pH range, it may also be adsorbed onto iron and manganese oxides, or form complexes with inorganic ligands (WHO, 1991). Reported Ni concentrations range between 0.2 and 0.7 µg/ℓ for the most probable species ($NiCO_3$, Ni^{2+}, $NiCl^+$) in oxygenated seawater at salinity 35 ppt, and between 0.5 and 3 µg/ℓ for oceanic waters (Riley and Chester, 1983; Riley and Skirrow, 1975).	

Interdependence & Fate in the environment	The fate of Ni in seawater is affected by several factors including pH, ionic strength, type and concentration of organic and inorganic ligands, as well as the presence of solid surfaces for adsorption (WHO, 1991).
Method	Nickel in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Hg – μg/ℓ (water) and μg/g dry weight (sediment)

Impacts & Thresholds

Biota	Range (μg/ℓ)	Effect	Reference
Algae	100,000–1,000,000	Growth rates of *Chlorella vulgaris* effected	Sakaguchi *et al.* (1977)
Copepods	13,180	LC_{50} value for *Eurytemora affinis* (adult)	Lussier and Cardin (1985)
	3,466	LC_{50} value for *Acartia clausi* (adult)	Lussier and Cardin (1985)
Polychaetes	49,900	LC_{50} value for *Nereis arenaceodentata* (adult)	Petrich and Reish (1979)
	25,000	LC_{50} value for *Nereis virescens* (adult)	Petrich and Reish (1979)
	17,000	LC_{50} value for *Ctenodrilus serratus* (adult)	Petrich and Reish (1979)
	>50,000	LC_{50} C50 value for *Capitella capitata* (adult)	Petrich and Reish (1979)
Flatworms	16,800	LC_{50} value (96 hrs) for *Dugesia tigrina*	See *et al.* (1974)
Mollusca	72,000	LC_{50} value for *Nassarius obsoletus* (adult)	Eisler and Hennekey (1977)
	1,180	LC_{50} value for *Crassostrea virginica* (embryo)	Calabrese *et al.* (1973)
	133	EC_{50} value for *Mytilus edulis* (larvae)	Blewett *et al.* (2018)
Amphipods	40,000	EC_{50} value (10 days) for *Ampelisca abdita*	Haley and Kurnas (1996)
	310	LC_{50} value for *Mercenaria mercenaria* (embryo)	Calabrese and Nelson (1974)
Mysids	1,517	LC_{50} value for *Heteromysis formosa* (juvenile)	Gentile *et al.* (1982)
	508	LC_{50} value for *Mysidopsis bahia* (juvenile)	Gentile *et al.* (1982)
	634	LC_{50} value for *Mysidopsis bigelowi* (juvenile)	Gentile *et al.* (1982)
Echinoids	207	EC_{50} value (96 hr) for *Strongylocentrotus purpuratus* (embryo)	Blewett *et al.* (2018)
Coral	>100	Reduction of fertilization rate by 60% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)

Silver (Ag)

Recommended target	**Water**	**Total Ag concentration should not exceed 0.8 µg/ℓ (99% protection) or 1.4 µg/ℓ (95% protection)**
	Sediment	**Ag concentration should not exceed Threshold Effect Level = 0.73 µg/g (dry weight)**
		Probable Effect Level = 1.77 µg/g (dry weight)
Description	Ag exists principally in the +1 oxidation state as $AgCl_2^-$ complexes in seawater (Riley and Chester, 1983).	
Natural occurrence	Ag probably has a nutrient-type chemistry, which is substantially depleted in surface relative to deep waters. Concentrations between $53.9 \text{ x} 10^{-6}$ and $3.78 \text{ x } 10^{-3}$ µg/ℓ have been reported for the most probable species ($AgCl_2^-$) in seawater with a salinity of 35 ppt, and between 0.01 and 0.08 µg/ℓ for dissolved Ag in oceanic waters (Riley and Chester, 1983; Riley and Skirrow, 1975).	
Interdependence & Fate in the environment	In coastal waters it was observed that more than half the total Ag is associated with particulate phases. Ag adsorbs onto clay particles and other organic matter in river water and may be desorbed when it reaches the sea. The solubility of Ag decreases in anoxic waters due to the presence of hydrogen sulphide (Ag_2S is very insoluble) (Riley and Skirrow, 1975).	
Method	Silver in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Ag – µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts & Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Macroalgae	50	LC_{50} value for algae (species not reported)	WHO (1982)
Fish	10–40	LC_{50} value for fish (species not reported)	WHO (1982)
	2,700	LC_{50} value (96 hrs) for *Fundulus heteroclitus* (adult)	Dorfman (1977)
	1,170	LC_{50} value (96 hrs) for *Cyprinodon variegatus* (juvenile)	US-EPA (1993)
	356	LC_{50} value (96 hrs) for *Cymatogaster aggregata* (adult)	Dinnel *et al.* (1983)
	800	LC_{50} value (96 hrs) for *Parophrys vetulus* (adult)	Dinnel *et al.* (1983)
	487	LC_{50} value (96 hrs) for *Oncorhynchus mykiss* (adult)	Dinnel *et al.* (1983)

Sn (as tributyltin)

Recommended target	**Water**	**Sn (as tributyltin) concentration should not exceed 0.0004 µg/ℓ (99% protection) or 0.006 µg/ℓ (95% protection)**
	Sediment	**TBT concentration should not exceed Threshold Effect Level = 0.009 µg/g (dry weight)***
		Probable Effect Level = 0.07 µg/g (dry weight)*
Description	The most probable species of inorganic tin in marine waters is $SnO(OH)_3^-$. Inorganic Sn is accepted to be relatively non-toxic because the metal does not react, and its oxides are insoluble at physiological pH (Riley and Chester, 1983). Tributyltin (TBT) compounds are organic derivatives of tetravalent Sn, and although inorganic Sn is relatively non-toxic, organotin compounds are toxic. In seawater TBT exists as three species (hydroxide, chloride, and carbonate) which remain in equilibrium. At pH values less than 7, the predominant forms are BuSnOH2 and Bu SnCl, while at a pH of 8, they are Bu SnCl, Bu SnOH and Bu SnCO and at pH values above 10, Bu SnOH, and Bu SnCO predominate (WHO, 1990; Heard, 1989).	
Natural occurrence	A range between 0.0001 and 0.001 µg/ℓ has been reported for the most probable species (SnO(OH)3-) in oxygenated seawater with a salinity of 35 ppt (Riley and Chester, 1983). TBT is not a natural component of seawater (WHO, 1990).	
Interdependence & Fate in the environment	The extent of adsorption of TBT onto particles depends on the salinity, nature and size of particles in suspension, amount of suspended matter, temperature and the presence of dissolved organic matter. As a result of its low water solubility and lipophylic character, TBT adsorbs readily onto particles. Progressive disappearance of adsorbed TBT is not due to desorption but to degradation. The degradation of TBT involves the splitting of the carbon-tin bond. TBT bioaccumulates in organisms because of its solubility in fat. It is known that TBT degradation rates in sediments are slower than in the water column, particularly in anaerobic conditions (WHO, 1990).	
Method	Tributyltin can be analysed using Gas Chromatography-Mass Spectrometry (GC-MS) and high-performance liquid chromatography (HPLC). Unit: Total Sn – µg/ℓ (water) and µg/g dry weight (sediment)	

** Not available in MacDonald et al. (1996), adopted from Australia and New Zealand Government (2018)*

Impacts & Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Diatom	0.14	LC_{50} value (72 hrs) for *Skeletonema costatum*	Nehring (1999)
Copepod	18	LC_{50} value (96 hrs) for *Tigriopus japonicus*	Bao *et al.* (2011)
Amphipod	9.4	LC_{50} value (96 hrs) for *Elasmopus rapax*	Bao *et al.* (2011)
Coral	0.38	LC_{50} value (24 hrs) for *Acropora tumida* larvae	Bao *et al.* (2011)
Barnacle	31	LC_{50} value (24 hrs) for *Balanus amphitrite* (larvae)	Bao *et al.* (2011)

Polychaete	0.97	LC$_{50}$ value (48 hrs) for *Hydroides elegans* (embryos)	Lau *et al.* (2007)
	2.36	LC$_{50}$ value (48 hrs) for *Hydroides elegans* (larvae)	Lau *et al.* (2007)
	2.86	LC$_{50}$ value (48 hrs) for *Hydroides elegans* (juveniles)	Lau *et al.* (2007)
	4.36	LC$_{50}$ value (48 hrs) for *Hydroides elegans* (adults)	Lau *et al.* (2007)
Mollusc	1.78	LC$_{50}$ value (48 hrs) for *Nassarius reticulatus* (larvae)	Sousa *et al.* (2005)
Shrimp	0.88	LC$_{50}$ value (48 hrs) for *Penaeus japonicus* (nauplii)	Lignot *et al.* (1998)
	19.4	LC$_{50}$ value (48 hrs) for *Penaeus japonicus* (post-larva 5)	Lignot *et al.* (1998)
	370	LC$_{50}$ value (96 hrs) for *Penaeus japonicus* (juveniles)	Lignot *et al.* (1998)

Vanadium (V)

Recommended target	**Water**	**Total V concentration should not exceed 50 µg/ℓ (99% protection) or 100 µg/ℓ (95% protection)**	
	Sediment	**No recommended target could be set**	
Description	Vanadium (V) can exist in three common oxidation states, largely present as found as vanadate ($H_2VO_4^-$) in oxidized waters of near-neutral pH. V is widely recognized as a trace contaminant in coal and oil (V and Ni are the two most abundant metals in petroleum) (Schlesinger *et al.,* 2017).		
Natural occurrence	V is naturally mobilized from the Earth's crust mainly through mechanical and chemical rock weathering. The dissolved concentration in seawater has been reported as ~1.8 µg/ℓ. This is higher than in river water indicative additional sources of V in seawater, most likely released from suspended or accumulating sediments under higher pH of seawater under oxic conditions (Schlesinger *et al.,* 2017).		
Interdependence & Fate in the environment	The transport and partitioning of V in water and sediments is influenced by pH, redox potential, and the presence of particulate. Upon entering the marine waters, V in suspension or adsorbed and/or absorbed onto particulate is deposited upon the seabed. Adsorption/absorption and biochemical processes are thought to contribute to the extraction of vanadium from sea water. Only about 0.001% of V entering the oceans is estimated to persist in soluble form (WHO, 1988).		
Method	Vanadium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total V – µg/ℓ (water) and µg/g dry weight (sediment)		
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Dinoflagellate	3	LC$_{50}$ value (15 days) for *Prorocentrum micans* (adults)	Miramand and Unsal (1978)
Green alga	0.5	LC$_{50}$ value (15 days) for *Dunaliella salina* (adults)	Miramand and Unsal (1978)
Diatom	2	LC$_{50}$ value (15 days) for *Asterionella japonica* (adults)	Miramand and Unsal (1978)
Polychaete	10	LC$_{50}$ value (9 days) for *Asterionella japonica* (adults)	Miramand and Unsal (1978)

Mysid shrimp	7.7	LC$_{50}$ value (7 days) for *Americamysis bahia* (juveniles)	Woods *et al.* (2004)
Crab	35	LC$_{50}$ value (9 days) for *Carcinus maenas* (adults)	Miramand and Unsal (1978)
Fish	0.62	LC$_{50}$ value (96 hrs) for *Terapon jarbua* (juveniles)	Gajbhiye *et al.* (1983)

Zinc (Zn)

Recommended target	**Water**	**Total Zn concentration should not exceed 7 µg/ℓ (99% protection) or 15 µg/ℓ (95% protection)**	
	Sediment	**Zn concentration should not exceed Threshold Effect Level = 124 µg/g (dry weight)**	
		Probable Effect Level = 217 µg/g (dry weight)	
Description	Zn occurs abundantly in nature and is comparatively non-toxic. In the marine environment, the equilibrium species are Zn^{2+}, $ZnOH^{+}$, $ZnCO_3$ and $ZnCl^{+}$ (Riley and Chester, 1983).		
Natural occurrence	A range from 0.003–0.59 µg/ℓ has been reported for the most probable species (Zn^{2+}, $ZnOH^{+}$, $ZnCO_3$ and $ZnCl^{+}$) in oxygenated seawater with salinity of 35 ppt, and in oceanic waters between 0.5–4.0 µg/ℓ (Riley and Chester, 1983; Riley and Skirrow, 1975). Zinc concentrations in estuaries and coastal waters frequently are much higher than those in the ocean, with concentrations often as high as 4 µg/ℓ and occasionally as high as 25 µg/ℓ (Morse *et al.,* 1993, Law *et al.,* 1994).		
Interdependence & Fate in the environment	The toxicity of Zn increases in the presence of Cd, while it decreases in anoxic water due to the presence of hydrogen sulphide (ZnS is very insoluble). Also, the speciation of dissolved Zn is very sensitive to pH changes. At a pH of 8.2 (seawater), the principal species are Zn^{2+} and $ZnCO_3$ (Riley and Skirrow, 1975). A significant fraction of the total zinc in seawater may be adsorbed to particles or complexed with dissolved organic matter.		
Method	Zinc in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Zn – µg/ℓ (water) and µg/g dry weight (sediment)		
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Phytoplankton	0.00065	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is inhibited	Sunda and Huntsman (1992)
	0.00065–0.65	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is optimal	Sunda and Huntsman (1992)
	>0.65	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is inhibited	Sunda and Huntsman (1992)
Macroalgae	50	LC$_{50}$ value for algae (species type not reported)	WHO (1982)
	>80	Reduced growth rates of *Sargassum* seaweed	Joshi *et al.* (1982)
Copepod	1,860	LC$_{50}$ value (24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)

Molluscs	2,250	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians*	Nelson *et al.* (1976)
	2,950	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima*	Nelson *et al.* (1976)
	1,940–4,740	LC_{50} value (96 hrs) for *Donax faba*	Ong and Din (2001)
	>10,000	50% Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
Shrimp	>10,000	LC_{50} value (96 hrs) for *Palaemon* sp. (adult)	Ahsanullah and Arnott (1978)
	1,230	LC_{50} value (96 hrs) for *Palaemon* sp. (adult)	Ahsanullah (1976),
	13,100	LC_{50} value (48 hrs) for adult *Palaemon* sp. (adult)	Burton and Fisher (1990)
	6,200	LC_{50} value for *Penaeus indicus* post larvae	Chinni and Yallapragda (2000)
	11,300	LC_{50} value (48 hrs) for *Palaemonetes pugio* juveniles	Burton and Fisher (1990)
Abalone	19	No observed effects in *Haliotis rufescens* larvae (48 hrs)	Hunt and Anderson (1989)
	39	No observed effects in *Haliotis rufescens* larvae over nine days	Hunt and Anderson (1989)
Fish	10–40	LC_{50} value for fish (specific species not reported)	WHO (1982)

2.2.6 Petrochemicals (mono- and poly-cyclic aromatic hydrocarbons)

	Compound	Water (µg/ℓ)	Sediment (ng/g dry weight)	
			Target	Probable effects concentration
Recommended target	Benzene (C6)	600 (99% protection) 950 (95% protection)	–	–
	Toluene (C7)	110 (99%); 180 (95%)	–	–
	Ethylbenzene (C8)	50 (99%); 80 (95%)	–	–
	m-Xylene (C8)	50 (99%); 75 (95%)	–	–
	Naphthalene (C9)	50 (99%); 70 (95%)	34.6	391
	Acenaphthene (C12)	–	6.71	88.9
	Acenaphthylene (C12)	–	5.87	128
	Fluorene (C13)	–	21.2	144
	Anthracene (C14)	0.01 (99%); 0.4 (95%)	46.9	245
	Phenanthrene (C14)	0.6 (99%); 2 (95%)	86.7	544
	Fluoranthene (C15)	1 (99%); 1.4 (95%)	113	1,494
	Pyrene (C16)	–	153	1,398
	Benzo(a)anthracene (C18)	–	74.8	693
	Chrysene (C18)	–	108	846
	Benzo(a)pyrene (C20)	0.1 (99%); 0.2 (95%)	88.8	763
	Dibenzo(a,h)anthracene (C22)	–	6.22	135
	Total PAH	–	1,684	16,770
Description	The mono-aromatic hydrocarbons - benzene, toluene, ethylbenzene and xylene (BTEX) – are constituents of petroleum and its products such as petrol and diesel fuel (Phelps and Young, 1999). Poly-cyclic aromatic hydrocarbons (PAHs) comprise multi-ring hydrocarbon compounds and can be categorized into : • Low molecular weight two- to three-ring PAHs, including naphthalene, acenaphthene, acenaphthylene, phenanthrene, anthracene and fluorenes (usually display acute toxicity with short half-life in water) • High molecular weight three- to four-ring PAHs, including fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(a)pyrene and dibenzo(a,h)anthracene (usually displaying chronic toxicity, with longer half-life in water) (ANZECC, 2000). The toxicity of aromatic hydrocarbons to marine organisms is highly variable, depending on species, compound and environmental conditions.			

Natural occurrence	PAHs are found naturally, but anthropogenic activity has markedly increased environmental levels of PAHs. There are four categories of PAH inputs to the marine environment, namely biogenic (produced by organism), pyrogenic (from incineration processes), petrogenic (derived from fossil fuels) and diagenic (derived from transformation processes in soils and sediments) (Lima *et al.,* 2005; Hylland, 2006).
Interdependence & Fate in the environment	The overall environmental fate of aromatic hydrocarbons depends on several factors such as solubility, absorptivity, photolysis, oxidation and volatilization. The rate of the various transformation and removal processes in the environment depends on the physical and chemical properties of the individual compounds. Solubility and absorptivity are the most important physical properties in this context. Although the solubility of pure PAHs in water is extremely low, these compounds can be solubilized by other organic substances, particularly detergents. PAHs can also form associates with colloids present in water and can be transported through water in this form. Amongst the chemical properties, photochemical reactivity is particularly relevant. Tricyclic and larger PAHs have strong UV absorption at wavelengths longer than 300 nm and most are readily photo-oxidized (Hutsinger, 1980). Concentrations of PAHs in aquatic ecosystems are generally highest in sediments, intermediate in aquatic biota and lowest in the water column.
Method	Various techniques exist for the analysis of petroleum hydrocarbons in seawater and sediment, including spectro-fluorimetric analysis, gas chromatography (GC) and high-performance liquid chromatography (HPLC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)
Impacts & Thresholds	
BTEX and PAHs also bio-accumulate through aquatic food chains, contributing to morbidities and mortalities (Akinsanya *et al.,* 2020). PAHs are known to be carcinogenic. Carcinogenic PAHs are metabolized through cellular phases I and II, present in all vertebrates including fish. Their non-carcinogenic effects include oxidative stress, impacts on immune systems and endocrine regulation, and well as development (Hylland, 2006).	

2.2.7 Agrochemicals (organochlorine pesticides)

	Compound	Water (µg/ℓ)	Sediment (ng/g dry weight)	
			Target	Probable effects concentration
Recommended target	Aldrin	0.003	–	–
	Chlordane	0.001	2.26	4.79
	Chloropyros	0.0005 (99% protection) 0.009 (95% protection)	–	–
	DDT	0.0004	3.89	51.7
	p,p DDT	–	1.19	4.77
	p,p DDD	–	1.22	7.81
	p'p'- DDE	–	2.07	374
	Dieldrin	0.0019*	0.72	4.3
	Endosulfan	0.005 (99%); 0.01 (95%)	–	–
	Endrin	0.004 (99%); 0.008 (95%)	2.7**	60**
	Fenitrothion	0.001	–	–
	Lindane	0.007	0.32	0.99
	Methoxychlor	0.004	–	–
	Temephos	0.0004 (99%); 0.05 (95%)	–	–
	Toxaphene	0.1 (99%); 0.2 (95%)	–	–
Description	Pesticides (including insecticides, herbicides and fungicides) are typically categorized as organochlorine, organophosphate, and carbamate compounds. Insecticides are primarily designed to disrupt nervous system function, while herbicides target mainly photosynthetic pathways (e.g. to control weeds) (DeLorenzo *et al.,* 2001; Lewis *et al.,* 2009).			
Natural occurrence	Pesticides (in the context used here) do not occur naturally and are manufactured compounds aimed at destroying pests.			
Interdependence & Fate in the environment	Pesticide characteristics (water solubility, tendency to adsorb to the soil and pesticide persistence) and soil characteristics (clay, sand and organic matter) are important in determining the fate of the chemicals in the environment. Organochlorine pesticides (OCP) are typically resistant to environmental degradation, while organophosphate insecticides were found not to be long-lived in environment. Triazine herbicides also are persistent in environment, but acetanilide herbicides were found to be less persistent (Tiryaki and Temur, 2010). In general, OCPs have a low solubility and other properties that make them adsorb strongly into suspended material and sediment. As a result, in the aquatic environment OCPs are usually found in much higher concentrations in sediments than in the overlying water.			
Method	Various techniques exist for the analysis of pesticides in seawater and sediment, including gas chromatography (GC) and high-performance liquid chromatography (HPLC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)			

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (see US-EPA, 2022a)*
*** No QT provided in McDonald et al. (1996), adopted from Australia and New Zealand Government (2018)*

Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect** **Reference**	
Algae	>0.3	DDT: Biological effects on *Chlorella* sp.	DeLorenzo *et al.* (2001)
	3.6–36	p,p'-DDT: Inhibited photosynthetic processes in Green algae *Selenastrum capricornutum*	DeLorenzo *et al.* (2001)
	>10	DDT: Photosynthesis inhibited in marine algae	DeLorenzo et al. (2001)
	1,000	DDT: Blue-green algae *Anabaena* sp. display negative physiological effects	DeLorenzo *et al.* (2001)
	1,000	DDT: Population growth rates in Green algae *Chlorella* sp. Declines	Lowe (1965)
	50	Lindane: Accumulation in Green algae *Chlorella* sp. (24 hrs)	Geyer *et al.* (1984)
	300	Lindane: Mortality of Green algae *Anabaena* sp. (72 hrs)	Bringmann and Kuhn (1978)
	1,000	Lindane: Accumulation in Green algae *Anabaena* sp.	Mathur and Saxena (1986)
	60,000	Lindane: Mortality of Green algae *Anabaena* sp. (72 hrs)	Das and Singh (1977)
	>1,000	Dieldrin: Significant effects on respiration of Blue-green algae	DeLorenzo *et al.* (2001)
	15,000	Dieldrin: Mortality of blue-green algae *Anabaena cylindrica* (7 days)	Vance and Drummond (1969)
Diatoms	50	DDT: Growth of *Skeletonema costatum* reduced (48 hrs)	Fisher (1975)
	1.7	Dieldrin: Accumulation in *Skeletonema costatum* (2 hrs)	Sikka and Rice (1974)
Seagrass	50	DDT: Photosynthesis and respiration in *Halophila ovalis* affected	Ramachandra *et al.* (1984)
	50	DDT: Photosynthesis and respiration in *Halophila uninervis* affected	Ramachandra *et al.* (1984)
	50	Lindane: Reduction of photosynthetic processes in *Hadodule uninervis* (6 hrs)	Ramachandran *et al.* (1984)
	50	Endosulfan: Reduction of photosynthetic processes in *Hadodule uninervis* (6 hrs)	Ramachandran *et al.* (1984)
Coral	10	Endosulfan: Visual bleaching observed in *Acropora millepora* after 6–12 hrs	Markey *et al.* (2007)
	>30	Endosulfan: Fertilization of *Acropora millepora* gametes declined	Markey *et al.* (2007)

Copepods	1,000	Aldrin: Mortality of *Cyclops* copepods (24 hrs)	Ludemann and Neumann (1962)
	>5	DDT: Mortality (48 hrs) of *Cyclops* sp.	Naqvi and Ferguson (1968)
	10–13	DDT: LC$_{50}$ (I day) for *Eucalanus* sp. (Calanoid copepod)	Rajendran and Venugopalan (1988)
	28	DDT: LC$_{50}$ (I day) for *Acartia* sp. (Calanoid copepod)	Rajendran and Venugopalan (1988)
	1,000	Aldrin: Mortality (24 hrs) of *Cyclops* sp.	Ludemann and Neumann (1962)
	0.8	Lindane: EC$_{50}$ value for *Acartia tonsa*	Chen (1991)
	6.2	Lindane: Growth inhibition in *Acartia tonsa*	Chen (1991)
	400–600	Lindane: Mortality of *Cyclops* copepods (48 hrs)	Naqvi and Ferguson (1968)
	0.03	Endosulfan: LC$_{50}$ value (96 hrs) for *Acartia tonsa*	Schimmel (1981)
	0.1	Endosulfan: LC$_{50}$ value (48 hrs) for *Eucyclops* sp.	Naqvi and Hawkins (1989)
	0.6	Endosulfan: LC$_{50}$ value (48 hrs) for *Diaptomus* sp.	Naqvi and Hawkins (1989)
	176	Endosulfan: LC$_{50}$ value (24 hrs) for *Eucalanus* sp.	Rajendran and Venugopalan (1988)
Amphipods	60	Dieldrin: LC$_{50}$ value 24 hrs for *Ampelisca abdita*	Werner and Nagel (1997)

Shrimp	0.6	Aldrin: LC$_{50}$ value (48 hrs) for Penaeid juveniles	Lowe *et al.* (1970)
	6.3	Aldrin: Enzyme disruption in *Penaeus* indicus (96 hrs) (adult)	Reddy and Rao (1989)
	0.10	DDT: Growth inhibition in Penaeid adults (30 days)	Nimmo and Blackmann (1972)
	0.6	DDT: EC$_{50}$ value (48 hrs) for Penaeid juveniles	Lowe *et al.* (1970)
	1,000	Lindane: Mortality of *Penaeus* sp. (24 hrs) (adult)	Reddy and Rao (1989)
	0.5–10	Lindane: Reduction of growth in *Penaeus monodon* (30 days) (juvenile)	Reddy and Rao (1989)
	1	Lindane: *P. monodon* display development inhibition (24 hrs) (juvenile)	Reddy and Rao (1989)
	0.13	Endosulfan: LC$_{50}$ value (96 hrs) for *Penaeus indicus* juvenile	Rao *et al.* (1988)
	0.35	Endosulfan: LC$_{50}$ value (72 hrs) for *Penaeus indicus* juvenile	Rao *et al.* (1988)
	0.46	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus indicus* juvenile	Rao *et al.* (1988)
	0.98	Endosulfan: LC$_{50}$ value (24 hrs) for *Penaeus indicus* juvenile	Rao *et al.* (1988)
	4.64	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus monodon* post-larvae	Joshi and Mukhopadhyay (1990)
	7.53	Endosulfan: LC$_{50}$ value (24 hrs) for *Penaeus monodon* post-larvae	Joshi and Mukhopadhyay (1990)
	12.2	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus monodon* juveniles	Joshi and Mukhopadhyay (1990)
	17.6	Endosulfan: LC$_{50}$ value (24 hrs) for *Penaeus monodon* juveniles	Joshi and Mukhopadhyay (1990)
	26.3	Endosulfan: LC$_{50}$ value (96 hrs) for *Penaeus monodon* intermoult stage	Rao *et al.* (1988)
	37.3	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus monodon* intermoult stage	Rao *et al.* (1988)
Mud crab	178	Endosulfan: LC$_{50}$ value (96 hrs) for *Scylla serrata*	Rao *et al.* (1987)
	257	Endosulfan: LC$_{50}$ value (72 hrs) for *Scylla serrata*	Rao *et al.* (1987)
	389	Endosulfan: LC$_{50}$ value (48 hrs) for *Scylla serrata*	Rao *et al.* (1987)
	478	Endosulfan: LC$_{50}$ value (24 hrs) for *Scylla serrata*	Rao *et al.* (1987)

2.2.8 Pharmaceuticals

Recommended Target (water)	**Carbamazepine***	**Concentration in water should not exceed 1 µg/ℓ (99% protection) or 9.2 µg/ℓ (95% protection)**
	Diclofenac*	**Concentration in water should not exceed 180 µg/ℓ (99%) or 770 µg/ℓ (95%)**
	Fluoxetine*	**Concentration in water should not exceed 0.23 µg/ℓ (99%) or 1.6 µg/ℓ (95%)**
	Propranolol*	**Concentration in water should not exceed 3.5 µg/ℓ (99% protection) or 14 µg/ℓ (95%)**
Description	Human and veterinary pharmaceuticals are chemicals that are continuously introduced to water bodies mainly through municipal wastewater (Fabbri and Franzellitti, 2016). Pharmaceuticals are classified, based on their therapeutic uses, into the following groups (Ojemaye and Petrik, 2018): • anti-diabetics (e.g. alpha-glucosidase inhibitor), β-blockers (e.g. atenolol, metoprolol) • antibiotics (e.g. trimethoprim) • lipid regulators (e.g. gemfibrozil) • anti-epileptic (e.g. acetazolamide) • tranquilizers (e.g. diazepam) • antimicrobials (e.g. penicillins) • antiulcer and antihistamine drugs (e.g. cimetidine and famotidine) • antianxiety/hypnotic agents (e.g. diazepam) • anti-inflammatories and analgesics (e.g. ibuprofen, paracetamol, diclofenac) • antidepressants (e.g. benzodiazine-pines) • anticancer drugs (e.g. cyclophosphamide, ifosfamide) • antipyretics and stimulants (e.g. dexamphetamine, methylphenidate and modafinil) • estrogens and hormonal compounds (estriol, estradiol, and estrone)	
Interdependence & Fate in the environment	The fate of pharmaceuticals in the marine environment (either in water column, sediments or biota) is a function of their physico-chemical properties, their interactions with the different matrices and hydrodynamic conditions (Bayen *et al.*, 2013). These compounds can undergo biotic and abiotic transformations (degradation), or adsorbed to suspended solids or sediments, or accumulated in tissue of organisms, depending on their partition (Branchet et *al.*, 2020).	
Method	Various techniques exist for the analysis of pharmaceutical compounds in seawater and sediment, including gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography-mass spectrometry (HPLC-MS). Unit: µg/ℓ (water) and ng/g dry weight (sediment)	

** QTs provided for Australia in Kumar et al., 2016*

Impacts & Thresholds

Pharmaceuticals are biologically active compounds specifically designed to interact with physiological pathways of targeted organisms, but may cause a risk to the health of non-targeted marine organisms. Adverse ecological effects can act at sub-lethal levels and alter biochemical and cellular responses, disrupting vital functions such as reproduction, growth, metabolism, immunity, feeding and locomotion (Branchet *et al.*, 2020).

2.2.9 Other organic toxicants

Phenols

Recommended target	**Water: Total phenol concentration should not exceed 270 µg/ℓ (99%) or 400 µg/ℓ (95%)**
Description	Phenols comprise a group of chemicals with one or more hydroxyl groups (-OH) bonded to an aromatic hydrocarbon molecule. Phenolic compounds in the marine environment can arise from industrial activities, agricultural practices and natural substance degradation. They can be by-products in petrochemical industries, coal liquefaction plants, plastic and dye production, as well as pulp industries (Dimou *et al.*, 2006).
Natural occurrence	Phenols occur naturally during the decomposition of organic matter. A concentration ~1.5 µg/litre has been reported for coastal waters (WHO, 1994).
Interdependence & Fate in the environment	Based on their relatively high solubility in water and relatively low vapour pressure at room temperature, phenols largely end up in the water phase upon distribution between air and water (WHO, 1994). Phenols are not expected to be adsorbed by sediments and suspended particulates in the aquatic environment, but have been detected in sediments in polluted systems. Biodegradation and indirect reactions with photochemically produced hydroxyl radicals and peroxyl radicals are the most likely transport mechanisms (WHO, 1994; Duan *et al.*, 2018).
Method	Phenols can be analysed using gas chromatography (GC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)
Impacts & Thresholds	
In addition to overt toxicities at higher concentrations, phenols can also result in subtle effects to biota, including reduced fertility, decreased survival of young, and growth inhibition. The toxicity of phenol to aquatic biota is modified by several abiotic (e.g. dissolved oxygen, salinity, and temperature) and biotic (e.g. age, size, nutritional status) factors (Babich and Davis, 1981).	

Polychlorinated Biphenyls (PCBs)

Total PCB concentration not to exceed 21.6 ng/g	**Water**	**Total PCB concentration not to exceed 0.03 µg/ℓ***
	Sediment	**Total PCB concentration not to exceed 21.6 ng/g**
Description	Polychlorinated biphenyls (PCBs) are a group of man-made chemicals consisting of carbon, hydrogen and chlorine atoms. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties they are used in a wide range of products including hydraulic oils, electrical transformers and capacitors, concrete constructions, sealants and paint (Jartun *et al.*, 2009).	
Natural occurrence	PCBs are exclusively anthropogenic and do not occur naturally (Wolska *et al.*, 2012).	
Interdependence & Fate in the environment	PCBs have low water solubility, a high n-octanol/water partition coefficient, and resistance potential, particularly those which are highly chlorinated. As a result, in the aquatic environment PCBs are usually found in much higher concentrations in sediments than in the overlying water. They are persistent in the environment and it may take decades for them to degrade. The persistence and stability of PCBs increase with an increase in the number of chlorine atoms per molecule (Wolska et al., 2012). PCBs readily bio-accumulate in many organisms in the environment (Geyer *et al.*, 1984).	
Method	PCBs can be analysed using gas chromatography-mass spectrometry (GC-MS). Unit: µg/ℓ (water) and µg/g dry weight (sediment)	

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (see US-EPA, 2022a)*			
Impacts & Thresholds			
Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Coral	1,000	Aroclor 1254: significant decrease in photosynthetically generated oxygen production in *Montastrea annularis*, *Acropora cervicornis*, and *Madracis mirabilis*.	McCloskey & Chesher (1971)
Marine mammals	–	Bioaccumulation known to result in reproductive failure in sea mammals (e.g. dolphins)	WHO (1992b)

2.3 Guidance on deriving Site-Specific Quality Targets

For ease of use, Table 2.2 summarizes the recommended QTs for the protection of aquatic ecosystems in the WIO region as detailed in Section 2.2.

Table 2.2 Summary of recommended QTs in water for the protection of aquatic ecosystems in the WIO region.

Constituent	Recommended Quality Target
Objectionable matter	• Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance. • Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits. • Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use.

Physico-chemical properties			
Temperature (°C)	The concentration of the physico-chemical property defined by the 20%ile and/or 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in a study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.		
Salinity			
pH			
Turbidity (NTU)			
Total Suspended solids (mg/ℓ)			
Inorganic nutrients			
Dissolved nitrite and nitrate	The concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in a study area or comparable site elsewhere), considering possible differentiation between seasons or episodic events.		
Dissolved total ammonia			
Dissolved reactive phosphate			
Toxicants	**Water**	**Sediment**	
	Recommended QT (µg/ℓ)	**Recommended QT**	**Probable Effect Level**
Non-metallic inorganic toxicants			
Total Ammonia-N	500 (99% protection); 910 (95% protection)	–	–
Free Chlorine-Cl	0.5	–	–
Cyanide (CN^-)	2 (99%); 4 (95%)	–	–
Fluoride (F^-)	5,000	–	–
Sulphide (H2S)	2	–	–
Metals		**(µg/g dry weight)**	
Arsenic (As)	As [III] 2.3; As[V] 4.5	7.24	41.6
Cadmium (Cd)	0.7 (99%); 5.5 (95%)	0.68	4.21
Chromium (Cr)	Cr [III] 7.7 (99%); 27 (95%) Cr [VI] 0.14 (99%); 4.4 (95%)	52.3	160
Copper (Cu)	0.3 (99%); 1.3 (95%)	18.7	108
Lead (Pb)	2.2 (99%); 4.4 (95%)	30.2	112
Mercury (Hg)	0.1 (99%); 0.4 (95%)	0.13	0.7
Nickel (Ni)	7 (99%); 70 (95%)	15.9	42.8
Silver (Ag)	0.8 (99%); 1.4 (95%)	0.73	1.77
Tributyltin as Tin (Sn)	0.0004 (99%); 0.006 (95%)	0.009	0.07

Vanadium (V)	50 (99); 100 (95%)	–	–
Zinc (Zn)	7 (99%); 15 (95%)	124	271
Petrochemicals (mono- and poly-cyclic aromatic hydrocarbons)		**(ng/g dry weight)**	
Benzene (C6)	600(99%); 950 (95%)	–	–
Toluene (C7)	110 (99%); 180 (95%)	–	–
Ethylbenzene (C8)	50 (99%); 80 (95%)	–	–
m-Xylene (C8)	50 (99%); 75 (95%)	–	–
Naphthalene (C9)	50 (99%); 70 (95%)	34.6	391
Acenaphthene (C12)	–	6.71	88.9
Acenaphthylene (C12)	–	5.87	128
Fluorene (C13)	–	21.2	144
Anthracene (C14)	0.01 (99%); 0.4 (95%)	46.9	245
Phenanthrene (C14)	0.6 (99%); 2 (95%)	86.7	544
Fluoranthene (C15)	1 (99%); 1.4 (95%)	113	1,494
Pyrene (C16)	–	153	1,398
Benzo(a)anthracene (C18)	–	74.8	693
Chrysene (C18)	–	108	846
Benzo(a)pyrene (C20)	0.1 (99%); 0.2 (95%)	88.8	763
Dibenzo(a,h)anthracene (C22)	–	6.22	135
Total PAH	–	1,684	16,770
Agrochemicals (pesticides and herbicides)		**(ng/g dry weight)**	
Aldrin	0.003	–	–
Chlordane	0.001	2.26	4.79
Chloropyros	0.0005 (99%); 0.009 (95%)	–	–
DDT	0.004	3.89	51.7
p,p DDT	–	1.19	4.77
p,p DDD	–	1.22	7.81
p'p'- DDE	–	2.07	374
Dieldrin	0.0019	0.72	4.3
Endosulfan	0.005 (99%); 0.01 (95%)	–	–

Endrin	0.004 (99%); 0.008 (95%)	2.7	60
Fenitrothion	0.001	–	–
Lindane	0.007	0.32	0.99
Methoxychlor	0.004	–	–
Temephos	0.0004 (99%); 0.05 (95%)	–	–
Toxaphene	0.1 (99%); 0.2 (95%)	–	–
Pharmaceuticals			
Carbamazepine	1 (99%); 9.2 (95%)	–	–
Diclofenac	180 (99%); 770 (95%)	–	–
Fluoxetine	0.23 (99%); 1.6 (95%)	–	–
Propranolol	3.5 (99%); 14 (95%)	–	–
Other organic toxicants		**(ng/g dry weight)**	
Phenol	270 (99%); 400 (95%)	–	–
Polychlorinated Biphenyls (PCBs)	0.03	21.6	198

2.3.1 Deriving site-specific QTs for water

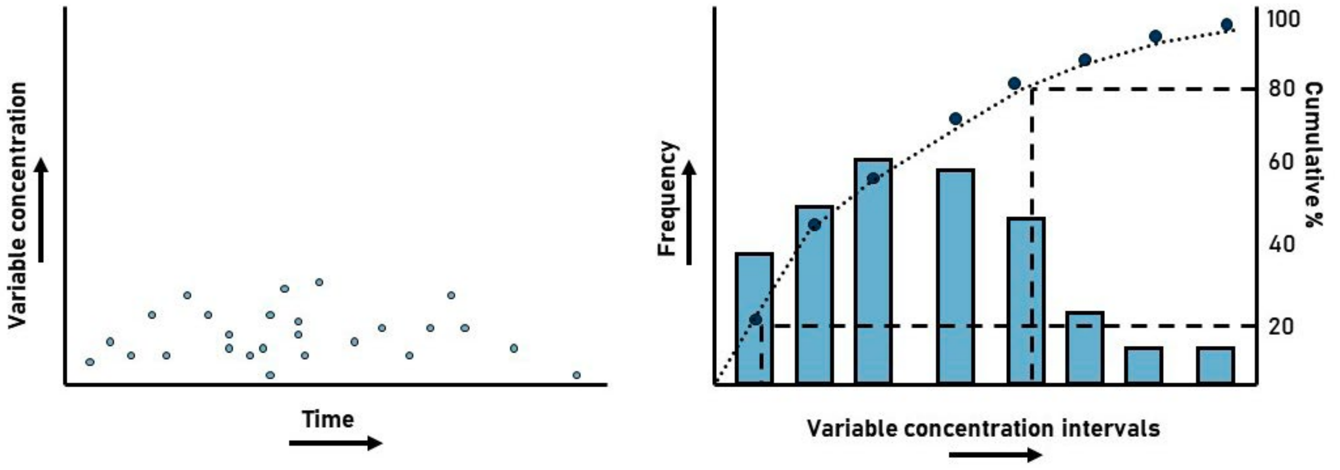
The Reference Data Approach has been recommended for derivation of QTs for physico-chemical properties and inorganic nutrients in the WIO region. This method uses an appropriate percentile (e.g. 20th and/or 80th %ile) of the physico-chemical data collected from a specific site prior to modification (or an appropriate Reference site) to derive QTs as is illustrated in Figure 2.3.

Where the QTs need to be derived using the Reference Data Approach (e.g. physico-chemical properties and inorganic nutrients), monthly data collected over a two-year period are considered sufficient to incorporate ecosystem variability if variables do not show large seasonal or event-scale effects (ANZECC, 2000). However, in ecosystems where concentrations of physico-chemical properties (and ecological and biological responses) do show strong seasonal and event-scale effects, it will be necessary to monitor (and/or model) to detect these seasonal influences or events. Therefore, where seasonal or event-driven processes dominate, data need to be grouped and QTs need to be derived for corresponding key periods.

Note: Where countries already have derived site-specific QTs for physico-chemical properties and nutrients, the approach proposed here does not exclude those countries from maintaining the current QTs.

It is recommended that target values derived from the Reference Data Approach be compared with the median or average (whichever is considered most appropriate) of the measured data from the study area (either measured spatially across various locations within a test area or over an appropriate time period at specific sites). Statistically, the median usually represents the most robust descriptor of the test site data and is the recommended approach.

Figure 2.3 **Illustration of using Reference data approach to derive QTs, using the 20th and/or 80th percentiles.**



In countries where few site-specific reference data are available and seasonal and event influences are poorly defined for the physico-chemical properties, single value QTs could be derived from available data based on professional judgement, as an interim measure. To assist in establishing such interim QTs, impacts and thresholds considered relevant to critical ecosystems within the WIO region were sourced and were translated into potential interim QT ranges for consideration by practitioners in the different countries (Table 2.3).

Recommended (single) value QTs for toxicants were based on large, international toxicological data sets, and provide a general (conservative) tolerance of biota to constituent concentrations, but it does not necessarily consider site-specific (natural) background conditions. Therefore, where site-specific studies show non-compliance with recommended QTs (or in the event that recommended QTs are considered to underestimate site-specific tolerance levels), a phased risk assessment process should be applied to refine QTs as illustrated in Figure 2.4.

Table 2.3 **Potential interim QT ranges in water to be consider for protection of aquatic ecosystems in WIO region.**

Constituent	Potential interim QT ranges for water		
	Seagrass	Mangroves	Coral reefs
Temperature (°C)	15–28	Tropical: 18–38 Subtropical: 16–36	20–29
Salinity	15–36	5–40	30–40
Dissolved oxygen (mg/ℓ)	4–12	2–12	4–10
Total inorganic N (µg/ℓ)	500	1,000	15
Total inorganic P (µg/ℓ)	50	100	5

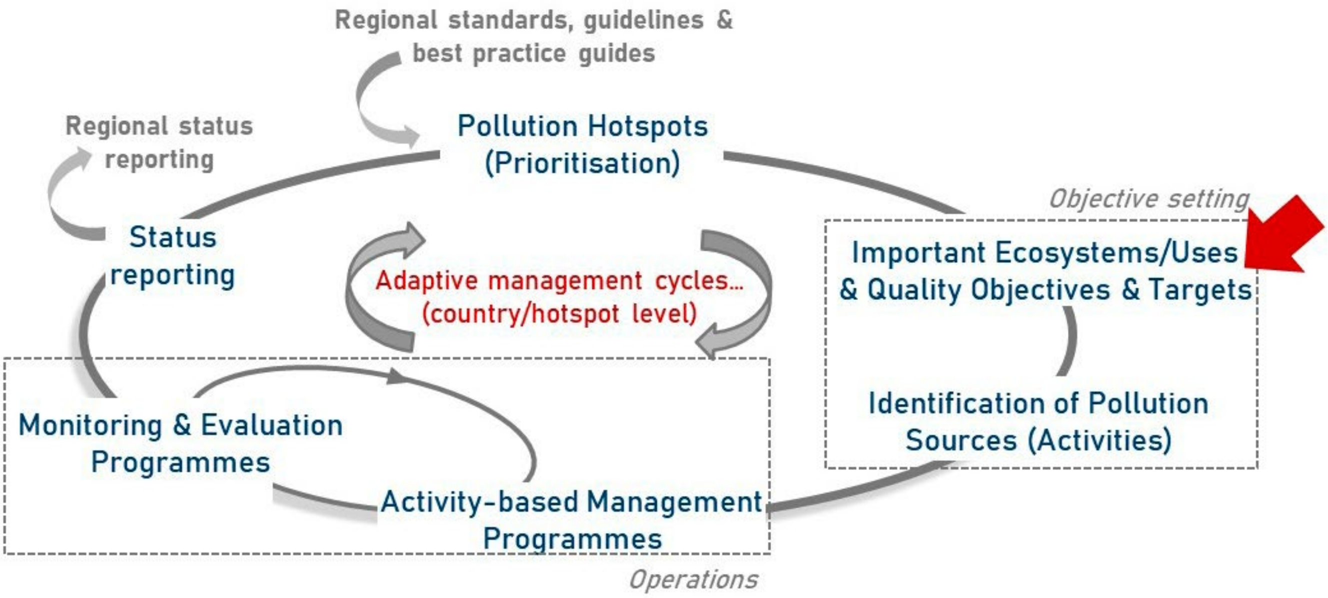
Incremental refinements may include, for example:

- Natural background concentrations of a particular variable exceed QTs
- Site-specific toxicity or bioavailability testing (i.e. exploring different lines of evidence) show need to refine QTs, for examples as a result of site-specific water quality characteristics such as dissolved organic matter, Ph, and the toxicity of different metal species
- Continuous and extensive ecological monitoring shows that exceedances of the recommended QT are consistently assessed as posing no risk to the ecosystem (i.e. QT may be relaxed).

When applying these (single) recommended QTs to measured data to test for compliance, **all data points should comply with such target values**.

It is good practice to apply the recommended QTs for the **protection of coastal and marine aquatic ecosystems** as widely as possible in coastal and marine areas, and not just limit their application to protected or conservation areas.

Figure 2.4 Proposed phased process for refinement of recommended QTs for site-specific application in the protection of aquatic ecosystems in the WIO region.



2.3.2 Deriving site-specific QTs for sediments

As with recommended QTs for toxicants in water, QTs for sediment derived from international toxicological data sets (Table 2.2) provide a general (conservative) tolerance of biota for constituent concentrations, and do not necessarily consider site-specific (natural) background conditions. Where site-specific studies show non-compliance with recommended QTs (or in the event that recommended QTs are considered to underestimate site-specific tolerance levels) a phased risk assessment process should be applied to refine QTs, as illustrated in Figure 2.4. In the case of sediment toxicants, it is also important to consider **sediment particle size** and **organic content (OC)**.

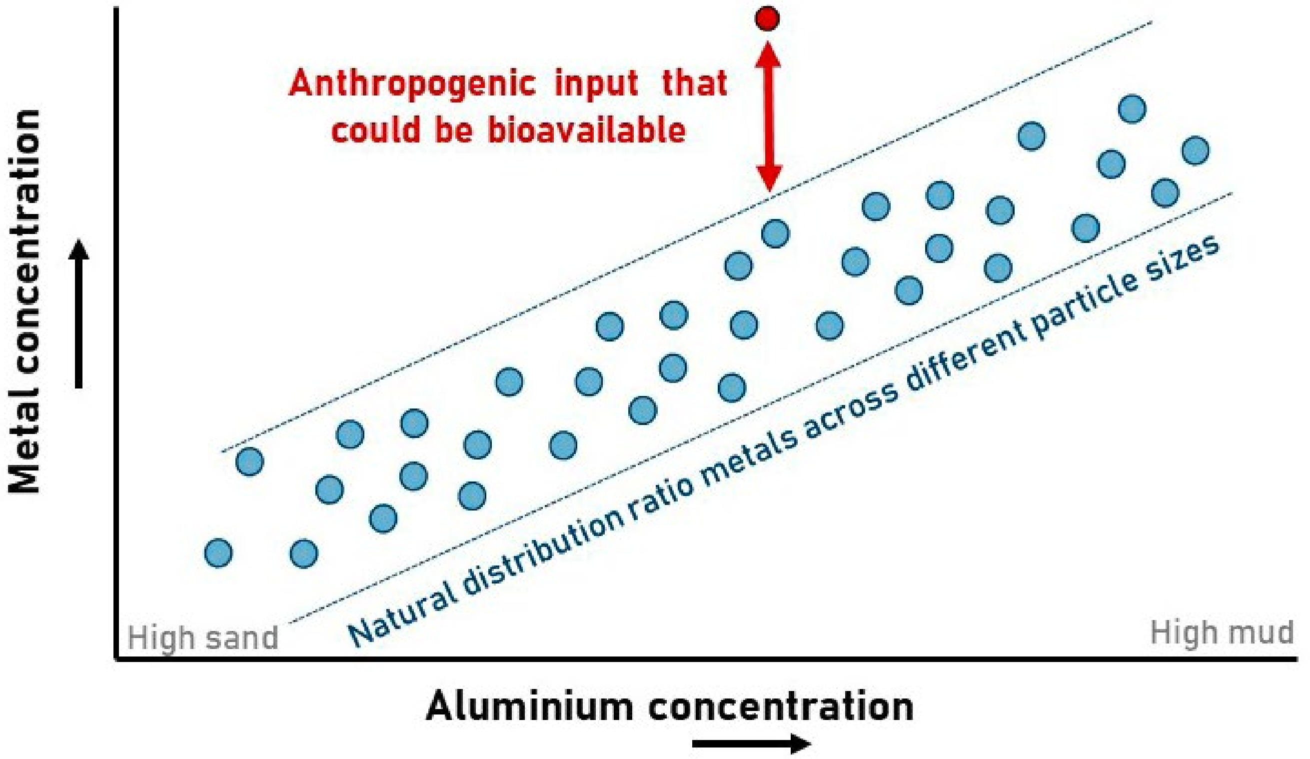
Sediment particle size influences the contaminant binding capacity of sediments, which decreases with increasing particle size, and as a result the concentrations of contaminants tend to be higher in finer grained sediment fractions (unless pollutant source is a particulate such as paint particles) (UNEP 2007). Data sets applied in the derivation of QTs usually consider finer sediment fractions rather than sandy sediments, so these targets are most applicable to finer sediments. Therefore, the <63 µm sediment particle size fraction (clay and silt) is considered most appropriate for comparison with recommended QTs. However, where whole sediment samples are used the particle size distribution of the samples must be taken into account when interpreting results against QTs. This is especially important for metals, which are ubiquitous, naturally occurring chemicals of which the concentration in uncontaminated sediment can vary by orders of magnitude over relatively small spatial scales. **Therefore, it is good practice to include particle grain size in toxicant monitoring programmes as lithological normalizer in estimating bioavailable fractions.**

Note: Normalization of toxicant data can only be recommended if there is a strong statistical relation between the contaminant concentration and the normalizer. Without such a strong relationship, it can distort the interpretation of data (UNEP, 2007).

An approach that could be applied to consider the influence of sediment particle size on metals, and to distinguish between natural concentrations versus anthropogenic contamination, is geochemical normalization (e.g. Newman and Watling, 2007). Geochemical normalization involves the development of metal baseline models using sediments of varying particle size (e.g. gravel to mud) from a specific area that have been subject to minimal impacts from anthropogenic activities (UNEP, 2007). Aluminium is generally considered as the most suitable normalizer since it is a major constituent of fine grained alumino-silicates (clays). It shows a strong inverse correlation to particle size and positive correlations to co-occurring metal concentrations. Therefore, normalization serves as a means of comparing aluminium versus metal concentration ratios of uncontaminated locations to those in potentially metal-enriched sediment, as illustrated in Figure 2.5.

Most metals in unpolluted sediment tend show a linear relationship with Aluminium concentrations in sediments (typically increasing with increase in mud content). As a result, one can establish a natural ratio across different particles sizes for a particular ecosystem. Measured data can then be compared with this ratio band. Where the measured data plots within the natural ratio band, it is most likely of natural origin, and not bioavailable. However, when the measured data plots above the natural ratio band, it could suggest anthropogenic input, and the fraction outside the natural ratio band should be compared with the recommended sediment QT for test for compliance. Because geological and geochemical properties can differ between regions (or catchments) it is most appropriate to develop these models for specific systems. **It is therefore good practice to include aluminium (and possibly iron) analysis in metal monitoring programmes as geochemical normalizers in estimating bioavailable fractions.**

Figure 2.5 **Illustration of the concept of geochemical normalization using aluminium as normalizer** (Source: adapted from Newman and Watling, 2007).



Organic content (OC) also affects the partitioning of certain metals and toxic organic chemicals to sediment particles (UNEP 2007). Partitioning to OC, therefore, may affect the bioavailability of chemicals. **It is therefore good practice to include total organic carbon measurements in toxicant monitoring programmes as geochemical normalizers in estimating bioavailable fractions.** Such normalization is typically undertaken to 1% organic content OC (dry weight) in sediments before comparing to QT. Such normalization should only be applied to sediments with total organic carbon [TOC] concentration between 0.5% and 10% because at lower concentrations, other physical and chemical factors influence partitioning. At higher concentrations of carbon may be present as oils or tar, and not organic binding substances (e.g. humic substances) (Simpson *et al.*, 2013; Batley *et al.*, 2002). For example, if sediment contains 5 µg/g of a hydrophobic toxicant with a TOC of 2% (dry weight), then the normalized concentration of the hydrophobic organic toxicant would be equal to 5 divided by 0.5 = 2.5 µg/g (Australia and New Zealand, 2018).

Photo: © Lisa Murray, UNEP – Fishermen from Andranomavo village attempt to catch fish at dawn in Nosy Hara Marine National Park, Madagascar.

3. RECREATIONAL USE

For recreational use of coastal and marine waters the overarching environmental quality objective is:

> *Environmental quality is suitable for recreational use from an aesthetic, safety and hygienic point of view*

Recreational use of coastal and marine waters varies from bathing to mere enjoyment of its scenic aspects. Recreational activities can be classified by the degree of water contact as follows (WHO, 2003; Australian Government, 2008):

- Whole-body contact (primary contact) — activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wet by spray, and where it is likely that some water will be swallowed or inhaled, or come into contact with ears, nasal passages, mucous membranes or cuts in the skin (e.g. swimming, diving, surfing or white-water canoeing).

- Incidental contact (secondary contact) — activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading), and including occasional and inadvertent immersion through slipping or being swept into the water by a wave.

- No contact (aesthetic uses) — activity in which there is normally no contact with water (e.g. angling from shore), or where water is incidental to the activity (such as sunbathing on a beach).

In whole-body contact activities, the probability that some water will be ingested is high, although actual quantities swallowed during recreational water use are difficult to obtain (WHO 2003). Inhalation can be important where there is a significant amount of spray, such as in the case of water skiing or even sunbathing at a surf beach. In water sports, the skill of the participant will also be important in determining the extent of involuntary exposure, particularly ingestion.

Typical water quality problems associated with recreational use of coastal and marine waters include:

- Aesthetics (e.g. bad odours, discolouration of water and presence of objectionable matter)

- Human health and safety (e.g. gastrointestinal problems, skin, eye, ear and respiratory irritations, physical injuries and hypo-/hyperthermia)

- Mechanical interference (e.g. clogging and choking of mechanical equipment in the waters such as boat engines and diving gear).

Parameters typically used to assess the water quality status with regards to the above-mentioned problems are indicated in Table 3.1.

Table 3.1 **Type of constituents (key indicators) typically used to set QTs for recreational use of coastal and marine waters, as well as associated potential problems.**

Type of constituent	Growth stimulation	Biological health	External behaviour response
Objectionable matter (including algal blooms)	●	●	●
Microbiological indicator organisms		●	
Physico-chemical properties		●	
Toxicants (including toxic algal blooms)		●	

3.1 Approach and Methodology

3.1.1 Objectionable substances

Recommended QTs for objectionable matter are usually narrative and typically require that areas be free from:

- Solid waste, including macroplastics (floating, submerged, settleable matter and algal blooms) (aesthetics and human safety risks)
- Oil and greasy films (aesthetics)
- Microplastics (aesthetics)
- Substances resulting in objectionable odours (aesthetics)

Following international trends, a similar approach is adopted for the WIO region, i.e. providing descriptive (or narrative) targets for matters related to objectionable matter.

3.1.2 Physico-chemical properties

In terms of setting recommended QTs for physico-chemical properties linked to safe recreational use, temperature, and pH are most common (e.g. Australian Government, 2008; Health Canada, 2012). Guidelines for these properties are, therefore, based on these international recommended levels.

3.1.3 Microbiological indicator organisms

Following a detailed review of international studies conducted by the WHO (2003), it was concluded that in marine waters intestinal enterococci was the most appropriate *microbiological indicator* to show a dose–response relationship for both gastrointestinal illness (GI) and acute febrile respiratory illness (AFRI). This was based on data collected from mainly temperate regions in the world (WHO, 2003, Kay *et al.*, 2004).

Microbiological Indicators: Because it is often impractical and expensive to conduct regular sampling of disease-causing bacteria, viruses and protozoa, "microbiological indicators" are used. These are organisms that may not necessarily cause disease but show sufficient correlation with disease-causing pathogens and which are more practical and affordable to monitor regularly (Australian Government, 2008).

Although not well correlated with health risks, thermotolerant coliforms may be used as indicators in seawater, in addition to enterococci, under conditions in which enterococci levels alone may be misleading. For example, *E. coli*, rather than enterococci should be used as an indicator wherever the primary source of faecal contamination is from a waste stabilization pond (WSP). Enterococci are damaged in WSPs, whereas thermotolerant coliforms that emerge from a pond appear to be more sunlight resistant than those that enter it. Thus, WSP enterococci are inactivated in receiving water faster than WSP thermotolerant coliforms (NZME, 2003). Estuarine and brackish waters may require analysis of a combination of intestinal enterococci and *E. coli*.

Also, while it is correct to infer that water exceeding guideline values poses an unacceptable health risk, the converse is not necessarily true. This is because wastewater may be treated to a level where the indicator bacteria concentrations are very low, but pathogens such as viruses and protozoa may still be present at substantial concentrations. Specific investigation of this would require the generation of statistically robust data to establish that the treatment process produces an effluent that meets the guideline indicator bacteria values, but at the same time can destroy pathogenic micro-organisms. Wastewater plants may also not always operate 100% of the time (e.g. during high water flows) (NZME, 2003).

Countries and agencies across the world have chosen the geometric mean or various statistical threshold values (STV) (e.g. percentiles) as QTs for this microbiological indicator (for more information, refer to Appendix A). Three major groupings of QT approaches could be identified, namely:

- WHO's risk-based statistical threshold QTs (using enterococci as indicator organism), also adopted in New Zealand and Australia (WHO, 2003; NZME, 2003; Australian Government, 2008)

- EU's risk-based statistical threshold QTs (using both enterococci and *E. coli* as indicators), also adopted by South Africa (CEC, 2006a; RSA DEA, 2012)

- US-EPA and Canadian combined geometric mean and statistical threshold QTs (using enterococci as indicator) (US-EPA, 2012; Canada Health, 2012).

The UNEP *et al.* (2009) proposed the WHO (2003) approach for the WIO region, using enterococci as the key indicator (but also proposed estimated limits for *E. coli*). Since then the EU adopted an approach that considers both enterococci and *E. coli* (CEC, 2006a). Both the WHO and EU adopt a rating system for microbiological health, allowing countries to reflect incremental improvement (but also excellent performance), rather than only rating recreational waters as "safe" or "unsafe". Therefore, it is recommended that countries in the WIO region select either of these approaches, depending on whether they want to select a single or two-indicator approach.

Although intestinal enterococci were shown to be the most appropriate microbiological indicator for coastal marine waters based on data from temperate regions (WHO, 2003), recent studies have shown the potential for both *E. coli* and intestinal enterococci to survive and re-grow in tropical areas. This has given rise to doubts concerning the interpretation of these microbiological indicator concentrations in tropical environments, especially as studies used to establish target values excluded tropical regions. The concern is that in tropical regions, microbiological indicator concentrations can be elevated beyond that from faecal impacts alone, primarily due to the persistence and regrowth of these indicators within the environment (Shibata *et al.*, 2004). For this reason, QTs for *Clostridium perfringens* are also included as an additional indicator for subtropical and tropical areas (e.g. South Africa) (DEA, 2012).

Microbiological aspects of beach sand quality: The WHO (2003) concluded the following on microbiological aspects of beach sand quality, which is also considered relevant to the South African situation: "Bacteria, fungi, parasites and viruses have all been isolated from beach sand. A number of them are potential pathogens. Factors promoting the survival and dispersion of pathogens include the nature of the beach, tidal phenomena, the presence of sewage outlets, season, the presence of animals and the number of swimmers. Transmission may occur through direct person-to-person contact or by other means, although no route of transmission has been positively demonstrated. Concern has been expressed that beach sand or similar materials may act as reservoirs or vectors of infection. However, the capacity of microorganisms that have been isolated from beach sand to infect bathers and beach users remains undemonstrated, and the real extent of their threat to public health is unknown. There is therefore no evidence to support establishment of a guideline value for index organisms or pathogenic microorganisms in beach sand. The principal microbial risk to human health encountered upon beaches and similar areas is that arising from contact with animal excreta, particularly from dogs. Regulations that restrict access seasonally on frequently used beaches or place an obligation upon the owner to remove animal excreta, increased public awareness and beach cleaning are preventive management actions."

3.1.4 Toxicants

With reference to toxicants, it is proposed that appropriate drinking water quality guidelines (e.g. WHO, 2017) be consulted to make preliminary risk assessments in areas where toxicants are expected to be present at levels that pose a risk to human health as long as care is taken in the application. Drinking water quality targets relate, in most cases, to lifetime exposure following consumption of 2 litres of drinking water per day. For recreational water contact, an intake of 200 ml per day—100 ml per recreational session with two sessions per day—may often be reasonably assumed. However, it should be noted that this approach may not be appropriate to substances of which the effects are related to direct contact with water (e.g. skin irritations).

Chlorine: The increasing presence of chlorine, used by local authorities to treat/disinfect wastewater effluent or wastewater spills, has been highlighted as a concern. Therefore, it is recommended that managers responsible for monitoring of beach water quality specifically observe for the presence of chlorine contamination (e.g. as an item on the monitoring log sheet). Where contamination is suspected, appropriate monitoring must be carried out by reputable scientists to establish potential health risks.

Regarding toxicants from harmful algal blooms, no specific target values are prescribed, but when the presence of such harmful algal proliferation occurs, appropriate monitoring must be carried out by reputable scientists to establish potential health risks. According to Horstman et al. (1991) the most well-known toxicants include:

- paralytic shellfish poison (PSP) caused by the toxicant known as saxitoxicant in shellfish which have fed on toxic dinoflagellate plankton (red tide) of the genus Gonyaulax
- diarrhetic shellfish poisoning (DSP), and
- neurotoxic shellfish poisoning (NSP) (aerosol toxicants), with Ptychodiscus breve being the most widely studied organism causing NSP.

Human intoxication related to PSP has only been associated with the consumption of contaminated shellfish, and rarely, if ever, with recreation in seawater. NPS toxicants differ from PSP and DPS in that the toxic effects do not result from ingestion of affected shellfish. Algal physiological processes and/or cell lysis results in the release of these toxicants in the water where they act as contact poisons.

3.2 Recommended Quality Targets for Recreational Use

This section provides the recommended QTs for the different constituent types considered most appropriate for the coastal and marine recreational use (e.g. Table 1.1), and provides useful information on the selected constituents, including a short description, their natural occurrence, interdependencies and fate in the environment, as well as recommended methods and units of measurement. Common sources of these pollutants are discussed in the Strategic Framework for C&MWQM for the WIO Region (UNEP et al., 2022b).

3.2.1 Objectionable substances

Recommended target	• **Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance.** • **Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits.** • **Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use.** • **Water should not contain substances producing objectionable colour, odour, taste, or turbidity.**
Description	Floating matter refers to debris, oil, grease, wax, scum, foam, submerged (just below water surface) objects or any other visible substances.
Natural occurrence	Naturally occurring floating matter is usually limited to macrophytes and algae, or organic foams generated at sea during storm events.

Interdependence & Fate in the environment	Objectionable floating matter accumulates on beaches and in sheltered areas.
Method	Floating matter is not usually measured quantitatively in marine waters but is rather "measured" in terms of a qualitative description.
Impacts & Thresholds	
Typical water quality problems which may be associated with the presence of objectionable floating matter include: • physical injuries • unpleasant aesthetics • clogging and blockage of equipment	

3.2.2 Physico-chemical properties

Temperature

Recommended target	**For prolonged exposure, temperatures should be in the range 15–35 °C**
Description	Temperature is a fundamental property of water.
Natural occurrence	In the WIO region, mostly situated in the tropics, seawater temperature typically between 20–30 °C, but is much lower along the south and west coasts of South Africa. Upwelling is a seasonal phenomenon in some parts of the region and results in warmer surface waters being replaced by cool bottom water of about 14 °C (Kanagev *et al.*, 2009; Bakun *et al.*, 1998).
Interdependence & Fate in the environment	Generally, the temperature is not interdependent on any other water quality properties or constituents.
Method	Temperature is usually measured in situ, using a Conductivity-Temperature-Depth-Salinity (CTDS) meter. An ordinary thermometer can also be used. Units: °C
Impacts & Thresholds	
<15	Extended periods of continuous immersion may cause death in some individuals and will be extremely stressful for anyone who is not wearing underwater protective clothing (Health Canada, 2012)
15–35	No detrimental effect (Health Canada, 2012)
26–30	Comfortable for most individuals throughout prolonged periods of moderate physical exertion (Von Schirnding *et al.*, 1992)

pH

Recommended target	**The pH of water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low**
Description	pH is a measure of the concentration of hydrogen ions in solution, according to the expression: $pH = -\log_{10} [H^+]$, where H^+ is the hydrogen ion concentration. Water is acidic at pH less than seven, while at a pH greater than seven, water is alkaline.

Natural occurrence	The pH of seawater usually ranges between 7.9 and 8.2 (Huguenin and Colt, 1989) Seawater in equilibrium with atmospheric CO2 is slightly alkaline, with a pH of about 8.1–8.3. The pH may rise slightly through the rapid abstraction of CO_2 from surface waters during photosynthesis (Open University, 1989). Decomposition of organic matter under anaerobic (anoxic) conditions involves the reduction of CO_2 itself, and leads to the formation of hydrocarbons, such as methane. Under these conditions, the pH may rise to values as high as 12 (Open University, 1989).
Interdependence & Fate in the environment	Aqueous solutions containing salts of weak acids or bases, such as seawater, show a resistance to pH change (known as buffering), on the addition of acids and bases (Riley and Skirrow, 1975).
Method	pH is measured using a pH meter. The pH of seawater cannot be measured against the low ionic strength National Bureau of Standards (USA) buffers. Seawater has a high ionic strength resulting in significant errors in measurements. Artificial seawater buffers should be used (Hawkins, 1981).
Impacts & Thresholds	
<5.0	Severe eye irritations occur (NAS/NAE, 1973) Skin, ear and mucous irritations are likely to occur (NAS/NAE, 1973)
5.0–6.5	Where the buffering capacity of the water is low, swimming in water with this pH is acceptable. However, in seawater where the buffering capacity can be very high eye, ear, skin and mucous irritations may occur (NAS/NAE, 1973)
6.5–8.5	No detrimental effects. Minimal eye irritations may occur. The pH is well within the buffering capacity of the lachrymal fluid of the human eye (NAS/NAE, 1973)
8.5–9.0	Where the buffering capacity of the water is low, swimming in water with this pH is acceptable. However, in seawater where the buffering capacity of water is high, eye, ear, skin and mucous irritations may occur (NAS/NAE, 1973)
<5 or >9.0	Eye irritations can occur (Health Canada, 2012)

3.2.3 Microbiological indicator organisms

Enterococci (recommended for marine waters)

Recommended Target (EU, SA)	**Category**	**Estimated risk per exposure**	**Count per 100 mℓ**
	Excellent	2.9% gastrointestinal (GI) illness risk	<100 (95th %ile)
	Good	5% GI illness risk	<200 (95th %ile)
	Sufficient (min QT)	**8.5% GI illness risk**	**<185 (90th %ile)**
	Poor	>8.5% GI illness risk	>185 (90th %ile)
OR			

Recommended Target (WHO, Australia, NZ)	A	<1% gastrointestinal (GI) illness risk; <0.3% acute febrile respiratory (AFRI) risk	<40 (95th%ile)
	B	1–5% GI illness risk; 0.3–1.9% AFRI risk	41–200 (95th %ile)
	C (min. QT)	**5–10% GI illness risk; 1.9–3.9% AFRI risk**	**201–500 (95th %ile)**
	D	>10% GI illness risk; >3.9% AFRI risk	>500 (95th %ile)
Description	Enterococci and faecal streptococci refer to vaguely defined groups of Gram-positive spherical bacteria, some of which are of human and/or animal faecal origin, and some of which are members of the natural flora of various environments. Because of the limited specificity of tests commonly used in these groups, they can be considered the same for all practical purposes. Enterococci have been shown to be a valuable indicator for determining the extent of faecal contamination in marine waters (Standard Methods, 1989).		
Natural occurrence	Although enterococci are not a natural water quality property/constituent of marine waters, they are consistently excreted by warm-blooded animals (Standard Methods, 1989).		
Interdependence & Fate in the environment	The survival of enterococci in the marine environment depends on various variables, including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, and adsorption to solids and sediments and ingestion by molluscs. The rate of bacterial die-off in the marine environment is usually expressed in T_{90} values, which is the time required for the bacterial density to decrease by 90%. The T90 values are usually greater during daytime than night-time, primarily due to higher ultraviolet light irradiation during the day (Bellair *et al.*, 1977).		
Method	In routine monitoring, enterococci in seawater are usually measured according to the membrane filtration (Standard Methods, 1989) or most probable number (MPN) techniques. Unit: Enterococci counts per 100 mℓ		
Impacts & Thresholds			
Typical problems associated with the presence of microbiological indicators include gastrointestinal problems and skin, eye, ear and respiratory irritations. A number of large epidemiological studies have been conducted across the world to determine risk exposure ranges for a microbiological indicator organism (Von Schrinding *et al.*, 1992; Fatal *et al*, 1986; Cheung *et al*, 1990; Cheung *et al*, 1991a; Cheung *et al*, 1991b; Corbett *et al*, 1993; Cabelli *et al*, 1982; Fleischer, 1991; Alexander *et al*, 1992; Huisman, 1982; WHO, 2003).			

Escherichia coli (thermotolerant coliform)

	Category	**Estimated risk per exposure**	**Count per 100 mℓ**
Recommended Target (EU, SA)	Excellent	2.9% gastrointestinal (GI) illness risk	<250 (95 %ile)
	Good	5% GI illness risk	<500 (95 %ile)
	Sufficient (QT)	**8.5% GI illness risk**	**<500 (90 %ile)**
	Poor	>8.5% GI illness risk	>500 (90 %ile)

Description	Thermotolerant coliforms refers to a group of total coliforms that are more closely related to faecal contamination, and which generally do not readily replicate in the water environment. Escherichia coli (*E. coli*) are thermotolerant coliform bacteria. They have the important feature of being highly specific to warm-blooded animals' faeces, and for all practical purposes, these bacteria cannot multiply in any natural water environment. These bacteria were selected as indicators of faecal pollution because they typically occur in the faeces of man and warm-blooded animals. However, some human diseases associated with polluted seawater are caused by viruses. Certain shortcomings of thermotolerant coliforms as indicators of virological quality have been shown which might be attributed to the following: • viruses are only excreted by infected individuals and coliform bacteria by almost all humans and warm-blooded animals; • viruses are excreted for relatively short periods, while coliform bacteria are excreted fairly consistently; • the structure, composition, morphology and size of viruses differ fundamentally from that of bacteria, which implies that behaviour and survival in water differ extensively.
Natural occurrence	Although thermotolerant coliforms are not a natural water quality property/constituent of marine waters, they are consistently excreted by humans and other warm-blooded animals.
Interdependence & Fate in the environment	The survival of thermotolerant coliforms in the marine environment is dependent on a variety of constituents including temperature, exposure to ultraviolet light irradiation in sunlight, high salinity, osmotic shock, microbiological antagonism, adsorption to solids and sediments and ingestion by molluscs. The rate of bacterial die-off in the marine environment is usually expressed in T90 values, which is the time required for the bacterial density to decrease by 90%. The T90 values are usually greater during daytime than night-time, primarily due to higher ultraviolet light irradiation during the day (Bellair *et al.*, 1977).
Method	In routine monitoring, thermotolerant coliform in seawater is usually measured according to the membrane filter or MPN techniques (Standard methods 1989) Unit: *E. coli* counts per 100 mℓ
Impacts & Thresholds	
Typical problems associated with the presence of microbiological indicators in seawater used for recreational purposes are usually related to human health, for example gastrointestinal problems and skin, eye, ear and respiratory irritations. A number of large epidemiological studies have been conducted across the world to determine risk exposure ranges for microbiological indicator organism (Von Schrinding *et al.*, 1992; Fatal *et al.*, 1986; Cheung *et al.*, 1990; Cheung *et al.*, 1991a; Cheung*et al.*, 1991b; Corbett *et al.*, 1993; Cabelli *et al.*, 1982; Fleischer, 1991; Alexander *et al.*, 1992; Huisman, 1982; WHO, 2003).	

Clostridium perfringens

Recommended target	***C. perfringens*: Geometric mean < 5 counts per 100 mℓ ***
** Whilst waiting on the outcome of scientific studies by organizations such as the WHO, interim measures to mitigate potential issues in tropical water include the use of an additional microbiological indicator—Clostridium perfringens, a spore-forming obligate anaerobe—in the assessment of recreational waters along tropical coasts (Hawaii Department of Health, 2000). The use of this indicator* ***has shortcomings (e.g. although C. perfringens is not capable of re-growth in aerobic environments****, it persists for long periods, and its detection in the environment may not be an indicator of* ***recent*** *sewage contamination).*	
Description	*Clostridium perfringens* is a spore-forming, obligate anaerobic bacterium

Natural occurrence	Although *C. perfringens* is not a natural water quality constituent/property of marine waters this species is ubiquitous in nature, including soil and marine sediments (Butler *et al.*, 1986). Type A strains form part of the microflora of both soil and the intestinal tracts of humans, while Types B, C, D and E are obligate parasites of warm-blooded animals and occasionally are found in man (Smith, 1975).
Interdependence & Fate in the environment	In the absence of fermentable carbohydrates *C. perfringens* tends to form spores, a highly resistant resting phase whereby it can survive in a dormant state through long periods of starvation or other adverse environmental conditions (Cruickshank, 1969). In this state the organism can remain viable for many years. When external conditions become favourable for growth, i.e. access to moisture, nutrients and anaerobic growth conditions (*C. perfringens* is an obligate anaerobe), germination of the spores occurs, and the organism reverts to a vegetative state.
Method	In routine monitoring, C. perfringens in seawater is enumerated by the membrane filtration method using mCP agar and incubation under anaerobic conditions
Impacts & Thresholds	
Sub-cutaneous invasion by *C. perfringens* through existing deep tissue wounds can result in gas gangrene and septicaemia. Direct oral ingestion of seawater contaminated with the spore form of the organism does not have a detrimental effect.	

3.3 Guidance on Applying Quality Targets Site-Specifically

For ease-of-use Table 3.2 summarize the recommended QTs for recreational waters in the WIO region as detailed in Section 3.2.

Table 3.2 Summary of recommended QT for recreational water in WIO region.

Parameter	Recommended Quality Target		
Objectionable matter	• Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance. • Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits. • Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins, and which would be a danger, cause nuisance or interfere with any designated/recognized use. • Water should not contain substances producing objectionable colour, odour, taste, or turbidity.		
Temperature (°C)	For prolonged exposure, temperatures should be in the range 15–35°C		
pH	pH of water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits		
Enterococci (counts per 100 mℓ)	Excellent: < 100 (95th %ile)	OR	A: <40 (95th %ile)
	Good: < 200 (95th %ile)		B: 41 – 200 (95th %ile)
	Sufficient: < 185 (90th %ile) (QT)		**C (min QT): 201–500 (95th %ile)**
	Poor: > 185 (90th %ile)		D: > 500 (95th %ile)

E. coli **(counts per 100 mℓ)**	Excellent: < 250 (95 %ile)		No guidelines provided
	Good: < 500 (95 %ile)		
	Sufficient: < 500 (90 %ile) (QT)		
	Poor: > 500 (90 %ile)		
C. perfringens	Geometric mean < 5 counts per 100 mℓ		

Where pollution sources are present in recreational areas that may introduce pollutants that can cause deterioration in aesthetics or put users at risk due to unacceptable pH, temperature or toxicants, conditions should be monitored and compared with recommended QTs.

Based on international best practice (for more information, refer to Appendix A), the **assessment of the quality of marine recreational waters** should ideally comprise of:

- A microbiological quality assessment (applying the rating as per the recommended QT)
- Regular sanitary inspections.

In the **microbiological water quality assessment**, statistical analyses are required for comparison with the recommended target values. Where microbiological assessments are rated against a percentile target value it is important to ensure an appropriate sample size. For example, in **rating beach water quality using microbiological data collected weekly or bi-weekly, it is recommended that a 12-month running period is applied (in contrast to the typical 5-year period recommended internationally).** This is considered most appropriate for situations where the microbiological quality of recreational waters can change markedly over a short period. This approach allows for a more real-time classification process (e.g. monthly rather than yearly), recognizing such variability (RSA DEA, 2012).

Calculation of percentile values for microbiological parameters: Parametric: Based upon percentile evaluation of the $\log_{10}$ normal probability density function of microbiological data acquired from a bathing water, the percentile value is derived as follows (CEC, 2006a):

- Take the $\log_{10}$ value of all bacterial enumerations in the data sequence to be evaluated (if a zero value is obtained, take the $\log_{10}$ value of the minimum detection limit of the analytical method used instead)
- Calculate the arithmetic mean of the $\log_{10}$ values (μ)
- Calculate the standard deviation of the $\log_{10}$ values (σ)

The upper 95%ile point of the data probability density function is derived from the following equation: upper 95 %ile = antilog ($\mu + 1{,}65\ \sigma$)

The upper 90 %ile point of the data probability density function is derived from the following equation: upper 90 %ile = antilog ($\mu + 1{,}282\ \sigma$)

Non-parametric: Firstly, the data are ranked into ascending order and then the “rank” of the required percentile calculated using an appropriate formula—each formula giving a different result. There is no one correct way to calculate percentiles in this manner although the Hazen method is typically considered most appropriate as the “middle of the road” option (e.g. the Excel method always give the lowest percentile while Weibull method always gives the highest). The Hazen procedure is as follows (NZME, 2003):

- For n data, X_i, such that $i = 1, 2, \ldots, n$, rank the n data from lowest to highest where ranked data is X_i: $i = 1, 2, \ldots, n$
- Compute the percentile fraction (i.e., proportion) as $p = P/100$ (P is e.g. 95 %ile)
- Check if there are enough data to make the calculation, i.e., if $n >= 1/[2(1-p)]$ and $n >= 1/(2p)$ [first limit applies for an upper percentile ($p > 1/2$), and vice versa]
- If there are enough data, then calculate the Hazen rank (usually non-integer) $r_{Hazen} = 1/2 + pn$
- Interpolate between integer ranks (i.e., ranked data) adjacent to the Hazen rank using Hazen *P*th percentile = $(1-rf)Y_{ri} + rfY_{ri+1}$, where ri = the integer part of r_{Hazen} and rf = fractional part of r_{Hazen} [note that the formula still works if there is just enough data, i.e., for equalities, instead of inequalities].

Percentile values can be calculated by different percentile calculation approaches, based on data availability, statistical considerations and local resources. Two main approaches can be used, either parametric or non-parametric (WHO, 2003). The parametric approach assumes that the samples have been drawn from a particular distribution, typically the $\log_{10}$ normal distribution for microbiological data, while the non-parametric approach does not assume any particular distribution and uses data ranking. The *Hazen method* is the preferred procedure although the *Excel spreadsheet method* can also be applied where users do not have access to a suitable Hazen template.

The **sanitary inspection** aims to identify all potential sources of faecal pollution (particularly human faecal pollution) and to grade a recreational area accordingly (Table 3.3).

Table 3.3 **Example of a Sanitation Inspection Checklist**
(Source: adapted from NZME, 2003).

Site name		
Location		
Map position	**Latitude**	**Longitude**
Person completing checklist		
Information about area		
Key features of area		
Total annual rainfall (mm)		
Seasonal rainfall pattern		
Water use activities		
Seasonal loading patterns		

Land-use or human activities surrounding recreation site (Tick all that apply and note key findings)		
Natural vegetation	Cultivated land	Road/rail
Urban area	Residential	Landfill/dump sites
Sand dunes	Commercial	Other potential polluting activities (specify)
Pastures	Industry (specify)	
Notes:		

Effluent/wastewater/stormwater direct to recreational water		Present?	Likely to cause effect?
1	Discharge of untreated human effluent onto or adjacent to a recreational area		
2	Storm water outlet with potential sewage contamination onto or adjacent to recreational area		
3	Urban stormwater outlet protected from sewage ingress		
4	On-site or other private sewage disposal systems (e.g. septic tank / conservancy tanks/package plant)		
5	Sewage discharge: untreated, primary or secondary treatment		
6	Sewage discharge: tertiary treatment		
7	Intensive agricultural use in immediate catchment and potential for run-off from untreated animal effluent (e.g.		
8	dairy farms, livestock)		
9	Incidence and density of bird life (particularly lagoons/estuaries)		

Quality of river/stream inflows to recreational area (if present)		Present?	Likely to cause effect?
10	Discharge of untreated human effluent, primary or secondary wastewater treatment plant discharge, on-site or other private sewage disposal systems (e.g. septic tank /conservancy tanks/ package plant)		
11	Storm water outlets with potential sewage contamination		
12	Sewage discharge after tertiary treatment		
13	High-intensity agricultural/rural activities, incidence and density of feral animal/bird population		
14	Focal points of drainage, as run-off from low-intensity agriculture/ urban/rural catchment		

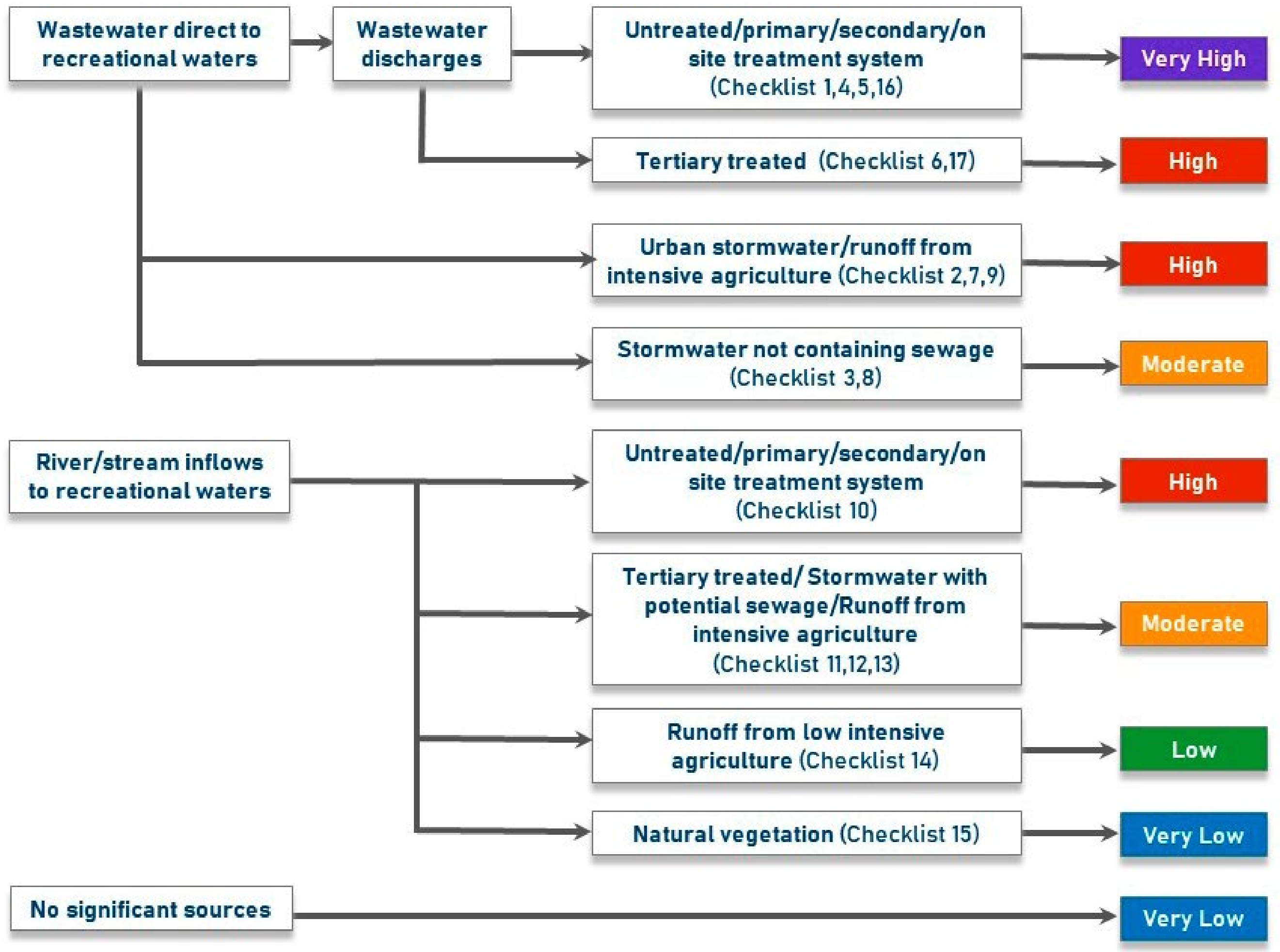
Other influences		Present?	Likely to cause effect?
16	Tidal movements or onshore winds likely to carry water polluted by untreated/ primary/secondary treated effluent or onsite waste treatment systems into recreational area		
17	Tidal movements or onshore winds that are likely to carry water polluted by tertiary treated wastewater into recreational area		
Note: *If the box is ticked indicating the presence of any of the above, the answer as to whether it is causing an effect may be obvious (e.g. discharge of human or animal effluent onto or adjacent to a recreational area). If it is unclear whether it is causing an effect, a more detailed investigation may be required to establish relative importance and magnitude of the effect.*			
Other considerations		**Yes**	**No**
Does rainfall trigger contamination events?			
Does microbiological water quality data exceed single sample guideline (280 counts per 100 ml) on any occasion?			
Is there additional information implying risk (such as notified illness related to recreational water activities)?			

In this regard, the three most important sources of human faecal contamination are considered to be:

- Sewage (e.g. wastewater discharges, sewage pump station overflow, seepage from septic/conservancy tanks, contaminated storm-water run-off)
- Riverine discharges (e.g. where rivers are receiving sewage discharges)
- Contamination from bathers (e.g. excreta), and
- Shipping and boating activities (e.g. inappropriate sewage disposal practices).

The sanitation inspection should be conducted at least once a year, or when significant change in sanitary conditions is expected. Figure 3.1 illustrates how the results from the sanitation inspection (Table 3.3) can be rated.

Figure 3.1 **Rating recreational areas based on the results from a Sanitation Inspection** (see Table 3.3).



Recreational water can also be classified using the Microbiological Quality Assessment results and the Sanitary Inspection as illustrated in Table 3.4, linked to the recommended QTs (Table 3.2) and the Sanitation inspection ratings (Figure 3.1).

Table 3.4 **Classification matrix for recreational waters** (Source: WHO, 2003).

		Microbiological quality assessment category (95th %ile enterococci per 100 ml)				
		Excellent/A	**Good/B**	**Sufficient/C**	**Poor/D**	**Exceptional circumstances**[3]
Sanitary inspection category	**Very Low**	Very good	Very good	Follow-up[1]	Follow-up[1]	Take mitigating action
	Low	Very Good	Good	Fair	Follow-up[1]	
	Moderate	Good	Good	Fair	Poor	
	High	Good	Fair	Poor	Very poor	
	Very high	Follow-up[2]	Fair	Poor	Very poor	
	Exceptional circumstances	Take mitigating action				

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1 Implies non-sewage sources of faecal indicators (e.g. livestock), and this should be verified.

2 Indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most commonly associated with Combined Sewer Overflow presence. These results should be investigated further and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include “event” periods. Confirm analytical results. Review possible analytical errors.

3 Exceptional circumstances relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

A grade of “Very Good” reflects consistent compliance with microbiological targets with few sources of faecal contamination in the area and surrounds. Consequently, there is a low risk of illness from contact recreation. At the other extreme, “Very Poor” reflects significant sources of faecal contamination and rare compliance with microbiological targets. The risk of illness from contact recreation in such waters is high, and swimming is not recommended.

Photo: © UNEP – Crab near mangrove forest in Seychelles.

4. MARINE AQUACULTURE

Marine aquaculture refers to the farming of marine (or estuarine) organisms, either in off-stream (land-based) facilities or in-stream in the marine environment. Marine aquaculture typically focuses on seaweeds, shellfish, crustaceans and fish culture. Water quality related requirements that apply to marine aquaculture are also relevant to activities in which marine organisms are collected (e.g. subsistence use) or harvested from natural stocks for human usages (e.g. fisheries). These include activities such as:

- Seaweed collection (e.g. *Gracilaria*)
- Shellfish collection (for human consumption)
- Recreational fishing
- Subsistence fishing
- Commercial fisheries.

With respect to marine aquaculture and the harvesting of seafood for human consumption, pollution impacts typically comprise:

- Mechanical interference (e.g. where floating matter damages equipment)
- Biological health (e.g. toxic compounds affecting, for example, the reproductive rate of organisms)
- Human health (e.g. through bacteriological contamination and bioaccumulation of toxicants)
- Organoleptic effects (e.g. pollutants causing tainting of seafood).

For marine aquaculture activities (including harvesting or collecting of organisms for human consumption) the following general environmental quality objective is proposed:

> *Environmental quality sustains acceptable product quality and prevents any health risks to consumers*

Parameters typically used to assess the status regarding the above-mentioned problems are indicated in Table 4.1.

Table 4.1 Type of constituents (key indicators) typically used to set QTs for marine aquaculture in coastal and marine areas as well as associated potential impacts.

Type of constituent	Associated potential impacts			
	Mechanical interference	Biological health	Human health	Aesthetics (tainting)
Objectionable matter	●	●		
Physico-chemical properties		●		
Nutrients		●		
Toxicants		●	●	
Microbiological indicator organisms			●	
Tainting substances				●

4.1 Approach and Methodology

4.1.1 Mechanical Interference (objectionable matter)

Recommended QTs related to objectionable matter are usually narrative and typically require that areas be free from:

- Solid waste, including macroplastics (floating, submerged and settleable matter) (mechanical interference, smothering, ingestion of marine organisms)
- Oil and greasy films (mechanical interference and ingestion/behavioural risks to organisms)
- Microplastics (ingestion by organisms)
- Tainting substances (quality of products).

Following international trends, a similar approach is adopted for the WIO region, i.e. providing descriptive (or narrative) targets for matters related to objectionable matter (for more information, refer to Appendix A).

4.1.2 Organism health

With reference to the protection of aquatic organisms cultured and harvested for seafood, it is proposed that the recommended QTs for the protection of coastal aquatic ecosystems be applied (see Section 2.1). This simplified approach is also applied internationally, particularly where activities rely on natural stocks.

4.1.3 Human health

The protection of consumers' health is mainly a concern with shellfish farming or where these organisms are harvested from natural stocks. Shellfish, such as mussels and oysters, are filter feeders. These organisms filter food from the water in which they live and tend to retain contaminants and pathogenic organisms, which can accumulate to high concentrations in their tissue. As human pathogenic organisms (such as bacteria, protozoa and viruses) are usually very expensive to measure on a routine basis, most countries opt for the use of microbiological indicator organisms (i.e. micro-organisms that may not pose a major human health risk, but that are indicative of the presence of human pathogens).

With reference to the protection of human consumers, it is proposed that the WIO region also adopt a classification for shellfish waters as is applied internationally (for more information, refer to Appendix A), comprising a sanitary survey and a microbiological assessment against required QTs.

4.1.4 Organoleptic (tainting) effects

Tainting substances refer to a large variety of chemicals, usually organics, that can taint marine products, thus affecting their quality and market price. These substances can seriously affect the palatability of seafood, resulting in major adverse impacts to the marine aquaculture and wild-capture fishing industries. International guidelines (e.g. ANZECC, 2000; US-EPA, 1986, 2022c) provide recommended QTs that can be adopted for the WIO region.

4.2 Recommended Water and Sediment Quality Targets for Marine Aquaculture

This section provides the recommended QTs for the different constituent types considered most appropriate for coastal and marine areas used for marine aquaculture (e.g. Table 1.1) and provides useful information on the selected constituents, including a short description, their natural occurrence, interdependencies and fate in the environment, as well as recommended methods and units of measurement. Common sources of these pollutants are discussed in the *Strategic Framework for C&MWQM for the WIO Region* (UNEP *et al.*, 2022b).

4.2.1 Objectionable substances (mechanical interference)

Table 4.2 provides a summary of the recommended QTs for objectionable matter linked to mechanical interference in marine aquaculture practice in the WIO region.

Table 4.2 Recommended QTs for objectionable substances in the WIO region.

Recommended target	• **Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance.** • **Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits.** • **Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use.** • **Water should not contain substances producing objectionable colour, odour, taste, or turbidity.**
Description	Floating matter refers to debris, oil, grease, wax, scum, foam, submerged (just below water surface) objects or any other visible substances.
Natural occurrence	Naturally occurring floating matter is usually limited to macrophytes and algae, or organic foams generated at sea during storm events
Interdependence & Fate in the environment	Objectionable floating matter accumulates on beaches and in sheltered areas.
Method	Floating matter is not usually measured quantitatively in marine waters, but is rather “measured” in terms of a qualitative description.
Impacts & Thresholds	
Typical water quality problems that may be associated with the presence of objectionable floating matter include: • Clogging and blockage of equipment	

4.2.2 Biological health of organisms

Apply QTs for physico-chemical properties, nutrients and toxicants in water for the protection of aquatic ecosystems (see Section 2.2).

4.2.3 Human health

Table 4.3 provides a summary of the recommended QTs for shellfish harvesting areas in the WIO region.

Table 4.3 **Recommended QTs for microbiological parameters (water and flesh) for application in shellfish water classification in the WIO region** (Source: Adapted from ASQAAC, 2019; US-FDA, 2019).

Recommended target	*E. coli* (direct consumption) Systematic random sampling strategy [1] • Membrane Filtration (MF) – 14 per 100 mℓ and estimated 90th %ile in water not to exceed 21 per 100 mℓ or • Most Probable Number (MPN) – 14 per 100 mℓ and estimated 90th %ile in water not to exceed 43 per 100 mℓ for a five-tube decimal dilution test, or 49 per 100 mℓ for a three-tube decimal dilution test • Median or geometric mean (MPN) in flesh not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and estimated 90th %ile not to exceed 700 counts per 100 g Adverse pollution condition sampling strategy [2] • MF – 14 per 100 mℓ and not more than 10% of water samples exceed 21 per 100 mℓ or • MPN – 14 per 100 mℓ and not more than 10% of water samples exceed 43 per 100 mℓ for five-tube decimal dilution test, or 49 per 100 mℓ for three-tube decimal dilution test • Median or geometric mean (MPN) in flesh not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 700 counts per 100 g.
	E. coli (relaying or depuration required) Systematic Random Sampling Strategy • MF – 70 per 100 mℓ and estimated 90th %ile in water samples not to exceed 85 per 100 mℓ or • MPN – 88 per 100 mℓ and estimated 90th %ile in water samples not to exceed 260 per 100 mℓ for a five-tube decimal dilution test, or 300 per 100 mℓ for a three-tube decimal dilution test • Median or geometric mean (MPN) in flesh not to exceed of 4,600 counts per 100 g of flesh and intravalvular liquid and estimated 90th %ile not to exceed 14,100 counts per 100 g. Adverse pollution condition sampling strategy • MF – 70 per 100 mℓ and not more than 10% of water samples exceed 85 per 100 mℓ or • MPN – 88 per 100 mℓ and not more than 10% of water samples exceed 260 per 100 mℓ for five-tube decimal dilution test, or 300 per 100 mℓ for three-tube decimal dilution test • Median or geometric mean (MPN) in flesh not to exceed of 46,000 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 14,100 counts per 100 g.

Description	Thermotolerant coliforms refer to a group of total coliform bacteria that are more closely related to faecal contamination, and which generally do not readily replicate in the water environment. *E. coli* are thermotolerant coliform bacteria. It has the important feature of being highly specific to the faeces of warm-blooded animals and for all practical purposes these bacteria cannot multiply in any natural water environment. These bacteria were selected as indicators of faecal pollution because they typically occur in the faeces of humans and warm-blooded animals. However, some human diseases associated with polluted seawater are caused by viruses. Certain shortcomings of thermotolerant coliforms as indicators of virological quality have been shown and might be attributed to the following: • viruses are only excreted by infected individuals and coliform bacteria by almost all humans and warm-blooded animals • viruses are excreted for relatively short periods, while coliform bacteria are excreted consistently • structure, composition, morphology and size of viruses differs fundamentally from that of bacteria, which implies that their behaviour and survival in water differs extensively.
Natural occurrence	Although thermotolerant coliforms are not a natural property/constituent of marine waters, they are consistently excreted by humans and other warm-blooded animals.
Interdependence & Fate in the environment	Survival of thermotolerant coliforms in the marine environment depends on a variety of constituents, including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, adsorption to solids and sediments and ingestion by molluscs. The rate of bacterial die-off in the marine environment is usually expressed in T90 values, which is the time required for the bacterial density to decrease by 90 %. The T90 values are usually greater during daytime than night-time, primarily due to higher ultraviolet light irradiation during the day (Bellair *et al.*, 1977).
Method	In routine monitoring, thermotolerant coliforms in seawater are usually measured according to the MF or MPN techniques (Standard methods, 1989). Unit: *E. coli* counts per 100 mℓ
Impacts & Thresholds	
E. coli food infection causes abdominal cramping, water or bloody diarrhoea, fever, nausea, and vomiting	
1 Systematic random sampling means a method of water sampling and data analysis (which may be applied to a growing area which is not impacted by point source pollution) 2 Adverse pollution sampling strategy means a water quality sampling programme designed to target adverse pollution conditions	

4.2.4 Tainting substances

Estimated threshold concentrations for tainting substances for consideration in the WIO region are listed in Table 4.4.

Table 4.4 Recommended QTs for tainting substances in coastal waters used for marine aquaculture in the WIO region (Source: adapted from ANCEZZ, 2000 and US-EPA, 1986, 2022c).

Tainting substance	Threshold QT (mg/ℓ)	Tainting substance	Threshold QT (mg/ℓ)
Acenaphthene	0.02	Dimethylamine	7
Acetophenone	0.5	Diphenyloxide	0.05
Acrylonitrile	18	B,B-dichlorodiethyl ether	0.09
Copper	1	*o*-dichlorobenzene	< 0.25
m-cresol	0.2	*p*-dichlorobenzene	0.25
o-cresol	0.4	Ethylbenzene	0.25
p-cresol	0.12	Momochlorobenzene	0.02
Cresylic acids (meta, para)	0.2	Ethanethiol	0.24
Chlorobenzene	–	Ethylacrylate	0.6
n-butylmercaptan	0.06	Formaldehyde	95
o-sec. butylphenol	0.3	Gasoline/Petrol	0.005
p-tert. butylphenol	0.03	Guaicol	0.082
2-chlorophenol	0.001	Kerosene	0.1
3-chlorophenol	0.001	Kerosene plus kaolin	1
3-chlorophenol	0.001	Hexachlorocyclopentadiene	0.001
o-chlorophenol	0.001	Isopropylbenzene	0.25
p-chlorophenol	0.01	Naphtha	0.1
2,3-dinitrophenol	0.08	Naphthalene	1
2,4,6-trinitrophenol	0.002	Naphthol	0.5
2,3 dichlorophenol	0.00004	2-Naphthol	0.3
2,4-dichlorophenol	0.001	Nitrobenzene	0.03
2,5-dichlorophenol	0.023	a-methylstyrene	0.25
2,6-dichlorophenol	0.035	Oil, emulsifiable	15
3,4-dichlorophenol	0.0003	Pyridine	5
2-methyl-4-chlorophenol	0.75	Pyrocatechol	0.8
2-methyl-6-cholorophenol	0.003	Pyrogallol	0.5

3-methyl-4-chlorophenol	0.02–3	Quinoline	0.5
o-phenylphenol	1	*p*-quinone	0.5
Pentachlorophenol	0.03	Styrene	0.25
Phenol	1	Toluene	0.25
2,3,4,6-tetrachlorophenol	0.001	Outboard motor fuel as exhaust	0.5
2,4,5-trichlorophenol	0.001	Zinc	5
2,3,5-trichlorophenol	0.001		
2,4,6-trichlorophenol	0.003		
2,4-dimethylphenol	0.4		

4.3 Guidance on applying Quality Targets Site-specifically

Where pollution sources are present in marine aquaculture areas that potentially introduce pollutants that can cause mechanical interference (e.g. objectionable matter) or affect the health of marine organisms or potentially taint seafood, conditions should be monitored and compared with recommended QTs.

It is recommended that a classification system for shellfish growing areas be adopted for the WIO region in terms of human health. **Major export markets may eventually dictate** such an approach for countries in the WIO region that export seafood internationally. The classification of coastal and estuarine areas for the harvesting of shellfish (e.g. clams, oysters, scallops, mussels and other bivalve molluscs) is based on the results for a sanitary survey that consists of:

- Sanitary survey – identification and evaluation of all potential and actual pollution sources in the harvesting area (for details see ASSAC, 2019 or US-FDA, 2019)

- Microbiological survey – based on faecal coliform monitoring results obtained from harvesting area (for details see ASSAC, 2019 or US-FDA, 2019).

The proposed classification system for shellfish growing areas in the WIO region is provided in Table 4.5.

Table 4.5 **Recommended classification of shellfish waters in the WIO region** (Source: adapted from ASSAC, 2019 and US-FDA, 2019).

Category	Microbiological standard (water quality)
Approved	Sanitary survey determines area is not subject to contamination from human or animal faecal matter presenting actual or potential public health hazard or toxic substances exceed required levels. Microbiological levels must comply with *E. coli* QTs (direct consumption) (Table 4.3).

Conditionally Approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period are known, predictable, and not so complex as to prevent a practical management approach. Microbiological levels must comply with *E. coli* QTs (direct consumption) (Table 4.3).
Restricted	Sanitary survey finds area is subject to only a limited degree of pollution and level(s) of faecal pollution, and human pathogens and toxic or deleterious substances are at such an amount that shellfish can be made fit for human consumption by either relaying or depuration. Microbiological levels must comply with *E. coli* QTs (relaying or depuration required) (Table 4.3).
Conditionally Restricted	Sanitary survey finds area open for purposes of harvesting shellfish for relaying or depuration for a reasonable period of time and factors determining this period are known, predictable, and are not so complex as to preclude a reasonable management approach, Microbiological levels must comply with *E. coli* QTs (relaying or depuration required) (Table 4.3).
Prohibited	Shellfish so highly or frequently contaminated that harvesting controls cannot be implemented to adequately ensure protection of public health.

Photo: © Watamu Marine Trust – Machine crushed plastic at Ecoworld Recycling Kenya.

5. INDUSTRIAL USE

It is proposed that industrial water use be recognized as a (beneficial) use of coastal waters in the WIO region. In waters used for industrial purposes, the primary environmental quality objective is:

> *Environmental quality does not result in mechanical interferences, sustains acceptable product quality and prevents any health risks to consumers*

While industrial activities are intuitively sources of marine pollution, there are numerous industries that also rely on acceptable quality of coastal and marine waters (UNEP *et al.*, 2009), including:

- Fish processing – seawater intake used in the processing, washing and canning of seafood which requires good quality intake to ensure product quality and safety for human consumption
- Salt production – pumping of seawater into solar evaporation ponds
- Desalination – abstracting seawater to produce potable water
- Oceanariums – abstracting seawater directly from the sea
- Cooling water – seawater intake for cooling purposes in various industries
- Ballast water intake – intake of seawater for vessel trim, stability and manoeuvrability, usually occurs inside harbours and ports
- Exploration drilling – using seawater in oil and gas exploration drilling operations
- Scrubbing and scaling – using seawater to scrub smokestack to remove dust particles.

With respect to the industrial uses of seawater (UNEP *et al.*, 2009), pollution impacts primarily relate to:

- Human health (e.g. where contaminated seawater may be used for food processing)
- Aesthetics (e.g. tainting of seafood during processing)
- Biological health (e.g. animals in oceanariums)
- Mechanical and process interferences (e.g. through clogging of filters).

Parameters that may have to be considered to assess the suitability of marine waters for the various industrial uses are indicated in Table 5.1.

Table 5.1 **Type of constituents (key indicators) typically used to set QTs for industrial uses in coastal and marine areas as well as associated potential impacts**

Type of constituent	Associated potential impacts			
	Mechanical interference	Biological health	Human health	Aesthetics (tainting)
Objectionable matter	●	●		
Physico-chemical properties		●		
Nutrients		●		
Toxicants		●	●	

Microbiological indicator organisms			●	

Internationally, recommended QTs for industrial use are generally no longer proposed given the large variation in environmental quality requirements that are mainly driven by specific processes and technologies applied by industries. QTs should be derived site-specifically, based on the specific requirements of industries in the area.

Photo: © Sustainable seas Trust – Fishing line entangled on a South African beach.

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Photo: © Credit WIOCESN – Msasani Tanzania beach clean up.

APPENDIX A: BACKGROUND INFORMATION

A.1 Review of International Guidelines: Aquatic Ecosystems

This review considered the following international guidelines that are considered to be most recent and most appropriate for the development of QTs at this broad, regional (WIO) level.

- United States of America (US-EPA, 1985, 1986, 2022a; Long *et al.*, 1995; MacDonald *et al.*, 1996)
- Australia and New Zealand (ANZECC, 2000, Australia & New Zealand Government, 2018; Warne *et al.*, 2018)
- Canada (CCME, 1995, 1999 as updated 2002, 2007)
- European Union (CEC, 2000, 2008, 2013, 2018)
- Mauritius (Mauritius Government, 1999).

The South African coastal water quality guidelines are currently under review and the previous 1995 guidelines (RSA DWAF, 1995), therefore, are not included in this review.

The World Bank Environmental Guidelines are not discussed as part this study, as these are emission guidelines and do not directly apply to the receiving environment (World Bank Group, 2004).

Various data sources can be used to derive QTs for aquatic ecosystems, including (Warne *et al.*, 2018; Simpson *et al.*, 2013):

- Laboratory effect data – undertaking laboratory tests for single parameters and single (or sensitive) species to derive targets
- Field effects data – obtained from biological effects tests of parameters using local biota in local waters to define QTs below which ecologically meaningful changes do not occur
- Reference site data – defining measurable target values based on a natural reference condition that, although ecological consequences are unknown, is unlikely to cause adverse effects
- Equilibrium partitioning approach – deriving existing QTs for water or sediment porewater or deriving sediment QTs from water or sediment porewater targets
- Spiked sediment bioassays – mixing and equilibrating sediments with a contaminant spike, added either to sediment slurry or to overlying water.

A.1.1

In the USA, the United States Environmental Protection Agency (US-EPA) compiled national recommended water quality criteria for the protection of coastal aquatic ecosystems, as required under Section 304(a) of the Clean Water Act (CWA) (US-EPA, 1985, 1986, 2001, 2002, 2013). The criteria provide guidance to States and Tribes in adopting their own water quality standards under Section 303(c) of the CWA.

The US-EPA guidelines for water quality, or criteria as they are referred to, are extensive. Unlike, for example, Australia and New Zealand where an approach and methodology for the derivation of target values are specified for different type of constituents (e.g. physico-chemical properties, nutrients and toxicants), the US-EPA lists a Federal Register citation, a US-EPA document number or an Integrated Risk Information System (IRIS) entry (www.epa.gov/iris) for each variable. Therefore, the information pertinent to the derivation of individual criteria is very extensive. Relevant information on a single variable may even be captured in more than one document. Within the constraints (time and resources) of this project, it was not possible to distil the approach and methodology used in deriving criteria for each and every variable listed in their guideline document. However, a brief overview of the processes and general QTs are provided here.

Nutrients

In terms of QTs for **nutrients**, the US-EPA provides extensive guidance through the Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (US-EPA, 2001). Its definition of “nutrient criteria” includes numerical values for both causative (e.g. inorganic nitrogen and phosphate) as well as response (e.g. algal biomass and water clarity) variables that are required to assess potential eutrophic conditions (in waters that already experience hypoxia, dissolved oxygen should be added as a response variable). The guidelines recognize that nutrient characteristics are site specific, depending on geographic and climate conditions, and it is therefore not appropriate to recommend generic QTs. The approach put forward by the US-EPA consists of a number of key steps, which can be summarized as follows:

- Establishment of **reference condition** and assessment of historical information – reference conditions in terms of nutrient related characteristics are required to provide a site-specific benchmark. Such information may be available from the literature but can also be obtained from the least affected sites remaining (e.g. areas of minimally developed shoreline, areas of least intrusive use or areas fed by rivers that are from least developed catchments). It is also important to assess historical information, in particular, to reveal the nutrient quality and to deduce the ambient, natural nutrient levels associated with periods of algal blooms (or eutrophication).

- Application of **environmental water quality** modelling – in this regard, models are usually applied to reduce ecosystem complexity to a manageable level, to improve the scientific basis for development of theory, to provide a framework for making and testing predictions, and to increase understanding of cause-and-effect relationships. Both empirical and mathematical models have been applied.

- **Statistical models** are empirical and are derived from observations. To be useful as predictive tools, relationships must have a basis, typically represented by conceptual models. However, extrapolation from empirical data is known to be uncertain. Thus, these models are most reliable when applied within the range of observations used to construct the model. Empirical models are typically useful if only a sub-system of the larger ecosystem is of primary interest.

- **Mathematical models** can address many more details of underlying processes when properly calibrated and validated. They also tend to be more useful forecasting (extrapolation) tools than simpler models, because they tend to include a greater representation of the physics, chemistry, and biology of the system being modelled. For example, these models can be used to (1) Develop a relationship between external nutrient loads and resulting nutrient concentrations, which can then be used to define allowable loads; (2) Define the relationship between nutrient concentrations and other endpoints of concern, such as biomass or dissolved oxygen; (3) Provide an increased understanding of the factors affecting nutrient concentrations, such as the relative importance of point and non-point source loads; and (4) Simulate relationships between light attenuation and expected depth of primary production.

- **Assessment and refinement of initial QTs** – the US-EPA requires that proposed targets be assessed by regional specialists prior to application. The refinement process also needs to include verification either by field trials or by use of an existing database of assured quality.

Toxicants

Numerical QTs in water were largely based on four types of adverse effects, namely: acute toxicity to animals, chronic toxicity to animals, toxicity to plants, and bioaccumulation. For marine QTs the following minimum data requirements applied (Russo, 2002):

- Results of acceptable acute toxicity tests with at least one animal species in at least eight different families such that all the following are included: two families in the phylum Chordata, a family in a phylum other than Arthropoda or Chordata, either the Mysidae or Penaeidae family, three other families not in Chordata, and any other family.

- Acute-chronic ratios with species of aquatic animals in at least three different families provided that of the three species: at least one is a fish, at least one is an invertebrate, and at least one is an acutely sensitive saltwater species (the other two may be freshwater species).
- Results of at least one acceptable test with a saltwater alga or vascular plant.
- At least one acceptable bio-concentration factor determined with an appropriate saltwater species, if a maximum permissible tissue concentration is available.

The US-EPA criteria provide two target values for toxic substances in water, based on the level of exposure (US-EPA, 1985, 1986, 2022a; Russo, 2002), namely:

- **Criterion Maximum Concentration** (CMC), which is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect, equals to half of the final acute value
- **Criterion Continuous Concentration** (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect, equals to lowest of the final chronic value, final plant value and final residue value.

Of note is that US-EPA QTs for metals in water (US EPA, 2022a) (see Appendix B) are expressed as dissolved metal concentrations. These concentrations were calculated from the aquatic life criteria (US-EPA, 1986), which were initially expressed in terms of total recoverable metal. The term "Conversion Factor" (CF) represents the recommended conversion factor used to convert a metal criterion expressed as the total recoverable fraction in the water column to a criterion expressed as the dissolved fraction in the water column (US-EPA, 2022a).

In the USA, the National Oceanic and Atmospheric Administration (NOAA) developed a set of sediment quality target values that were originally intended to provide a means of interpreting sediment monitoring data, collected as part of the National Status and Trends Program (Long and Morgan, 1990; revised by Long *et al.*, 1995) (see Appendix B). Originally, Long and Morgan (1990) combined data associated with biological effects derived from the equilibrium partitioning approach, the spiked sediment bioassay approach and various other approaches used to develop sediment quality criteria. The lower 10th percentile data were identified as Effects Range Low (ERL), below which adverse effects on sediment associated species occurred infrequently, and the median as Effects Range Median (ERM), above which adverse effects were frequently observed (Simpson *et al.*, 2013).

In the late 1990s, MacDonald and co-workers expanded on the NOAA approach when they developed a set of saltwater sediment quality target values for the State of Florida (USA), Department of Environmental Protection (MacDonald *et al.*, 1996; 2000) (see Appendix B). They expanded the saltwater database that was originally used by Long and co-workers with additional data on saltwater (referred to as BEDS and which is one of the most comprehensive documented sediment quality assessments yet reported). The data were sorted into effects and no effects data. From the no-effects data, the 50th percentile (No Effect Range Median – NERM) and the 85th percentile (No Effect Range High – NER-H) were calculated. For these a Threshold Effect Level (TEL) and a Probable Effect Level (PEL) were derived as follows:

$$\mathrm{TEL} = (\mathrm{ERL} \times \mathrm{NERM})^{1/2}$$
$$\mathrm{PEL} = (\mathrm{ERM} \times \mathrm{NER\text{-}H})^{1/2}$$

The TEL/PEL values (see Appendix B) form the basis of sediment QTs in several other countries, including Canada (CCME 1999, as updated 2002) and Australia and New Zealand (Simpson *et al.*, 2013). Also, studies on the reliability and predictability of these thresholds found that TEL values provide reliable and predictive tools for identifying concentrations of chemicals in sediments that are unlikely to be associated with adverse biological effects (to test predictability, a large independent data set compiled from studies along the Atlantic, Gulf and Pacific coasts was used). It was concluded that these targets provide a scientifically defensible basis for assessing the quality of soft sediments in marine and estuarine environments (Long and MacDonald, 1998). Key to the National Status and Trends Program approach is that it defines concentration ranges (rather than absolute values) to provide more flexible interpretative tools with broader application. Thus three ranges of concentrations are defined, namely, those that are rarely (<TEL), occasionally (TEL-PEL) and frequently (>PEL) associated with adverse biological effects.

A.1.2 Australia and New Zealand

Australia and New Zealand undertook a revision of their ANZECC (2000) guidelines, which is now an online system (Australian & New Zealand Government, 2018). Their website provides detailed information on the derivation of guidelines, as well as specific and default QTs.

Physico-chemical properties and nutrients

While local field and/or laboratory-effects data is the preferred approach in the development of guideline values, also for physical and chemical stressors, these types of data are expensive to obtain. The Australian and New Zealand guidelines, therefore, mainly pose the reference approach as most practical for deriving guideline values for physico-chemical properties and nutrients, regarding it as inherently conservative, and a good starting point. Their default approach is to calculate an appropriate percentile of reference-site data, typically the 80th and/or 20th percentile (see Appendix B). More conservative QTs based on lower percentiles can be considered where there are indications that the recommended deviation (as posed by 80th and/or 20th percentile) from the reference condition has potential to adversely affect aquatic ecosystems.

Ideally, reference sites need to be similar to assessment sites (e.g. similar in climate and oceanic conditions), be minimally impacted by human pressures, and have sufficient historical data to characterize water quality condition and variability (e.g. seasonality). For modified ecosystems, “best available” reference sites can be considered as a best alternative.

Nutrients typically refer to dissolved inorganic nutrients (i.e. nitrate, nitrite, ammonium, reactive phosphate and reactive silicate) as well as particulate and dissolved organic nutrients (mainly carbon and nitrogen). In the case of nutrients, impact or disturbance occurs through transformations in the environment. Because of other factors involved, there may not be a direct relationship between the ambient concentration of these variables and the biological response, but there is often a relationship between flux and biological response. For example, the concentration of dissolved inorganic nitrogen and phosphate measured in the water column reflects the net effect of the rate at which these nutrients are taken up by primary producers and the rate at which they are regenerated. A very low nutrient concentration could, therefore, indicate that a particular nutrient is essentially depleted from the water column and is therefore limiting primary production in the water column, but equally could simply be the net result of a very rapid uptake and release of the nutrient. Furthermore, these processes tend to occur over different timescales—turnover of inorganic nitrogen and phosphate pools may be measured in minutes, algal growth processes occur over periods of hours, days or weeks, and loading rates of nitrogen and phosphate may be seasonal. As a result, predictive modelling (dynamic simulation) also has become a useful tool for deriving QTs for nutrients, in addition to the other approaches (ANZECC, 2000).

Toxicants

For toxicants in water, the Australian and New Zealand guidelines pose the field and/or laboratory effects approach. The guidelines provide default (generic) QTs (see Appendix B), but also provide guidance on how these could be derived site-specifically. In selecting data to include in the derivation of toxicant QTs, acute, chronic (single- and multi-generation), laboratory and field toxicity data should be sourced from appropriate databases including the US-EPA ECOTOX database (https://www.epa.gov/chemical-research/ecotoxicology-database) and the Australasian Ecotoxicology Database (Warne *et al.*, 1998; Warne and Westbury 1999; Markich *et al.*, 2002; Langdon *et* *al.*, 2009), as well as peer reviewed literature and reliable, publicly available grey literature. An attempt is being made to phase out No Observed Effect Concentration (NOEC) data, and rather to use concentration-response based statistical estimates of toxicity (i.e. no effect concentration and EC/IC/LC data). Therefore, a hierarchical system is posed for estimating chronic toxicity (Warne *et al.*, 2018), in order of preference:

- No effect concentrations (NEC)
- Effect, inhibition or lethal concentration (EC/IC/LCx – in order of preference), where x < 10
- 10% bounded effect concentration (BEC_{10})
- EC/IC/LCx, where 10 <x < 20
- No Observed Effect Concentration (NOEC) (e.g. NOEC data should not be used when there are acceptable data for ≥8 species that belong to ≥4 taxonomic groups)
- NOEC estimated from a chronic Maximum Acceptable Toxicant Concentration (MATC), Lowest Observed Effect Concentration (LOEC) or median lethal/effect value (LC/EC_{50}).

The preferred methods for deriving QTs from such data are the species sensitivity distribution (SSD) of chronic toxicity data and the assessment factor (AF) approach. The SSD, however, is the preferred method, requiring toxicity data for at least five species that belong to at least four taxonomic groups (using toxicity data from at least eight species is strongly encouraged, and from more than 15 species is considered optimal) (see Warne *et al.*, 2018 for further details on methods of calculation).

A re-classification on the reliability of QTs for toxicants in water also has been provided as summarized in Table A.1.

Table A.1 Classification of reliability of QTs derived through SSD method (Source: Warne *et al.*, 2018).

Sample size[1]	Data type	Adequacy of sample size	Adequacy of fit in SSD	Reliability
>15	Chronic[2]	Preferred	Good	**Very high**
			Poor	**Moderate**
8–14		Good	Good	**High**
			Poor	**Moderate**
5–7		Adequate	Good	**Moderate**
			Poor	**Low**

>15	Combined chronic & converted acute or Combined chronic fresh & chronic marine	Preferred	Good	**Moderate**
			Poor	**Low**
8–14		Good	Good	**Moderate**
			Poor	**Low**
5–7		Adequate	Good	**Moderate**
			Poor	**Low**
>15	Converted acute	Preferred	Good	**Moderate**
			Poor	**Low**
8–14		Good	Good	**Moderate**
			Poor	**Low**
5–7		Adequate	Good	**Low**
			Poor	**Very low**

1 Assumed to comprise data from at least four taxonomic groups

2 All types of data irrespective of whether chronic NEC, BEC_{10}, EC_{10} and NOEC values or estimates of chronic EC_{10} and NOEC values converted from chronic LOEC, MATC or EC_{50} data

The Guidelines recognise three categories of current or desired ecosystem conditions, with default guidance associated with each (see Australia & New Zealand Government [2018] for details), namely:

- High conservation or ecological value systems (99% of species to be protected)
- Slightly to moderately disturbed systems (95% of species to be protected)
- Highly disturbed systems (80/90% of species to be protected).

Appendix B lists the recommended QTs for marine waters Australia & New Zealand Government (2018).

While progress has been made in Australia and New Zealand with the derivation of sediment QTs based on local species, such data are slowly being accumulated but at high cost, and it is thus unlikely that sufficient new data will be forthcoming in the near future to derive site-specific targets. Therefore, as is being done in many other countries, Australia and New Zealand opted for using best available effects data from overseas studies and to refine these on the basis of knowledge of existing baseline concentrations, as well as using local effects data as they become available (Simpson *et al.*, 2013). Currently, sediment QTs derived from large effects databases, first applied by Long and Morgan (1990) as part of the NOAA National Status and Trends Program in the USA, and since updated by Long et al. (1995) and MacDonald *et al.* (1996, 2000) form the basis of the QTs for sediments in Australia and New Zealand (see Appendix B) (Simpson *et al.*, 2013).

A limitation in this derivation of sediment QTs is the difficulty in separating chemical-specific impacts, as measured effects are usually ascribed to all chemicals in the sediment mixture. Therefore, effects levels entered for some chemicals may be well below recommended effects thresholds. Because the derivation of sediment QTs were based on total rather than specific or bioavailable toxicants, QTs alone cannot always be used to identify the onset or extent of adverse effects on aquatic ecosystems. Consequently, using QTs as strict limits will likely result in many sediments being classified as toxic when there are no effects evident (a false positive). On the other hand, sediments may contain toxicants for which QTs have not been developed. Therefore, only assessing risk on published QTs may result in sediments being classifying as non-toxic when effects may be occurring due to toxicants that have not been considered (a false negative). A tiered approach, therefore, is adopted in the application of sediment QTs in Australia and New Zealand. Where samples do not meet a QT (or where a QT has not been developed), a systematic weight of evidence (WOE) approach should be followed (Simpson *et al.*, 2013) in refining the QT:

- Perform bioavailability testing, if not compliant then;
- Perform toxicity testing (first line of evidence [LOE]), if not compliant then;
- Perform bioaccumulation/biomagnification testing, if not compliant then; and
- Assess effects on benthic community structure (e.g. ecological malfunction).

The influence of **sediment particle size** and **organic content** in sediments on bioavailability and toxicity also is acknowledged in the Australian and New Zealand guidelines (Australian and New Zealand Government, 2018). The contaminant binding capacity of sediments decreases with increasing particle size, and as a result concentrations of contaminants tend to be greater in finer sediment fractions (unless pollutant source is a particulate such as paint particles). The data applied in the development of default sediment QTs were largely associated with silty rather than sandy sediments, so these targets are most applicable to finer sediments. Thus, in some cases more stringent QTs may have to be applied to sandy sediments because partitioning to pore waters could be more favourable. It has therefore recommended that the finer size fraction be used for comparison with sediment QTs so as to eliminate potential risks of contaminants being diluted by larger mass sediments (e.g. gravel). The <63 µm sediment particle size fraction (clay and silt) is considered representative of sediments most readily re-suspended or potentially ingested by organisms. Sediment fraction does play a role in the bioavailability of contaminants and should be considered when whole sediment samples are analysed prior to comparison with QTs.

High organic content (OC) in sediment samples can favour partitioning of both metals and organic toxicants s in sediments. Therefore, the measured hydrophobic organic toxicant concentrations in the sediment also need to be normalized to the OC content (Australian and New Zealand Governments, 2018), typically to 1.0% OC (dry weight). Kumar *et al.* (2016) also proposed water quality guidelines in Australia for four priority pharmaceuticals (carbamazepine, diclofenac, fluoxetine and propranolol) (see Appendix B).

A.1.3 Canada

The Canadian Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007) provides details on the systematic processes that are applied in the derivation of QTs for water. In essence, two types of QTs can be derived depending on the availability of data as set out in CMME (2007):

- **Type A**: When there are adequate primary and secondary toxicity data to apply a species sensitivity distribution (SSD) approach
- **Type B**: When there are inadequate or insufficient toxicity data for the SSD approach, but for which enough toxicity data from a minimum number of primary and/or secondary studies are available.

A summary document of the Canadian Environmental Quality Guidelines (as updated 2002) has been consulted to obtain specific guideline values for different substances (CCME, 1999 as updated 2002) (see Appendix B).

Environment Canada developed a formal protocol for the development of sediment quality guidelines (CCME, 1995), which is based primarily on the approach and methodology used by MacDonald et al. (1996) in the derivation of sediment QTs. A summary document of the Canadian EQTs (CCME, 1999, as updated 2002) has been consulted to obtain the target values for different substances (CCME, 1999, as updated 2002). Unless otherwise specified, sediment quality targets refer to the total concentration of the substance in surficial sediments (e.g. upper few centimetres) (see Appendix B).

A.1.4 European Community

The European Parliament and the Council adopted the Water Framework Directive, which establishes a framework for community action in the field of water policy, including coastal waters (CEC, 2000). In this regard, the Water Framework Directive provides guidance to Member States to set their own environmental quality standards. The Water Framework Directive does not give specific environmental quality standards for physico-chemical properties and nutrients, other than providing narrative targets associated with different classes (i.e. High, Good, Moderate). High-status waters are considered to be near pristine. For the purposes of this review, the narrative target for "Good Status" is therefore quoted as being equivalent to "water quality guidelines" as used elsewhere (CEC, 2000).

The Water Framework Directive also provides a list of pollutants for which member states must set environmental quality standards (CEC, 2000), namely:

Indicative list of the main pollutants
Organohalogen compounds and substances which may form such compounds in the aquatic environment
Organophosphorous compounds
Organotin compounds
Substances and preparations, or breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment
Persistent hydrocarbons and persistent and bio-accumulable organic toxicants
Cyanides
Metals and their compounds
Arsenic and its compounds
Biocides and plant protection products
Materials in suspension
Substances which contribute to eutrophication (in particular, nitrates and phosphates)
Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.)

The following procedure (as per CEC, 2000) applies to the setting of a maximum annual average concentration:

- Safety factors to be used are as follows:

	Safety factoR
At least one acute $L(E)C_{50}$ from each of three trophic levels of the base set	1000
One chronic NOEC (either fish or *Daphnia* or a representative organism for saline waters)	100
Two chronic NOECs from species representing two trophic levels (fish and/or *Daphnia* or a representative organism for saline waters and/or algae)	50
Chronic NOECs from at least three species (normally fish, *Daphnia* or a representative organism for saline waters and algae) representing three trophic levels	10
Other cases, including field data or model ecosystems, which allow more precise safety factors to be calculated and applied	Case-by-case assessment

- Where data on persistence and bioaccumulation are available, these shall be taken into account in deriving the final value of the environmental quality standard

- The standard thus derived should be compared with any evidence from field studies. Where anomalies appear, the derivation shall be reviewed to allow a more precise safety factor to be calculated

- The standard derived shall be subject to peer review and public consultation, including allowing for a more precise safety factor to be calculated, if required.

In addition to providing general guidance on setting environmental quality standards, the Water Framework Directive (CEC, 2000) requires the Commission to identify priority substances and to set EU Environmental Quality Standards (EQSs) for those substances. In 2008, EQSs for 33 priority substances were published in the EQS Directive (CEC, 2008). These were revised and updated with another 12 substances in 2013 (CEC, 2013) (see Appendix B).

The Technical Guidance for Deriving Environmental Quality Standards (CEC, 2018) provides guidance to countries on the derivation and application of EQSs. Of note is EQSs for transitional waters (e.g. estuaries): **As the default, waters with salinity greater than 5 ppt is recommended as the cut-off between saltwater systems, and therefore EQSs for salt (or marine) waters apply to such waters.**

A.1.5 Mauritius

The Coastal Water Quality Guidelines of Mauritius also set QTs for a few constituents in water to protect aquatic ecosystems (Mauritius Government, 1999) (see Appendix B). However, no details have been provided on the derivation of the targets.

A.2 Review of International Guidelines: Recreational use

In recent years, marine (and estuarine) water quality guidelines for recreational use have received much attention internationally, and include those developed by:

- World Health Organization (WHO, 2003, updated 2009)
- New Zealand (NZME, 2003)
- European Union (CEC, 2006a)
- Australia (Australian Government, 2008)
- South Africa (RSA DEA, 2012)
- Canada (Health Canada, 2012).
- United States of America (see US-EPA, 2022b)

A.2.1 World Health Organization

In 2003, the World Health Organization (WHO) published its *Guidelines for Safe Recreational Water Environments* (WHO 2003, amended in 2009), intended to provide a basis for national or local authorities to develop site-specific guidelines, standards and/or regulations pertaining the management of recreational waters. The WHO recommends a fairly broad assessment of recreational quality spanning aesthetic issues, faecal water quality, chemical and physical agents (e.g. toxicants), toxic algae and cyanobacteria, microbiological aspects of beach sand quality, drowning and injury prevention, sun, heat and cold, free-living microorganisms, and dangerous aquatic organisms.

Guidance on *aesthetics* is presented as a narrative, primarily requiring waters to be free from objectionable deposits, floating debris, oil, scum and other matter, substances producing objectionable colour, odour, taste or turbidity, and substances and conditions that produce undesirable aquatic life. The WHO found that for marine waters enterococci are the most appropriate microbiological indicator, showing the best dose–response relationship for both gastrointestinal illness (GI) and acute febrile respiratory illness (AFRI) (Kay *et al.*, 2004).

The WHO also opted a risk approach in setting QTs for microbiological parameters derived from a number of epidemiological studies (based on exposure of healthy adult bathers swimming in sewage impacted marine waters in a temperate climate with “exposure” as a minimum of ten minutes of swimming involving three head immersions) (Table A.2).

Table A.2 WHO recommended QTs for recreational waters with risk levels (WHO, 2003).

Category	Enterococci Counts per 100 ml	Estimated risk per exposure
A	<40 (95th %ile)	<1% gastrointestinal (GI) illness risk; <0.3% acute febrile respiratory (AFRI) risk. This relates to an excess illness of less than one incidence in every 100 exposures. The AFRI burden would be negligible. This value is below the no-observed-adverse-effect level (NOAEL) in most epidemiological studies.
B	41–200 (95th %ile)	1–5% GI illness risk; 0.3–1.9% AFRI risk. The upper 95th %ile value of 200 relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate at this water quality would be 19 per 1,000 exposures, or approximately 1 in 50 exposures. The 200 enterococci per 100 ml value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or lowest observed-adverse-effect level (LOAEL) for GI illness and AFRI.
C	201–500 (95th %ile)	5–10% GI illness risk; 1.9–3.9% AFRI risk. This range of 95th %iles represents a probability of 1 in 10 to 1 in 20 of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures, or a range of approximately 1 in 50 to 1 in 25 exposures. This level represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data is available
D	> 500 (95th %ile)	>10% GI illness risk; >3.9% AFRI risk. There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the 95th %ile point of 500 enterococci per 100 ml would be 39 per 1000 exposures, or approximately 1 in 25 exposures (above this level there may be a significant risk of high levels of minor illness transmission)

Calculation of 90th or 95th percentile (WHO, 2018): In their recommendation to the European Union pending revision of the EU's Bathing Water Directive (2006/7/EC) (CEC, 2006a), the WHO stated that data from bathing water sites (with at least 80 samples) should be tested for $\log_{10}$ normality. Where the data are shown to be log10 normally distributed, the following calculation method (as per CEC, 2006a) should be used:

- **Take the $\log_{10}$ value of all bacterial enumerations in the data sequence to be evaluated. (If a zero value is obtained then take the $\log_{10}$ value of the minimum detection limit of the analytical method used instead)**
- **Calculate the arithmetic mean of the $\log_{10}$ values (μ)**
- **Calculate the standard deviation of the $\log_{10}$ values (σ)**
- **Upper 90th %ile point of = antilog ($\mu + 1{,}282\ \sigma$)**
- **Upper 95th %ile point = antilog ($\mu + 1{,}65\ \sigma$)**

Where the *data do not exhibit $\log_{10}$ normality*, or where *inadequate data are available* the *Hazen calculation method* should be used.

With reference to microbiological aspects of sand quality, the WHO found that: *"Concern has been expressed that beach sand or similar materials may act as reservoirs or vectors of infection. However, the capacity of microorganisms that have been isolated from beach sand to infect bathers and beach users remains undemonstrated, and the real extent of their threat to public health is unknown. There is therefore no evidence to support establishment of a guideline value for index organisms or pathogenic microorganisms on beach sand. The principal microbial risk to human health encountered upon beaches and similar areas is that arising from contact with animal excreta. Regulations that restrict access seasonally on frequently used beaches or place an obligation upon the owner to remove animal ex-*

creta, increased public awareness and beach cleaning are preventive management actions."

Regarding potential risks from *chemical contamination* the WHO recommended that, as long as care is taken in their application, the WHO Guidelines for Drinking Water Quality (WHO, 2017) can be used in preliminary risk assessments. These guideline values relate, in most cases, to lifetime exposure following consumption of 2 litres of drinking-water per day. For recreational water contact, an intake of 200 mℓ per day (100 mℓ per recreational session with two sessions per day) is considered a reasonable assumption. This approach may, however, not apply to substances of which the effects are related to direct contact with water, e.g. skin irritations. While the WHO did recognise the risk for human health associated with the occurrence of marine toxic algae or cyanobacteria during recreational activities, they found this to be limited to a few species and geographical areas. As a result, it was considered inappropriate to recommend any specific QTs. They did, however, consider cell counts of 100 000 cells/mℓ as a condition that merits intervention.

The WHO guidelines also introduced the concept of "Classification of Recreational Waters" based on microbiological quality assessments (reflecting risk levels linked to microbiological indicators) and sanitary inspections as is illustrated in Table A.3.

Table A.3 **Classification matrix for recreational waters as per WHO** (WHO, 2003) [brackets indicate modification in New Zealand guidelines (NZME 2003)].

		Microbiological quality assessment category (95th %ile enterococci per 100 ml)				
		A (<40)	**B (41–200)**	**C (201–500)**	**D (>500)**	**Exceptional circumstances[3]**
Sanitary inspection category	**Very Low**	Very good	Very good	Follow-up[1]	Follow-up[1]	Require mitigating action
	Low	Very good	Good	Fair	Follow-up[1]	
	Moderate	Good (Follow-up)	Good	Fair	Poor	
	High	Good (Follow-up)	Fair (Follow-up)	Poor	Very poor	
	Very high	Follow-up[2]	Fair (Follow-up)	Poor (Follow-up)	Very poor	
	Exceptional circumstances	Take mitigating action				

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1 Implies non-sewage sources of faecal indicators (e.g. livestock), and this should be verified.

2 Indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most commonly associated with Combined Sewer Overflow presence. These results should be investigated further and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include "event" periods. Confirm analytical results. Review possible analytical errors.

3 Exceptional circumstances relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

Table A.4 **Recommended monitoring schedules for different risk categories** (WHO, 2003).

Category	Enterococci Counts per 100 ml	Estimated risk per exposure
Very low	Minimum of 5 samples per year	Annually
Low	Minimum of 5 samples per year	Annually
Moderate	4 samples x 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results obtained	Annually
High	4 samples x 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results obtained	Annually
Very high	Minimum of 5 samples per year	Annually

Data covering at least five years of monitoring (or 100 samples) should be used for such classification, although the sanitation inspection should be conducted annually to detect any possible change in condition. Different monitoring schedules apply to different risk categories as illustrated in Table A.4 where the sampling programme should be representative of conditions during the time when the areas is used for recreational purposes.

For classification purposes, all results taken during that period should be used. *It is not acceptable to resample should an unexpectedly high result be obtained, and then use the resample and discard the original sample*. On the other hand, samples that are taken following an adverse event to establish the extent of impact need not be included in the classification analysis but should be used to assist in better characterizing risks associated with such events.

Also, in areas where the sanitary inspection category has consistently remained "Very low" or "Low", or the microbiological water quality assessment is stable and based on at least 100 samples, microbiological sampling could be reduced to a minimum of five samples per year to still ensure that no major changes go unidentified. Also, in areas where the sanitary inspection category is "Very high" and thus susceptible to faecal pollution, recreational use should be strongly discouraged and enforced, rather than continuing with intensive monitoring until such time as pollution mitigation measures have been implemented. A more intensive sampling programme is warranted in intermediate-quality recreational water environments ("Moderate" and "High").

A.2.2 New Zealand

New Zealand updated its water quality guidelines for recreational use in 2003 (NZME, 2003), largely adopting the WHO approach (WHO, 2003). However, the New Zealand guidelines deal primarily with microbiological parameters (i.e. they do not provide explicit targets related to aesthetics, physico-chemical properties or toxicants).

The New Zealand guidelines apply the same risk value ranges for microbiological quality as the WHO (2003) (using the *Hazen method* for calculating the percentiles). The country also adopted a classification system derived from a microbiological quality assessment category and a sanitation inspection category, although slightly modified from the WHO matric (WHO, 2003). Similar to the WHO approach, at least 100 sampling points, collected over a five-year period, are required for the microbiological quality assessment. However, it is feasible to consider classification on a minimum of 20 data points collected over a full bathing season, but the classification should be considered as interim until five years of data have been collected.

In addition to the classification (or grading) system, New Zealand also introduced a three-tier surveillance/alert/action system (Table A.5) to be undertaken in areas classified as A to D (see Table A.2). New Zealand derived these target values from previous uncontrolled epidemiological studies (Cabelli, 1983). Recognizing numerous limitations of their approach, surveillance values were obtained by assuming that enterococci distributions would be log normal, that the standard deviation of the logarithms of the enterococci concentration is 0.7 (a reasonable average of available data), and that the enterococci concentration is at a limit of a median of 35 per 100 mℓ (corresponding to a swimming-associated risk of 19 per 1,000 bathing events). The alert and action limits were taken as the 80% and 90% upper one-sided tolerance limits for that distribution, calculated as 136 and 276 enterococci per 100 ml. Acknowledging the uncertainty in estimating the standard deviation (of the logarithms) it was considered appropriate to round these figures to 140 and 280 enterococci per 100 mℓ.

Weekly monitoring should be carried out during the bathing season, or when the water body is used for contact recreation through a systematic random-sampling regime (i.e. samples should be collected weekly regardless of the weather, although there may be exceptions if conditions present a health and safety hazard, in which case samples should be collected as soon after the programmed time as possible). Samples should be collected at approximately 15 cm below the surface at a point where the depth of the water is about 0.5 metres.

Table A.5 New Zealand's short-term management framework for marine recreational waters (NZME, 2003).

Mode	Sample reading	Action
Surveillance (Green Mode)	No single sample >140 enterococci/100 mℓ	• No action required • Continue routine (e.g. weekly) monitoring.
Alert (Amber Mode)	Single sample >140 enterococci/100 mℓ	• Increase sampling to daily (initial samples will be used to confirm if a problem exists). • Consult the CAC to assist in identifying possible location of sources of faecal contamination. • Undertake a sanitary survey, and report on sources of contamination.
Action (Red Mode)	Two consecutive single samples (resample within 24 hours of receiving 1st results, or as soon as is practicable) > 280 enterococci/100 mℓ	• Increase sampling to daily (initial samples will be used to confirm if a problem exists). • Consult on assistance in identifying possible location of sources of faecal contamination • Undertake a sanitary survey, and report on sources of contamination • Erect warning signs • Inform public through the media that a public health problem exists

A.2.3 European Union

The European Union adopted the Bathing Water Directive (2006/7/EC) (BWD) (CEC, 2006a). The EU ranks microbiological water quality QTs for three categories, namely “Excellent”, “Good”, “Sufficient”, based on targets for microbiological indicators (*E. coli* and enterococci) (Table A.6).

Table A.6 Recommended QTs for marine bathing waters in EU Bathing Water Directive (CEC, 2006a) and estimated risks (Kay, 2008).

Category	Estimated risk per exposure	*Enterococci* (counts per 100 mℓ	*E. coli* (counts per 100 mℓ)
Excellent	2.9% gastrointestinal (GI) illness risk	<100 (95th %ile)	<250 (95 %ile)
Good	5.4% GI illness risk	<200 (95th %ile)	<500 (95 %ile)
Sufficient	8.5% GI illness risk	<185 (90th %ile)	<500 (95 %ile)

This is applied in their bathing water classification system (Table A.7), which differs from the microbiological assessment system of the WHO (2003) (see Table A.2).

Table A.7 Marine bathing water classification system of the European Union (CEC, 2006a).

Quality level	Specification
Excellent	If in the set of bathing water quality data for the last assessment period, the percentile values for microbiological enumerations are equal to or better than the “excellent” values (Table A.6) If the bathing water is subject to short-term pollution, on condition that: • adequate management measures are being taken, including surveillance, early warning systems and monitoring, with a view to preventing bathers’ exposure by means of a warning or, where necessary, a bathing prohibition; • adequate management measures are being taken to prevent, reduce or eliminate the causes of pollution; and • number of samples disregarded because of short-term pollution during the last assessment period represented no more than 15% of the total number of samples provided for in the monitoring calendars established for that period, or no more than one sample per bathing season, whichever is the greater.

Good	If in the set of bathing water quality data for the last assessment period, the percentile values for microbiological enumerations are equal to or better than the “good” values (Table A.6) If the bathing water is subject to short-term pollution, on condition that: • adequate management measures are being taken, including surveillance, early warning systems and monitoring, with a view to preventing bathers’ exposure by means of a warning or, where necessary, a bathing prohibition; • adequate management measures are being taken to prevent, reduce or eliminate the causes of pollution; and • number of samples disregarded because of short-term pollution during the last assessment period represented no more than 15% of the total number of samples provided for in the monitoring calendars established for that period, or no more than one sample per bathing season, whichever is the greater.
Sufficient	If in the set of bathing water quality data for the last assessment period, the percentile values for microbiological enumerations are equal to or better than the “sufficient” values (Table A.6) If the bathing water is subject to short-term pollution, on condition that: • adequate management measures are being taken, including surveillance, early warning systems and monitoring, with a view to preventing bathers’ exposure by means of a warning or, where necessary, a bathing prohibition; • adequate management measures are being taken to prevent, reduce or eliminate the causes of pollution; and • number of samples disregarded because of short-term pollution during the last assessment period represented no more than 15% of the total number of samples provided for in the monitoring calendars established for that period, or no more than one sample per bathing season, whichever is the greater.
Poor	If in the set of bathing water quality data for the last assessment period, the percentile values for microbiological enumerations are worse than the “sufficient” values set (Table A.6).

The bathing water quality assessment should be done at the end of every season on the basis of information gathered during that season and the three preceding ones in principle. Following the assessment, bathing waters are allocated one of four quality levels: “poor”, “sufficient”, “good” or “excellent” according to corresponding criteria (Table A.7) with “sufficient” set as the minimum quality threshold (or environmental quality target).

Also included in the Bathing Water Directive is a bathing beach profile assessment (reviewed at regular intervals as specified in the Directive), comparable to the WHO’s sanitation inspection).

Bathing beach profile assessment (CEC, 2006a): A bathing beach profile assessment consists of:

- A description of the physical, geographical and hydrological characteristics of the bathing water, and of other surface waters in the catchment area of the bathing water concerned, that could be a source of pollution;
- An identification and assessment of causes of pollution that might affect bathing waters and impair bathers’ health;
- An assessment of the potential for proliferation of cyanobacteria; and
- An assessment of the potential for proliferation of macroalgae and/or phytoplankton.

If there is a risk of short-term pollution, the following information should be provided:

- the anticipated nature, frequency and duration of expected short-term pollution;
- details of any remaining causes of pollution, including management measures taken and the time schedule for their elimination;
- management measures taken during short-term pollution and the identity and contact details of bodies responsible for taking such action; and
- Location of the monitoring point.

The Bathing Water Directive requires that member states determine the duration of the bathing season and draw up a monitoring calendar for bathing waters that provides for at least four samples to be taken per season. The sampling interval should not be longer than one month. In the event of temporary pollution, a sample should be taken to confirm such an occurrence, but it may be excluded from the samples provided for in the calendar. In such cases, an additional sample should be taken after the pollution has ended, replacing the excluded sample. The Directive specifies that, where possible, samples be taken 30 centimetres below the water's surface and in water that is at least one metre deep. The monitoring point must be at a point where most bathers are expected or where the greatest risk of pollution is expected. In 2018, the WHO submitted recommendations to the EU pending the revision of the Bathing Water Directive planned for 2020 (see below).

WHO Recommendations on Bathing Water Directive (WHO, 2018): In their recommendation to the European Union pending revision of the EU's Bathing Water Directive (2006/7/EC) (CEC, 2006), the WHO recommended as follows:

- Intestinal enterococci and *E. coli* should be retained
- Four levels within the current classification system (excellent, good, sufficient and poor) should be retained.
- Classification system for each category should be based on a 95th %ile value and not a mixture of 95- and 90-%les.
- Annual minimum number of samples should be increased to 20.
- Data from bathing water sites should be tested for $\log_{10}$ normality. Where the data are shown to be $\log_{10}$ normally distributed, the Hazen calculation method should be used (Annex II, CEC, 2006). Where the **data do not exhibit $\log_{10}$ normality**, or where **inadequate data are available** the **Hazen calculation method** should be used.
- ISO method (9308-1) for *E. coli* analysis is no longer appropriate for the measurement of bathing water quality (following its update it is suitable for waters with low bacterial numbers and, as such not applicable to bathing waters)
- Sampling and sample analysis should be conducted by laboratories accredited for the methods being used.

Finally, the Bathing Water Directive (CEC, 2006a) also specifies the following additional parameters (other than microbiological) that could be taken into account:

- When the bathing water profile indicates a potential for cyanobacterial proliferation, appropriate monitoring shall be carried out to enable timely identification of health risks.
- When cyanobacterial proliferation occurs and a health risk has been identified or presumed, adequate

management measures shall be taken immediately to prevent exposure, including information to the public.

- When the bathing water profile indicates a tendency for proliferation of macroalgae and/or marine phytoplankton, investigations shall be undertaken to determine their acceptability and health risks and adequate management measures shall be taken, including information to the public.
- Bathing waters shall be inspected visually for pollution such as tarry residues, glass, plastic, rubber or any other waste. When such pollution is found, adequate management measures shall be taken, including, if necessary, information to the public.

A.2.4 Australia

The Australian Government published its *Guidelines for managing risks in recreational water* in 2008 (Australian Governmen,t 2008). These guidelines draw on approaches adopted by the WHO (WHO, 2003), as well as New Zealand (NZME, 2003).

Similar to the WHO, Australia also adopted a broader approach to the management of recreational waters including aesthetic aspects, physico-chemical properties (temperature, dissolved oxygen and pH), microbiological quality, chemical hazards, cyanobacteria and algae, physical hazards, and dangerous aquatic organisms, as summarized in Table A.8.

Table A.8 Recommended QTs for Australian recreational waters (Australian Government, 2008).

Parameter	Recommended environmental quality targets
Aesthetics	Recreational water bodies should be aesthetically acceptable to recreational users. The water should be free from visible materials that may settle to form objectionable deposits: • floating debris • oil, scum and other matter • substances producing objectionable colour, odour, taste or turbidity • substances and conditions that produce undesirable aquatic life.
Physical hazards	Recreational water bodies and adjacent areas should be free of physical hazards, such as floating or submerged objects that may lead to injury. Where permanent hazards exist, for example rips and sandbars, appropriate warning signs should be clearly displayed.
Physico-chemical properties	Temperature: 16–34 °C. pH: 6.5–8.5 Dissolved oxygen: > 80% saturation (indicator of extent of eutrophication)
Chemical hazards (toxicants)	Waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes.
Cyanobacteria and algae	Coastal and estuarine recreational water bodies should have < 10 cells/mℓ *Karenia brevis*[1] and/or have *Lyngbya majuscula*[2] and/or *Pfiesteria*[3] present in high numbers.

1 *Karenia brevis* (also known as *Gymnodinium breve* and *Ptychodiscus brevis*), is a marine dinoflagellate. Inhalation of sea-spray aerosol containing fragments of this algae has been associated with severe irritation of conjuctiva and mucous membranes (particularly of the nose), followed by persistent coughing and sneezing and tingling of the lips (Australian Government ,2008). Brevetoxicants, which are produced by *K. brevis*, can accumulate in seafood and cause neurotoxic shellfish poisoning.

2 *Lyngbya majuscula* is a toxic marine cyanobacterium found mainly in tropical waters. Its toxicants are highly inflammatory and promote skin tumours (Australian Government, 2008).

3 *Pfiesteria piscicida* is an organism believed to only occur rarely in marine waters. However, caution is required if these organisms are identified in a marine or estuarine area (Australian Government, 2008).

The Australian Guidelines adopt the same risk approach for microbiological quality as the WHO (2003) (see Table A.2), as well as the WHO's Classification system that combines the microbiological quality assessment with results from a sanitation inspection (see Table A.3). They also adopted the monitoring schedule for different classes as recommended by the WHO (see Table A.4). As the WHO, they consider it unacceptable, for classification purposes, to discard unexpectedly high counts or resampling, although reactive samples taken after an adverse event to investigate the full impact thereof need not be included in the analysis.

The Australian guidelines also adopted a short-term three-tiered monitoring framework that requires different responses depending on the water quality status as illustrated in Table A.9.

Table A.9 **Summary of Australia's short-term management framework for recreational waters** (Australian Government, 2008).

Parameter	Mode		
	Surveillance	Alert	Action
Chemical hazards (toxicants)	Monitoring results consistent with long-term classification, although water body may be subject to short-term advisories (e.g. during rains), continue sampling	Monitoring results not fully consistent long-term classification, requires increased sampling and investigation to assess risks	Monitoring indicates unacceptable risks, warn
Cyanobacteria and algae	*Karenia brevis*: < 1 cell/mℓ History of presence Regular monitoring, weekly sampling and cell counts, regular visual inspection for visible discolouration or scums	*Karenia brevis*: 1-10 cell/mℓ Present in low numbers Increase sampling frequency to twice weekly, decide on requirement for toxicity assessment or toxicant monitoring	*Karenia brevis*: > 10 cell/mℓ Present in high numbers Carry out toxicity assessment or toxicant measurement, advise public of risk to health

A.2.5 South Africa

South Africa revised its recreational water quality guidelines for coastal waters in 2012 (RSA DEA, 2012) (Table A.10). For toxicants the South African guidelines recommended the national drinking water quality guidelines be consulted to assess preliminary risk to human health (following the WHO approach). For microbiological indicators, South Africa adopted the microbiological target ranges of the Bathing Water Directive (CEC, 2006), also recommending the "sufficient" level as the recommended QT.

The guidelines recommend an additional microbiological indicator for subtropical waters, namely *Clostridium perfringens*, a spore-forming obligate anaerobe, based on findings in other tropical areas, e.g. Hawaii (Hawaii Department of Health, 2000). With regards to toxicants from harmful algal blooms, no specific target values are prescribed, but when the presence of such harmful algal proliferation occurs, appropriate monitoring must be carried out by reputable scientists to establish potential health risks.

Table A.10 Recommended QTs for South Africa's recreational waters (RSA DEA, 2012).

Parameter	**Recommended environmental quality targets**		
Objectionable matter	• Water should not contain litter, floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance. • Water should not contain materials from non-natural land-based sources which will settle to form objectionable deposits. • Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins, and which would be a danger, cause nuisance or interfere with any designated/recognized use. • Water should not contain substances producing objectionable colour, odour, taste, or turbidity.		
Physico-chemical properties	• Temperature: Should not exceed 15–35 °C for prolonged exposure • pH: Should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits.		
Microbiological indicators			
Category	**Estimated risk per exposure**	***Enterococci* (counts per 100 mℓ**	***E. coli* (counts per 100 mℓ)**
Excellent	2.9% gastrointestinal (GI) illness risk	< 100 (95 %ile)	< 250 (95 %ile)
Good	5% GI illness risk	< 200 (95 %ile)	< 500 (95 %ile)
Sufficient or Fair (minimum requirement)	8.5% GI illness risk	< 185 (90 %ile)	< 500 (90 %ile)
Poor (unacceptable)	>8.5% GI illness risk	> 185 (90 %ile)	> 500 (90 %ile)
Tropical waters	*Clostridium perfringens*		Geometric mean <5 counts per 100 mℓ

As proposed by the WHO (WHO, 2003), and New Zealand (NZME, 2003) and Australia (Australian Government, 2008), a recreation classification system for coastal waters has also been recommended (based on a combination of the microbiological quality assessment and a sanitation inspection), but this has not been widely applied in the country as yet. Rather, beaches are rated in terms of microbiological water quality only, ranging from "Excellent", "Good", "Fair" and "Poor" (Table A.10). An operational management system, based on that of New Zealand (see Table A.7), has been recommended, but also is not yet widely applied.

A.2.6 Canada

The Canadian guidelines, also published in 2012, provide guideline values for a range of related parameters, including aesthetic aspects, physico-chemical properties, microbiological indicators, chemical hazards, as well as cyanobacteria and their toxicants (Health Canada, 2012), as summarized in Table A.11. Canada selected enterococci as the most appropriate indicator of faecal contamination in marine recreational waters, but did no adopt the incremental risk-associated targets of the WHO (2003), rather adopting their target value as a geometric mean of five samples, together with a single target value). The risk of microbiological contamination of beach sands is also recognized, but no targets values have yet been provided due to a lack of suitable data.

Table A.11 Recommended QTs for Canadian recreational waters (Health Canada, 2012).

Parameter	Recommended environmental quality targets
Aesthetics	Turbidity: < 50 NTU Clarity: Secchi Disc visible depth > 1.2 m Colour: Should not be so intense as to impede visibility in areas used for swimming Oil and grease: Should not be present in concentrations that can be detected as a visible film, sheen, discolouration or odour; or that can form deposits on shorelines or bottom sediments that are detectable by sight or odour Litter: Areas should be free from floating debris as well as materials that will settle to form objectionable deposits
Physico-chemical properties	Temperature: Should not cause an appreciable increase or decrease in the deep body temperature of swimmers pH: 5.0 to 9.0
Chemical hazards (toxicants)	Risks associated with specific chemical hazards will be dependent on the particular circumstances of the area and should be assessed on a case-by-case basis.
Cyanobacteria and toxicants	Total cyanobacteria < 100 000 cells/mℓ Total mycrocystins < 20 µg/ℓ
Enterococci	• Geometric mean concentration (minimum of five samples) < 35 enterococci/100 mℓ
	• Single-sample maximum concentration < 70 enterococci/100 mℓ

For enterococci the calculation of the geometric mean concentration should be based on a minimum of five samples, collected at appropriate times and sites to provide representative information on the water quality likely to be encountered by users. For recreational water areas routinely used for primary contact recreation the guidelines advise monitoring at a minimum of once per week, with increased monitoring recommended for those beaches that are highly frequented or are known to experience high user densities. Similarly, under certain scenarios, a reduction in the recommended sampling frequency may be justified. For secondary recreational activities, the application of a factor of 5 to the existing geometric mean faecal indicator concentration used to protect primary contact recreation users is advised (Health Canada, 2012).

The Canadian guidelines do not adopt the Classification system of the WHO (2003) and rather pose a “multi-barrier approach” to the management of recreational areas, where different elements of the multi-barrier strategy include situation assessments (i.e. environmental health and safety surveys) and application/implementation of barriers such as compliance monitoring (measured against environment target values), public awareness and communication, public health advice and hazard control action (Health Canada, 2012).

A.2.7 United States of America

Based on an extensive review of available scientific literature and new studies by the United States Environmental Protection Agency (US-EPA), the agency published revised Recreational Water Quality Criteria (RWQC) in 2012 (2012, RWQC) (see US-EPA, 2022b). Additional insights were provided in a 2017 review, although no major changes to the 2012 RWQC were recommended (see US-EPA, 2022b).

The 2012 RWQC focus solely on primary contact recreation, providing QTs for microbiological indicators but no explicit QTs for aesthetics, physico-chemical properties or chemical hazards. Enterococci was considered most appropriate indicator for marine waters, recommending both a geometric mean and a statistical threshold value (90th %ile) value that must be complied with for sufficient protection for primary contact recreation. The 2012 RWQC also offers two sets of criteria based on different risk levels, as summarized in Table A.12. Both the geometric mean and 90th %ile (statistical threshold value) QTs should be complied with for primary contact recreation compliance.

Table A.12 Recommended QTs for marine recreational waters in the USA (see US-EPA, 2022b).

Indicator	Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreation	Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreation
Enterococci	Geometric mean < 35 cfu per 100 mℓ 90th %ile < 130 cfu per 100 mℓ	Geometric mean < 30 cfu per 100 mℓ 90th %ile < 110 cfu per 100 mℓ
Taken from at least 5 samples over a 30-day period. When exceeded at least 10 more samples need to be below the 90th %ile target before the water is considered unimpaired again.		

As the target values need to be applied to at least five samples over a 30-day period, the US-EPA recommends at least weekly sampling of more densely populated beaches. The preferred method of analysis for enterococci is the US-EPA Method 1600: Enterococci in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl-β-D-Glucoside Agar (mEI) (US-EPA, 2006).

Calculation of geometric mean and 90th percentile in 2012 RWQC (see US-EPA, 2022b): Geometric mean: Take $\log_{10}$ of sample values, average those values and then raise average to power 10.

90th %ile: 2012 RWQC is not explicit on calculation method, but Hazen method is most popular to calculate statistical threshold value (STV) elsewhere in the world.

Additional tools recommended for improved management of recreational waters include:

- **Sanitary survey** to collect information that relates to a site at a particular time, providing a snapshot of the conditions in a waterbody, assisting managers with identifying sources of faecal contamination, assess the magnitude of the contamination, and designate priority locations for water testing.
- **Beach Action Value (BAV)**, intended to be used as an early warning system, where exceedance of any single sample of 70 cfu per 100 mℓ (estimated Illness rate (NGI): 36 per 1,000 primary contact recreation) or estimated illness rate (NGI): or cfu per 100 mℓ (32 per 1,000 primary contact recreation) could trigger a beach notification until another sample below the BAV is collected.
- **Application of Quantitative Polymerase Chain Reaction** (qPCR) method (e.g. US EPA Method 1611: Enterococci in Water by TaqMan® Quantitative Polymerase Chain Reaction (qPCR) Assay [US-EPA 2012b]) aimed at detecting and quantifying enterococci more rapidly than the culture method for marine waters.

Important aspects highlighted in the 2017 review (see US-EPA, 2022b) include:

- **Risk to children**: Increased water ingestion among children may cause them to be more susceptible to swimming-associated GI illness, therefore they may encounter different risks compared with health adults.
- **Coliphage as an indicator**: Because evidence strongly suggests most illnesses in recreational waters are due to enteric viruses, development, and implementation of viral indicators, such as coliphage, may yield advances in public health protection.
- **Performance of qPCR Methods**: Advances in this method have shown greater reliability and utility to beach monitoring programmes. *Enterococcus* spp. measured by qPCR is a better predictor of swimming-associated GI illness and more timely than current culturable bacterial indicators.
- **Antimicrobial resistance**: Although drug-resistance genes are naturally occurring, anthropogenically released antibiotics and genes through clinical and agricultural use pose a major concern for human and ecological health. However, to develop a more complete picture regarding the threat and risks associated with antibiotic resistance requires further research to better understand the role that environment plays in transferring these contaminants primary contact recreation.
- **Tropical waters**: Researchers and regulators have long expressed concern regarding the applicability of enterococci and *E. coli* in tropical environments due to their potential to regrow and persist in the water, sand, and soil. Recent studies also suggested natural sources of these indicators in pristine tropical waters. In Hawaii, where enterococci are found at high densities in soils, numerous lines of evidence, including *Clostridium perfringens* were required to identify sewage as the cause of water quality impairment in an urbanized tropical watershed (Kirs *et al.*, 2017). However, a study in Brazil did find these indicators to be predictive of swimming-associated GI illness in tropical environ-

ments impacted by sources of human faecal contamination (Lamparelli *et al.*, 2015). Tropical waters thus continue to pose challenges in the selection of appropriate microbiological indicator organisms.

- **Microbial Source Tracking (MST)**: Accurate and reliable MST technologies could markedly improve future beach water quality management, possibly allowing site-specific targets based on the type of pollution sources present.

A.3 Review of International Guidelines: Marine Aquaculture

For this review guidelines from the following countries and organizations were considered:

- United States of America (US-EPA, 1986; 2022a; US-FDA, 2019)
- European Union (CEC, 2000: CEC, 2006b; CEC, 2017)
- Australia and New Zealand (ANZECC, 2000; ASQAAC, 2019)
- New Zealand (New Zealand Government, 2018)
- Canada (Government of Canada, 2020)
- South Africa (RSA DFFE, 2021).

A.3.1 United States of America

The protection of the health of consumers is mainly a concern with shellfish farming or where these organisms are harvested from natural stocks. However, the US-EPA provides a comprehensive list of QTs aimed at minimizing the risk of adverse effects occurring to humans from chronic (lifetime) exposure to substances through consumption of organisms obtained from surface waters (see US-EPA, 2022b).

An approach that is being implemented as part of the management and control of shellfish industries, in particular shellfish growing areas, is a classification approach. This classification approach finds its origin in the United States where it was first implemented by the United States Food and Drug Administration as part of the National Shellfish Sanitation Program (NSSP) (US-FDA, 2019).

This approach tends to move away from the traditional approach of classifying waters as either safe or unsafe for shellfish culture or harvesting (based on a percentage compliance with a faecal index organism) to a ranking approach. The classification of coastal and estuarine areas for the harvesting of shellfish (e.g. clams, oysters, scallops, mussels and other bivalve molluscs) is based on the results of Sanitary Surveys that consist of:

- Identification and evaluation of all potential and actual pollution sources (Shoreline Survey) — requiring studies to identify and quantify pollution sources and estimate the movement, dilution and dispersion of pollutants in the receiving environment
- Monitoring of growing waters and shellfish to determine the most suitable classification for the shellfish harvesting area (Bacteriological Survey) — this refers to the measurement of faecal indicator levels in the growing areas.

Re-surveys are conducted regularly to determine if sanitary conditions have undergone significant change. The water quality-related requirements pertaining to each of these classes as per the NSSP are summarized in Table A.13.

Table A.13 Summary of USA NSSP QTs (water) for shellfish water classes (US-FDA, 2019).

Class	Microbiological standard (water quality)
Approved	Sanitary survey finds that area is safe for the direct marketing of shellfish, not subject to contamination from human or animal faecal matter at levels that presents an actual or potential public health hazard and not contaminated with toxic substances or organisms. **Systematic Random Sampling Strategy**[1] - Faecal coliform median or geometric mean most probable number (MPN) or membrane filter (MF) (membrane-Thermotolerant *E. coli* [mTEC]) of **water** sample not exceed 14 per 100 mℓ, and not more than 10% of samples to exceed an MPN or MF (mTEC) of (i) 43 MPN per 100 mℓ for a five-tube decimal dilution test, (ii) 49 MPN per 100 mℓ for a three-tube decimal dilution test (iii) 28 MPN per 100 mℓ for a twelve-tube single dilution test or (iv) 31 colony-forming units (CFU) per 100 mℓ for a MF (mTEC) test. **Adverse Pollution Sampling Strategy**[2] - Faecal coliform median or geometric mean MPN or MF (mTEC) of **water** samples do not exceed 14 per 100 mℓ, and not more than 10% of samples exceed an MPN or MF (mTEC) of (1) 43 MPN per 100 mℓ for a five-tube decimal dilution test (ii) 49 MPN per 100 mℓ for a three-tube decimal dilution test (iii) 28 MPN per 100 mℓ for a twelve-tube single dilution test or (iv) 31 CFU per 100 mℓ for a MF (mTEC) test. **Non-point sources (Systematic Random Sampling)** - Faecal coliform median or geometric mean MPN or MF (mTEC) of **water** samples do not exceed 14 per 100 mℓ and estimated 90th %ile not exceed an MPN or MF (mTEC) of (i) 43 MPN per 100 mℓ for a five-tube decimal dilution test (ii) 49 MPN per 100 mℓ for a three-tube decimal dilution test or (iii) 31 CFU per 100 mℓ for a MF (mTEC) test.
Conditionally approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period is known, predictable and not so complex as to prevent a reasonable management approach (microbiological quality meets “Approved” when open).
Restricted	Sanitary survey finds area is subject to only a limited degree of pollution and level(s) of faecal pollution, human pathogens and toxic or deleterious substances are at such an amount that shellfish can be made fit for human consumption a suitable and effective treatment process through relaying or depuration. **Adverse Pollution Sampling Strategy** - Faecal coliform median or geometric mean MPN or MF (mTEC) of samples do not exceed 88 per 100 mℓ and not more than 10% of samples exceed an MPN or MF (mTEC) of (i) 260 MPN per 100 mℓ for a five-tube decimal dilution test (ii) 300 MPN per 100 mℓ for a three-tube decimal dilution test (iii) 173 MPN per 100 ml for a twelve-tube single dilution test or (iv) 163 CFU per 100 mℓ for a MF (mTEC) test. **Non-point sources (Systematic Random Sampling)** - Faecal coliform median or geometric mean MPN or MF (mTEC) of samples do not exceed 88 per 100 mℓ and estimated 90th %ile not exceed a MPN or MF (mTEC) of (i) 260 MPN per 100 mℓ for a five-tube decimal dilution test (ii) 300 MPN per 100 mℓ for a three-tube decimal dilution test or (iii) 163 CFU per 100 mℓ for a MF (mTEC) test.
Conditionally restricted	Sanitary survey finds that area meets criteria for restricted classification for a reasonable period and factors determining that period is known, predictable and not so complex as to prevent a reasonable management approach (Microbiological quality meets “Restricted” when open).
Prohibited area	Does not meet requirements as above.

1 Systematic random sampling means a method of water sampling and data analysis (which may be applied to a growing area which is not impacted by point source pollution)

2 Adverse pollution sampling strategy means a water quality sampling programme designed to target adverse pollution conditions described in growing area management plan

Estimated threshold concentrations above which tainting of aquatic food can be expected have been provided by the US-EPA (US-EPA, 1986, 2022c) (see Appendix B)

A.3.2 European Union

In terms of water quality management, the focus within the European Union is primarily on shellfish captured in two main directives, namely:

- EC Directive (CEC, 2000) – Water Framework Directive
- Directive (CEC, 2006b) – stipulating quality required for shellfish waters

The EU Water Framework Directive (2000/60/EC) repealed an earlier Council Directive (79/923/EEC) specifically dealing with requirements for shellfish waters (CEC, 2000). With this repeal the EU envisaged that water quality target values related to the health of aquatic organisms will eventually be consolidated in the Water Framework Directive (CEC, 2000).

In 2006, the EU issued a Directive (2006/113/EC) specifically addressing the quality of shellfish waters (see Appendix B) (CEC, 2006b), including limits for physico-chemical properties and toxicants. In addition, the Directive also sets limits for microbiological contamination in shellfish flesh as follows: “Faecal coliform levels in water shall be such that concentrations in shellfish flesh or intervalvular liquid are equal or less than 300 counts/100 mℓ”.

The EU Regulation (No. 854/2004, as amended in 2008 and 2015) classifies shellfish growing in the EU areas based on the limits of constituents in **shellfish flesh** (CEC, 2017). The classification systems consist of 3 classes, with different post- harvest treatment requirements (Table A.14).

Table A.14 Summary of EU QTs (flesh) for Classification of shellfish growing areas (CEC, 2017).

Class	Standard	Post-harvest treatment
A	Samples of live bivalve molluscs from these areas must not exceed, in 80% of samples collected during the review period, 230 *E. coli* per 100 g of flesh and intravalvular liquid. The remaining 20% of samples must not exceed 700 *E. coli* per 100 g of flesh and intravalvular liquid.	None
B	Live bivalve molluscs from these areas must not exceed, in 90% of samples, 4,600 MPN *E. coli* per 100 g of flesh and intravalvular liquid. In the remaining 10% of samples, live bivalve molluscs must not exceed 46,000 MPN *E. coli* per 100 g of flesh and intra-valvular liquid.	Purification, relaying or cooking by an approved method

C	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution MPN test of 46,000 *E. coli* per 100 g of flesh and intravalvular liquid.	Relaying or cooking by an approved method
Waters below Class C are prohibited for shellfish harvesting.		

A.3.3 Australia

Australia provides generic QTs for a range of physico-chemical, nutrient and toxicant parameters considered appropriate for the protection of marine aquaculture organisms (ANZECC, 2000) (see Appendix B). However, it can generally be accepted that the health of organisms used for aquaculture purposes will be protected if the water quality meets QTs as recommended for the protection of aquatic ecosystems (particularly where the activity relies on natural stocks). Further, in Australia the shellfish industry is controlled and managed in terms of the Australian Shellfish Quality Assurance Program. The programme includes a classification system, based on a sanitary survey and microbiological water quality, to determine the suitability of waters for the collection of shellfish for human consumption (ASQAAC, 2019). The QTs for water quality and flesh are summarized in Table A.15.

Table A.15 Summary of Australian QTs (water and flesh) for shellfish water categories (ASQAAC, 2019).

Category	Microbiological standard
Approved Remote	Sanitary survey determines area has no human habitation or any other actual or potential pollution sources: **Systematic Random Sampling Strategy** • Thermotolerant coliform (e.g. *E. coli*) median or geometric mean of **water sample** not exceed (i) Membrane filtration (MF) – 14 per 100 mℓ and estimated 90th %ile not exceed 21 per 100 mℓ; or (ii) MPN - 14 per 100 ml and the Estimated 90th %ile does not exceed 43 per 100 ml for a five-tube decimal dilution test, or 49 per 100 mℓ for a three-tube decimal dilution test. • *E. coli* median or geometric mean in **shellfish flesh** not to exceed of 2.3 per gram of flesh and intravalvular liquid and not more than 10% of samples shall exceed 7 counts per gram. **Adverse pollution conditions sampling strategy** • Thermotolerant coliform median or geometric mean of water does not exceed (i) MF – 14 per 100 mℓ and not more than 10% of the samples exceed 21 per 100 mℓ; or (ii) MPN – 14 per 100 mℓ and not more than 10% of the samples exceed 43 per 100 ml for a five-tube decimal dilution test, or 49 per 100 mℓ for a three-tube decimal dilution test. • *E. coli* median or geometric mean in **shellfish flesh** not to exceed of 2.3 counts per gram of flesh and intravalvular liquid and not more than 10% of samples to exceed 7 counts per gram.
Approved	Sanitary survey determines area is not subject to contamination from human or animal faecal matter presenting actual or potential public health hazard or toxic substances exceeds required levels (Microbiological quality meets "Approved").

Conditionally Approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period is known, predictable and not so complex as to prevent a reasonable management approach (Microbiological quality meets “Approved” when open).
Restricted	Sanitary survey finds area is subject to only a limited degree of pollution and level(s) of faecal pollution, human pathogens and toxic or deleterious substances are at such an amount that shellfish can be made fit for human consumption by either relaying or depuration: **Systematic random sampling strategy:** • Thermotolerant coliform median or geometric mean of the water sample results do not exceed (i) MF - 70 per 100 mℓ and estimated 90th %ile not exceed 85 per 100 mℓ; or (ii) MPN - 88 per 100 mℓ and estimated 90th %ile not exceed a MPN of 260 per 100 mℓ for a five-tube decimal dilution test, or 300 per 100 mℓ for a three-tube decimal dilution test. • E. coli median or geometric mean in shellfish flesh not to exceed of 46 counts per gram of flesh and intra-valvular liquid and not more than 10% of samples to exceed 141 counts per gram.
Conditionally Restricted	Sanitary survey finds area open for purposes of harvesting shellfish for relaying or depuration for a reasonable period and factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach (Microbiological quality meets “Restricted” when open).
Nursery/Source	Chemical assessment is undertaken of where potential risks are identified. Heavy metal tests show compliance with the *Food Standards Code*.
Prohibited	Shellfish so highly or frequently contaminated that harvesting controls cannot be implemented to adequately ensure protection of public health.

Estimated threshold concentrations above which tainting of seafood can be expected have been provided for Australia and New Zealand) (ANZECC 2000) (see Appendix B).

A.3.4 New Zealand

New Zealand (as Australia) provides generic QTs for a range of physico-chemical, nutrient and toxicant parameters considered appropriate for the protection of marine aquaculture organisms (ANZECC, 2000) (see Appendix B). The New Zealand government also classifies areas for shellfish harvesting according to their classification system (New Zealand Government, 2018). The QTs for water quality is summarized in Table A.16.

Table A.16 Summary of New Zealand QTs (water and flesh) for shellfish water categories (New Zealand Government 2018).

Category	Microbiological standard
Remote approved	Sanitary survey determines area has no human habitation or any other actual or potential pollution sources: • Faecal coliform median most probable number (MPN) of the water samples does not exceed 14 per 100 mℓ, and not more than 10% of the samples exceed an MPN of 43 per 100 mℓ, • *E. coli* median is shellfish flesh not to exceed 230 MPN per 100 grams and not more than 10% of the samples exceed 700 MPN per 100 grams,

Approved	Sanitary survey finds not subject to contamination from human or animal faecal matter presenting actual or potential public health hazard or toxic substances exceeds required levels: **Systematic Random Sampling Strategy** • Faecal coliform median MPN of the water does not exceed 14 per 100 mℓ and estimated 90th %ile not to exceed an MPN of 43 per 100 mℓ, • *E. coli* median is shellfish flesh does not exceed 230 MPN per 100 grams and estimated 90th %ile not exceed 700 MPN per 100 grams, **Adverse pollution conditions sampling strategy** • Faecal coliform median MPN not exceed 14 per 100 mℓ, and not more than 10% of samples exceed an MPN of 43 per 100 mℓ, • *E. coli* median is shellfish flesh not to exceed 230 MPN per 100 grams and not more than 10% of the samples exceed 700 MPN per 100 grams,
Conditionally Approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period is known, predictable and not so complex as to prevent a reasonable management approach (Microbiological quality meets “Approved” when open),
Restricted	Limited degree of pollution but sanitary survey finds levels of contamination are such that shellfish may be made fit for human consumption by relaying, depuration, or other post-harvest treatment: **Systematic Random Sampling Strategy** • Faecal coliform median MPN not exceed 88 per 100 mℓ and estimated 90th %ile not to exceed an MPN of 260 per 100 mℓ, • *E. coli* median is shellfish flesh not to exceed 4,600 MPN per 100 grams and estimated 90th %ile not to exceed 14,100 MPN per 100 grams, **Adverse pollution conditions sampling strategy** • Faecal coliform median MPN not exceed 88 per 100 mℓ and not more than 10% of samples exceed 260 per 100 mℓ. • *E. coli* median is shellfish flesh not to exceed 4,600 MPN per 100 grams and not more than 10% of the samples exceed 14,100 MPN per 100 grams.
Conditionally Restricted	Sanitary survey finds that area meets criteria for restricted classification for a reasonable period and factors determining that period is known, predictable and not so complex as to prevent a reasonable management approach (Microbiological quality meets “Restricted” when open).

A.3.5 Canada

In Canada, the Canadian Shellfish Sanitation Program (CSSP) controls the recreational and commercial harvesting of all shellfish for human consumption (Government of Canada, 2020). In according with others, Canada also classifies shellfish harvesting areas of which microbiological QTs are summarized in Table A.17.

Table A.17 **Summary of Canada QTs (water) for shellfish water categories** (Government of Canada, 2020).

Category	Microbiological standard
Approved	If area not contaminated with pathogenic micro-organisms to extent that consuming shellfish might be hazardous. Also, actual and potential sources of pollution sources have been identified, and these have been determined not to impact the shellfish harvest area and not otherwise contaminated by harmful substances. Following criteria must be met at representative marine sample sites: • Median faecal coliform MPN does not exceed 14 per 100 mℓ, and not more than 10% of samples exceed a faecal coliform MPN of 43 per 100 mℓ, for a five-tube decimal dilution test or • Geometric mean faecal coliform MPN not exceed 14 per 100 mℓ, and the estimated 90th %ile of faecal coliform MPNs not exceed 43 per 100 mℓ, for a five-tube decimal dilution test.
Conditionally Approved	If area meets approved classification criteria for a defined period, as determined by shellfish control authority. Such shellfish harvest areas may be subject to intermittent pollution such as releases/discharges from wastewater and collection systems, seasonal human or wildlife populations, non-point source pollution or seasonal boating activity.
Restricted	Area exceeds the approved classification standard but is not contaminated to extent where it would be classified as prohibited. No harvesting except by licence from controlling authority. If harvested for purpose of depuration: median or geometric mean faecal coliform MPN of water must not exceed 88 per 100 mℓ and not more than 10% of samples exceed a faecal coliform MPN of 260 per 100 mℓ, for a five-tube decimal dilution test.
Conditionally Restricted	Area meets restricted classification criteria for a defined period, as determined by shellfish control authority. Such shellfish harvest areas may be subject to intermittent pollution such as releases/discharges from wastewater and collection systems, seasonal human or wildlife populations, non-point source pollution or seasonal boating activity.
Prohibited	Depending on degree of contamination in harvest waters, it may not be possible to adequately depurate or naturally purify shellfish. Such areas are classified as prohibited and harvest is not permitted.

A.3.6 Mauritius

The Coastal Water Quality Guidelines of Mauritius set targets for marine aquaculture and shellfish waters, including physico-chemical, nutrients and toxicants (see Appendix B) (Mauritius Government, 1999). The Mauritian QTs for microbiological parameters for marine aquaculture and shellfish water are summarized in Table A.18.

Table A.18 **Summary of Mauritian microbiological QTs for marine aquaculture and shellfish waters** (Mauritius Government, 1999).

Category	Microbiological QTs
Marine aquaculture	Total coliform: 1,000 colony forming units (CFU) per 100 mℓ Faecal coliforms: 200 cfu per 100 mℓ
Shellfish areas	Total coliform: 70 cfu per 100 mℓ (by MPN method) Faecal coliforms: 14 cfu per 100 mℓ (by MPN method)

A.3.7 South Africa

The South African water quality guidelines for marine aquaculture (DWAF ,1995) are currently also under review and were therefore not considered in this assessment.

The country has a classification system for shellfish under control of the Department responsible for fisheries, but this classification system is related to concentration in flesh (as summarized in Table A.19) (RSA DFFE, 2021).

Table A.19 **Summary of South Africa's QTs (flesh) for shellfish water categories** (RSA DFFE, 2021).

Category	Microbiological standard (water quality)
Approved (A)	Sanitary survey concludes that harvesting for direct human consumption may take place at any time provided temporary closure is not in effect due to adverse pollution or biotoxin events. • *E. coli* MPN not exceed 230 MPN per 100 g of flesh and intravalvular liquid in 80% of samples. • No sample may exceed 700 E. coli per 100 g of flesh and intravalvular liquid. • Flesh not to contain hazardous concentrations of toxic substances that exceed regulatory limits.
Restricted (B)	Sanitary survey concludes that harvesting for direct human consumption is restricted, can only be harvested for depuration or relaying. • *E. coli* MPN not exceed 4,600 MPN per 100 g of flesh and intravalvular liquid in 90% of samples. • No sample may exceed 14,000 *E. coli* per 100 g of flesh and intravalvular liquid. • Flesh not to contain hazardous concentrations of toxic substances that exceed regulatory limits.
Prohibited (C)	Shellfish not to be harvested, either for direct human consumption, depuration, relaying or further processing if any of the following exist: • No current sanitary survey or annual evaluation report. • Sanitary survey indicates levels of microbiological pollution exceeding restricted area limits referred. • Sanitary survey or other data indicate contamination of shellfish with heavy metals, radionuclides, pesticides or other hazardous chemicals that exceed the regulatory limits. Petrochemical contamination also considered a food hazard. • Pollution sources may unpredictably contaminate the shellfish.

Photo: © Gélica Inteca – Mosquito net found in Pemba during the survey.

APPENDIX B: SUMMARY OF INTERNATIONAL GUIDELINES

Protection of aquatic ecosystems (water): Physico-chemical properties and Nutrients

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
Salinity	–	20%ile or 80%ile of reference system(s) distribution, depending upon whether low salinity or high salinity effects are being considered. Test data: Median (or mean) concentration for the period.	–	Salinity not to fluctuate by more than 10% of natural level expected at that time and depth.	–
Temperature	Ambient	Range defined by 20%ile and 80%ile of seasonal distribution for the reference system. Test data: Median (or mean) concentration for the period.	Maximum acceptable increase in weekly average temperature as a result of artificial sources is 1°C during all seasons of the year, providing the summer maximum is not exceeded. Daily temperature cycles should not be altered in amplitude or frequency.	Ambient temperature of marine and estuarine waters not to exceed ±1 °C at any time, location, or depth. Maximum rate of any human-induced temperature change should not exceed 0.5 °C per hour.	Temperature does not reach levels outside the ranges established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
pH	7.5–8.5	Range defined by 20%ile and 80%ile of seasonal distribution for the reference system. pH changes > 0.5 pH units from seasonal maximum or minimum of reference systems to be investigated. Test data: median (or mean) concentration for the period	6.5–8.5	7.0–8.7, result of natural processes. Within this range, pH should not vary by more than 0.2 pH units from natural pH expected at that time. Where pH is naturally outside this range, human activities should not cause pH to change by more than 0.2 pH units from the natural pH expected at that time.	pH does not reach levels outside the ranges established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.
Dissolved oxygen	> 5 mg/ℓ	20%ile of reference system(s) distribution. Where possible, determine QT during low flow and high temperature periods when DO concentrations are likely to be at their lowest. Test data: median DO concentration for the period, calculated using the lowest diurnal DO concentrations.	2.3 mg/ℓ (CMC); 4.8 mg/ℓ (CCC)	8 mg/ℓ unless as result of natural processes DO concentrations >8 mg/ℓ, human activities should not cause DO levels to decrease by more than 10% of natural concentration expected in receiving environment at that time	Oxygenation conditions do not reach levels outside the ranges established to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.
Chemical oxygen demand	2 mg/ℓ	–	–	–	–

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
Turbidity/Water Clarity	–	80%ile of reference system(s) distribution. Additionally, natural euphotic depth (Zeu) should not be permitted to change by more than 10%. Test data: Median (mean) concentration for period.	Water shall be virtually free from substances producing objectionable colour for aesthetic purposes. Increased colour (in combination with turbidity) should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life.	Maximum increase of 8 NTUs from background levels for a short-term exposure (e.g. 24-h period). Maximum average increase of 2 NTUs from background levels for a longer-term exposure (e.g., 30-d period) (clear waters) Maximum increase of 8 NTUs from background levels at any one time when background levels are between 8 and 80 NTUs. Should not increase more than 10% of background levels when background is >80 NTUs (turbid waters.	Transparency does not reach levels outside the ranges established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
Suspended solids	5 mg/ℓ	–	–	Maximum increase of 25 mg/ℓ from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/ℓ from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d) (clear flow). Maximum increase of 25 mg·L-1 from background levels at any time when background levels are between 25 and 250 mg/ℓ. Should not increase more than 10% of background levels when background is >250 mg/ℓ (high flow).	–

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
Dissolved inorganic nutrients	Coral communities: NO_3–N: 200 µg/ℓ PO_4–P: 40 µg/ℓ Other natural areas: NO_3–N: 300 µg/ℓ PO_4–P: 50 µg/ℓ	Where an appropriate local reference system(s) is available, and there are sufficient resources to collect the necessary information for the reference system, the trigger concentrations should be determined as the 80%ile of the reference system(s) distribution. Where possible, the trigger value should be obtained for that part of the seasonal or flow period when the probability of aquatic plant growth is most likely. Test data: Median (or mean) concentrations measured during growth periods.	Refer to US-EPA (2001) for details on criteria.	–	Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.

Variable	Mauritius (Mauritius Government, 1999)	Australia /New Zealand (Australia & New Zealand Government, 2018)	USA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC, 2000)
Chlorophyll a	–	80%ile of the reference system(s) distribution. Where possible, determine QT in seasonal period when probability of aquatic plant growth is most likely. Test data: Median (or mean) concentrations measured during growth periods.	Refer to US-EPA (2001) for details on criteria.	–	The composition and abundance of phytoplanktonic taxa show slight signs of disturbance. There are slight changes in biomass compared to type-specific conditions. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the quality of the water. A slight increase in the frequency and intensity of the type-specific planktonic blooms may occur. The composition and abundance of planktonic taxa show signs of moderate disturbance.

Protection of aquatic ecosystems (water): Toxicants

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
NON-METALIC INORGANIC TOXICANTS					
Total Ammonia-N (µg/ℓ)	–	500 (99% protect); 910 (95% protect)	pH and Temperature dependent	–	–
Chlorine-Cl (µg/ℓ)	–	–	13 (CMC); 7.5 (CCC)	0.5	–
Cyanide (CN-) (µg/ℓ)	10	2: 4	1 (CMC; 1 (CCC)	–	–
Fluoride(F-) (µg/ℓ)	–	–	–	120 (freshwater)	–
Hydrogen sulphide (µg/ℓ)	–	–	2 (CCC)	–	–
METALS (µg/ℓ)					
Arsenic	50	2.3 As (III)	69 (D, CMC); 36 (D, CCC)	12.5 (T)	–
		4.5 (As (V)			
Cadmium	20	0.7; 5.5	40 (D, CMC); 8.8 (D, CCC)	0.12 (T)	0.2 (AA); 0.45-1.5 (MAC depending on Class)
Chromium	50	Cr (III): 7.7; 27.0	–	56 (T)	–
		Cr (VI): 0.14; 4.4	1100 (D, CMC); 50 (D, CCC) (Cr VI)	1.5 (T)	
Cobalt	–	0.005; 1.0	–	–	–
Copper	50	0.3; 1.3	4.8 (D, CMC); 3.1 (D, CCC)	–	
Lead	50	2.2; 4.4	210 (D, CMC); 8.1 (D, CCC)	–	1.3 (AA); 14 (MAC)
Mercury (inorganic Hg)	0.5	0.1; 0.4	1.8 (D, CMC); 0.94 (D, CCC)	–	0.07 (MAC)
Nickel	–	7: 70	74 (D, CMC); 8.2 (D, CCC)	–	8.6 (AA); 34 (MAC)
Selenium	–	–	290 (D, CMC); 71 (D, CCC)	–	–

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
Silver	–	0.8; 1.4	1.9 (D, CMC)	–	–
Sn (in Tributyltin)	–	0.0004; 0.006	0.37 (CMC); 0.01 (CCC)	0.001	0,0002 (AA); 0.0015 (MAC)
Vanadium	–	50; 100	–	–	–
Zinc	–	7; 15	90 (D, CMC); 81 (D, CCC)	–	–
MONO-AROMATIC HYDROCARBONS (µg/ℓ)					
Benzene	–	600; 950	–	110	8 (AA); 50 (MAC)
Toluene	–	110; 180	–	215	–
Ethylbenzene	–	50; 80	–	25	–
m-Xylene	–	50; 75	–	–	–
Cumene	–	20; 30	–	–	–
POLYCYCLIC AROMATIC HYDROCARBONS (µg/ℓ)					
Naphthalene	–	50; 70	–	1.4	2.0 (AA); 130 (MAC)
Anthracene	–	0.01; 0.4	–	–	0.1 (AA & MAC)
Phenanthrene	–	0.6; 2.0	–	–	–
Fluoranthene	–	1.0; 1.4	–	–	–
Benzo(a)pyrene	–	0.1; 0.2	–	–	0,00017 (AA); 0.024 (MAC)
Benzo (b) fluoranthene	–	–	–	–	0.017 (MAC)
Benzo (k) fluoranthene	–	–	–	–	0.017 (MAC)
Benzo (g,h,i) perylene	–	–	–	–	0.00082 (MAC)
PESTICIDES & HERBICIDES (µg/ℓ)					
Aclonifen	–	–	–	0.012 (AA & MAC)	–
Alachlor	–	–	–	–	0.3 (AA); 0.7 (MAC)

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
Aldicarb	–	–	–	0.15	–
Aldrin	–	0.003 (unknown)	1.3 (CMC)	0.32	–
Antrazine	–	–	–		0.6 (AA); 2.0 (MAC)
Bifenox	–	–	–	0.0012 (AA)’ 0.004 (MAC)	–
Carbaryl	–	–	1.6 (CMC)	–	–
Chlordane	–	0.001 (unknown)	0.09 (CMC); 0.004 (CCC)	–	–
Chlorfenvinphos	–	–	–	–	0.1 (AA); 0.3 (MAC)
Chloropyrifos	–	0.0005; 0.009	0.011 (CMC); 0.0056 (CCC)	–	0.03 (AA); 0.1 (MAC)
Chlorothalonil	–	–	–	0.36	–
Chlorpyros	–	–	–	0.002	–
Cybutryne	–	–	–	–	0.0025 (AA); 0.016 (MAC)
Cyclodien pesticides	–	–	–	–	0.005 (AA)
Cypermethrin	–	–	–	–	0.000008 (AA); 0.00006 (MAC)
DDT	–	0.0004 (unknown)	–	–	0.025 (AA)
4,4-DDT	–	–	0.13 (CMC); 0.001 (CCC)	–	–
Demeton	–	–	0.1 (CCC)	–	–
Dichlorvos	–	–	–	–	0.00006 (AA); 0.00007 (MAC)
Dieldrin	–	–	0.71 (CMC); 0.0019 (CCC)	–	–
Diuron	–	–	–	–	0.2 (AA); 1.8 (MAC)
Docifol	–	–	–	–	0.000032 (MAC)
Endosulfan	–	0.005; 0.01	0.034 (CMC); 0.0087 (CCC)	–	0.0005 (AA); 0.04 (MAC)

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
Endrin	–	0.004; 0.008	0.037 (CMC); 0.0023 (CCC)	–	–
Fenitrothion	–	0.001 (unknown)	–	–	–
Fluoranthene	–	–	–	–	0.0063 (AA); 0.12 (MAC)
Guthion	–	–	0.01 (CCC)	–	–
Heptachlor	–	0.0004 (unknown)	0.053 (CMC); 0.0036 (CCC)	–	0.00000001 (AA); 0.00003 (MAC)
Hexabromocyclododecane (HBCDD)	–	–	–	–	0.0008 (AA); 0.05 (MAC)
Lindane (gamma-BHC)	–	0.007 (unknown)	1.16 (CMC)	–	–
Malathion	–	–	0.1 (CCC)	–	–
Methoxychlor	–	0.004 (unknown)	0.03(CCC)	–	–
Mirex	–	–	0.001 (CCC)	–	–
Para-para-DDT	–	–	–	–	0.01 (AA)
Quinoxyfen	–	–	–	–	0.015 (AA); 0.54 (MAC)
Simazine	–	–	–	–	1.0 (AA); 4.0 (MAC)
Temephos	–	0.0004; 0.05	–	–	–
Terbutryn	–	–	–	–	0.0065 (AA); 0.034 (MAC)
Toxaphene	–	0.1; 0.2	0.21 (CMC); 0.0002 (CCC)	–	–
OTHER TOXIC ORGANIC COMPOUNDS (µg/ℓ)					
1,1,2-Trichloroethylene	–	220; 330	–	–	10 (AA)
1,1,2,2-Tetrachloroethylene	–	40; 70	–	–	10 (AA)
1,2 dichloroethane	–	1.000; 1.900	–	–	10 (AA)

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
1,2,4-Trichlorobenzene	–	20; 80	–	5.4	–
1,2-Dichlorobenzene	–	–	–	42	–
Brominated diphenyl ethers	–	–	–	–	0.014 (MAC)
C10-13 chloro-alkanes	–	–	–	–	0.4 (AA); 1.4(MAC)
Dichloromethane	–	–	–	–	20 (AA)
Di-phthalate (DEHP)	–	–	–	–	1.3 (AA)
Hexachlorobenzene	–	0.05; 0.1	–	–	0.05 (MAC)
Hexachlorobutadiene	–	–	–	–	0.6 (MAC)
Hexachloro-cyclohexane	–	–	–	–	0.002 (AA); 0.02 (MAC)
Isoproturon	–	–	–	–	0.3 (AA); 1.0 (MAC)
Monochlorobenzene	–	15; 55	–	25	–
Nonylphenols	–	–	–	–	0.3 (AA); 2.0 (MAC)
Octylphenols	–	–	–	–	0.01 (AA)
Pentachlorobenzene	–	1.5; 2.0	–	–	0.0007 (AA)
Pentachlorophenol	–	11; 22	13 (CMC); 7.9 (CCC)	–	0.4 (AA); 1.0 (MAC)
Phenol (µg/ℓ)	50	–	–	–	–
Polychlorinated biphenyls (PCBs)	–	–	Total: 0.03 (CCC)	–	–
Trichalomethane	–	–	–	–	2.5 (AA)
Trichlorobenzene	–	8: 13 (1,3,5)	–	–	0.4 (AA)

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (Australia & New Zealand Government, 2018)*	US-EPA (see US-EPA, 2022a)	Canada (CCME, 1999, as revised 2002)	European Community (CEC. 2008, 2013)
Others toxic organic pollutants	–	Refer to https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/search AUSTRALIA (Kumar *et al.*, 2016)	–	–	–
PHARMACEUTICALS (µg/ℓ)					
Carbamazepine	–	<1.0; 9.2	–	–	–
Diclofenac	–	180; 770	–	–	–
Fluoxetine	–	0.23; 1.6	–	–	–
Propranolol	–	3.5; 14	–	–	–

Note*: * Lists QTs recommended 99% protection of species and 95% protection of species; AA = Annual Average; MAC = maximum allowable concentration; T = Total; D = Dissolved; CCC = Criteria Maximum concentration; CMC = Criteria Continuous Concentration*

Protection of aquatic ecosystems (water): Toxicants

Variable	Australia/New Zealand (Australia & New Zealand Government, 2018)		NOAA (Long *et al.*, 1995)		State of Florida (MacDonald, 1996)		Canada (CCME, 1999 as revised 2002)	
	Default QT	PEL	ERL	ERM	TEL	PEL	QT	PEL
METALS (µg/g dry weight)								
Antimony	2	25	–	–	–	–	–	–
Arsenic	20	70	8.2	70	7.24	41.6	7.24	41.6
Cadmium	1.5	10	1.2	9.6	0.68	4.21	0.7	4.2
Chromium	80	370	81	370	52.3	160	52.3	160
Copper	65	270	34	270	18.7	108	18.7	108
Lead	50	220	46.7	218	30.2	112	30.2	112
Mercury	0.15	1	0.15	0.71	0.13	0.7	0.13	0.7
Nickel	21	52	20.9	51.6	15.9	42.8	–	–
Silver	1	4	1	3.7	0.73	1.77	–	–
Tin as Tributyltin-Sn	0.009	0.07	–	–	–	–	–	–
Zinc	200	410	150	410	124	271	124	271
POLYCYCLIC ARAMATIC HYDRBARBONS (PAHs) (ng/g)								
Total PAHs	10,000	50,000	4,022	44,792	1684	16,770	–	–
Acenaphthene	–	–	16	500	6.71	88.9	6.71	88.9
Acenaphthylene	–	–	44	640	5.87	128	5.87	128
Anthracene	–	–	85.3	1,100	46.9	245	46.9	245
Fluorene	–	–	19	540	21.2	144	21.2	144
2-methyl naphthalene	–	–	–	–	20.2	201	20.2	201
Naphthalene	–	–	160	2,100	34.6	391	34.6	391
Phenanthrene	–	–	240	1,500	86.7	544	86.7	544

Variable	Australia/New Zealand (Australia & New Zealand Government, 2018)		NOAA (Long *et al.*, 1995)		State of Florida (MacDonald, 1996)		Canada (CCME, 1999 as revised 2002)	
	Default QT	PEL	ERL	ERM	TEL	PEL	QT	PEL
Benzo(a)anthracene	–	–	261	1,600	74.8	693	74.8	693
Benzo(a) pyrene	–	–	430	1,600	88.8	763	88.8	763
Dibenzo(a,h) anthracene	–	–	63.4	260	6.22	135	6.22	135
Chrysene	–	–	384	2,800	108	846	108	848
Fluoranthene	–	–	600	5,100	113	1,494	113	1494
Pyrene	–	–	665	2,600	153	1,398	153	1398
Toxaphene	–	–	–	–	–	–	0.1	–
PESTICIDES & HERBICIDES (ng/g dry weight)								
Total DDT	1.2	5	1.58	46.1	3.89	51.7	1.19	4.77
p DDT	–	–	–	–	1.19	4.77	–	–
p p DDE	1.4	7	2.2	27	2.07	374	2.07	374
p,p DDD	3.5	9	–	–	1.22	7.81	1.22	7.81
Aroclor	–	–	–	–	–	–	63.3	709
Chlordane	4.5	9	–	–	2.26	4.79	2.26	4.79
Dieldrin	2.8	7	–	–	0.72	4.3	0.71	4.3
Endrin	2.7	60	–	–	–	–	2.67	62.4
Heptachlor	–	–	–	–	–	–	0.6	2.74
Lindane	0.9	1.4	–	–	0.32	0.99	0.32	0.99
OTHER TOXIC ORGANIC COMPOUNDS (ng/g dry weight)								
Total PCBs	34	280	–	–	21.6	189	21.5	189

Marine Aquaculture: Protection of organism health—Physico-chemical properties and nutrients

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (ANZECC, 2000)	European Community (CEC, 2006b)
Salinity (ppt)	–	33–37 30–35 (brackish)	< 40 or discharges affecting shellfish waters must not cause the salinity of the waters to exceed by more than 10% of waters not so affected (I) 12–38 (G) (95% of sample to comply based on monthly sampling over 12 months)
Temperature	Ambient	Less than 2.0oC change over 1 hour	Discharges affecting shellfish waters must not cause the temperature of the waters to exceed by more than 2oC the temperature of waters not so affected (G) (75% of sample to comply based on quarterly sampling over 12 months)
pH	7.0–8..5	6–9	7–9 (I) (75% of sample to comply based on quarterly sampling over 12 months)
Carbon Dioxide	–	<15 mg/ℓ	–
Dissolved oxygen	>5 mg/ℓ	>5 mg/ℓ	> 70% saturation, should n individual measurement indicate a value lower than 70% saturation, repeat. No individual measurements may show < 60% saturation unless there are no harmful consequences for the development of shellfish colonies (I) > 80% saturation (G) (95% of sample to comply based on monthly sampling over 12 months)
Chemical oxygen demand	5 mg/ℓ by alkaline potassium permanganate method	–	–
Gas super-saturation	–	<100%	–

Variable	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (ANZECC, 2000)	European Community (CEC, 2006b)
Turbidity/Water clarity	–	–	Discharge affecting shellfish waters must not cause the colour of the waters after filtration to deviate by more than 10 mg Pt/l from the colour of waters not so affected (I) (75% of sample to comply based on quarterly sampling over 12 months)
Suspended solids	15 mg/ℓ	<10 mg/ℓ (<75 mg/ℓ brackish)	Discharge affecting shellfish waters must not cause content of waters to be more than 30% of the content of waters not so affected (I) (75% of sample to comply based on quarterly sampling over 12 months)
Floating matter, including oil and grease	Oil and grease: Not detectable by N-hexane extraction method	–	Hydrocarbons must not be present in shellfish water in such quantities as to produce a visible film on the surface of the water (I) (75% of sample to comply based on quarterly sampling over 12 months)
Dissolved inorganic nutrients	NO_3–N: 800 µg/ℓ PO_4–P: 80 µg/ℓ	NO_3–N: 100 000 µg/ℓ NO_2–N: 100 µg/ℓ Total Available N: 1000 µg/ℓ PO_4–P: 50 µg/ℓ	–

Marine Aquaculture: Protection of organism health – Toxicants

Variable (µg/ℓ)	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (ANZECC, 2000)	European Community (CEC, 2006b)
Total Ammonia-N	–	100 (un-ionized)	
Total Free Chlorine-Cl	–	3	
Cyanide (CN-)	10	5	
Sulfides (S-)	–	2	
Phenol	50	–	
Methane	–	65,000	
Aluminium	–	10	
Arsenic	50	30	Concentration of each substance in shellfish flesh must be so limited that it contributes, in accordance to Article 1, with the quality of the shellfish products (G) Concentration of each substance in the shellfish water or in the shellfish flesh must not exceed a level which gives rise to harmful effects on the shellfish and their larvae. The synergistic effects of metals must also be taken into consideration (I) (100% of sample to comply based on half yearly sampling over 12 months)
Cadmium	20	0.5–5	
Chromium	50	20	
Cobalt	–	–	
Copper	50	5	
Iron	–	10	
Lead	50	1–7	
Manganese	–	10	
Mercury	0.5	1	
Nickel	–	100	
Selenium	–	10	
Silver	–	3	
Tributyltin-Sn	–	0.01	
Vanadium	–	100	
Zinc	–	5	

Variable (µg/ℓ)	Mauritius (Mauritius Government, 1999)	Australia/ New Zealand (ANZECC, 2000)	European Community (CEC, 2006b)
Naphthalene	–	–	Petroleum hydrocarbons must not be present in shellfish water in such quantities as to produce a visible film on the surface of the water and/or a deposit on the shellfish or have harmful effects on the shellfish (I) (75% of sample to comply based on quarterly sampling over 12 months)
Anthracene	–	–	
Phenanthrene	–	–	
Fluoranthene	–	–	
Benzo(a) pyrene	–	–	
Chlordane	–	0.004	
Endosulfan	–	0.001	
Lindane	–	0.004	
Paraquat	–	0.01	
Poly chlorinated biphenyls (PCBs)	–	2	Concentration of each substance in shellfish flesh must be so limited that it contributes, in accordance to Article 1, with the quality of the shellfish products (G) Concentration of each organo-halogenated substance in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae (I). (100% of sample to comply based on half-yearly sampling over 12 months)

Marine Aquaculture: Tainting of organism flesh – Estimated threshold concentration of substances

Variable (mg/ℓ)	Australia/New Zealand (ANZECC, 2000)	US-EPA (see US-EPA, 2022c)
Acenaphthene	0.02	0.02
Acetophenone	0.5	–
Acrylonitrile	18	–
Copper	1	1
m-cresol	0.2	–
o-cresol	0.4	–
p-cresol	0.1	–
Cresylic acids (meta, para)	0.2	–
Chlorobenzene	0.02	–
n-butylmercaptan	0.06	–
o-sec. butylphenol	0.3	–
p-tert. butylphenol	0.03	–
2-chlorophenol	–	0.0001
3-chlorophenol	–	0.0001
o-chlorophenol	0.0001–0.015	–
p-chlorophenol	0.0001	–
2,3-dinitrophenol	0.08	–
2,4,6-trinitrophenol	0.002	–
2,3 dichlorophenol	–	0.00004
2,4-dichlorophenol	0.0001–0.014	0.0003
2,5-dichlorophenol	0.02	0.0005
2,6-dichlorophenol	0.03	0.0002

Variable (mg/ℓ)	Australia/New Zealand (ANZECC, 2000)	US-EPA (see US-EPA, 2022c)
3,4-dichlorophenol	0.0003	0.0003
2-methyl-4-chlorophenol	2.0	1.8
2-methyl-6-cholorophenol	0.003	0.02
3-methyl-4-chlorophenol	0.02–3	3
o-phenylphenol	1	–
Pentachlorophenol	0.03	0.03
Phenol	1–10	0.3
Phenols in polluted rivers	0.15–0.02	–
2,3,4,6-tetrachlorophenol	0.001	0.001
2,4,5-trichlorophenol		0.001
2,3,5-trichlorophenol	0.001	–
2,4,6-trichlorophenol	0.002	0.002
2,4-dimethylphenol	0.4	0.4
Dimethylamine	7	–
Diphenyloxide	0.05	–
B,B-dichlorodiethyl ether	0.09–1	–
o-dichlorobenzene	<0.25	–
p-dichlorobenzene	–	–
Ethylbenzene	0.25	–
Momochlorobenzene	–	0.02
Ethanethiol	0.2	–
Ethylacrylate	0.6	–
Formaldehyde	95	–
Gasoline/Petrol	0.005	–
Guaicol	0.08	–
Kerosene	0.1	–
Kerosene plus kaolin	1	–

Variable (mg/ℓ)	Australia/New Zealand (ANZECC, 2000)	US-EPA (see US-EPA, 2022c)
Hexachlorocyclopentadiene	0.001	0.001
Isopropylbenzene	<0.25	–
Naphtha	0.1	–
Naphthalene	1	–
Naphthol	0.5	–
2-Naphthol	0.3	–
Nitrobenzene	0.03	0.03
a-methylstyrene	0.25	–
Oil, emulsifiable	>15	–
Pyridine	5–28	–
Pyrocatechol	0.8–5	–
Pyrogallol	20–30	–
Quinoline	0.5–1	–
p-quinone	0.5	–
Styrene	0.25	–
Toluene	0.25	–
Outboard motor fuel as exhaust	7.2	–
Zinc	5	5

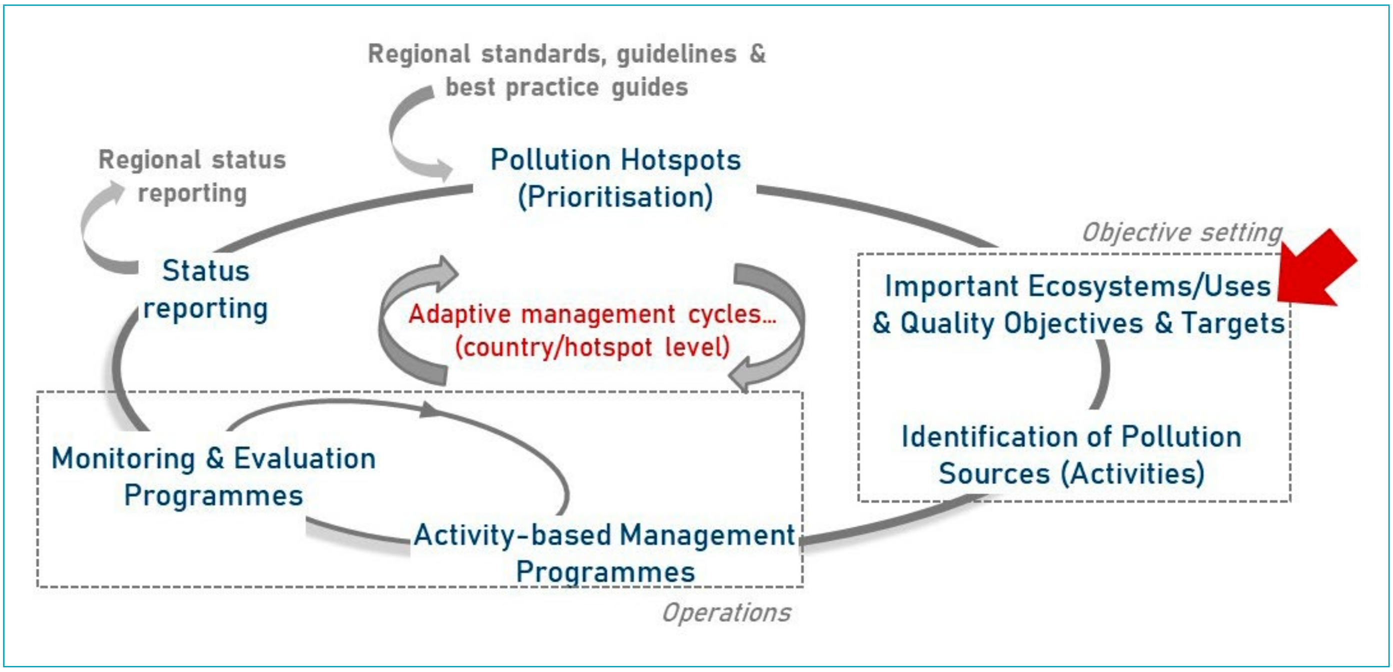
Photo: © Salomao Bandeira – Restored seagrass in Inhaca Island Mozambique.

APPENDIX C:
PROPOSED TEMPLATE FOR PILOT TESTING REGIONAL WATER AND SEDIMENT QUALITY OBJECTIVES AND TARGETS

Chapter 1: Introduction

Following agreement by the countries in the Western Indian Ocean (WIO) the Nairobi Convention Secretariat, in consultation with Regional Task Force for Coastal and Marine Water Quality Management (C&MWQM), commissioned the CSIR (South Africa) to undertake the *Development a Strategic Framework for C&MWQM for the WIO region*, including the *Guidelines for Setting Water and Sediment Quality Targets for the Coastal and Marine Environment*. The aim of Guidelines is to assist responsible national authorities and water quality managers to prepare Quality Objectives and Targets for their particular coastal and marine environments towards effective implementation of national-level C&MWQM.

The *Ecosystem-based Implementation Framework for C&MWQM*, developed as part of the above-mentioned project, is conceptualized below showing the context of Quality Objectives and Targets:



To wisely apply human and financial resources, it may be necessary to tackle C&MWQM in a phased approach. In this regard, the identification of **marine pollution hotspots** or emerging hotspots, provides a transparent mechanism to prioritise study areas where coastal and marine environmental quality is most at risk or impacted by human activities. The identification and **mapping of important ecosystems, and key socio-economic beneficial uses** in a specific area, as well as their environmental quality objectives and associated targets are key components in a C&MWQM programme. Agreement on important aquatic ecosystems and other the beneficial uses within a specific coastal management area (or hotspot), as well as associated water and sediment QTs, should be negotiated in a consultative process using appropriate institutional structures, e.g. stakeholder fora. As part of the objective setting phase, another key component is the identification and characterization (including location and quantification) of potential **marine pollution sources** (both land-based and sea-based) that may alter water and sediment quality within a specific study area, as well as setting limits. **Activity-based management programmes** involve the operational management of specific activities potentially contributing to marine pollution. The design and implementation of environmental quality **monitoring and evaluation programmes** forms an integral and critical element in the Implementation Framework's operational phase. Status reporting provides for a high-level reflection on progress and transparency on issues of concern which need to be addressed through a cycle of adaptive management.

The primary purpose of C&MWQM is to manage activities and developments, potentially contributing to coastal and marine pollution, so as to keep these natural resources suitable for designated uses. To achieve this goal, it is important to identify **important or sensitive aquatic ecosystems, as well as other beneficial uses** of coastal and marine areas that rely on good water and sediment quality. For the WIO region, the following were considered appropriate:

- Protection of aquatic ecosystems
- Recreational use (including tourism)
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial uses (e.g. intakes for desalination, cooling water intake and seafood processing).

In this light, the phased approach in proposed for the integration of these *Target Guidelines* as tools for C&MWQM at national level. First, it is proposed that the quality objectives and targets for sediment and water quality, as recommended for the WIO region at large, be adopted as **interim national sediment and water quality guidelines**. Thereafter, it is proposed that a country's responsible authorities commission a few pilot or case studies to test the applicability of these objectives and targets (e.g. pollution hotspots along a country's coastal and marine environment). This should be done in collaboration with local authorities, local universities, as well as local stakeholders, in accordance with the Framework for C&MWQM (see above).

This document presents an Annotated Table of Content (in the following sections) to provide Guidance on the **Implementation of Pilot Studies** (e.g. at a few selected marine pollution hotspots) to test application level of the proposed interim sediment and water quality objective and targets.

Chapter 2: Information Requirements on Pilot site

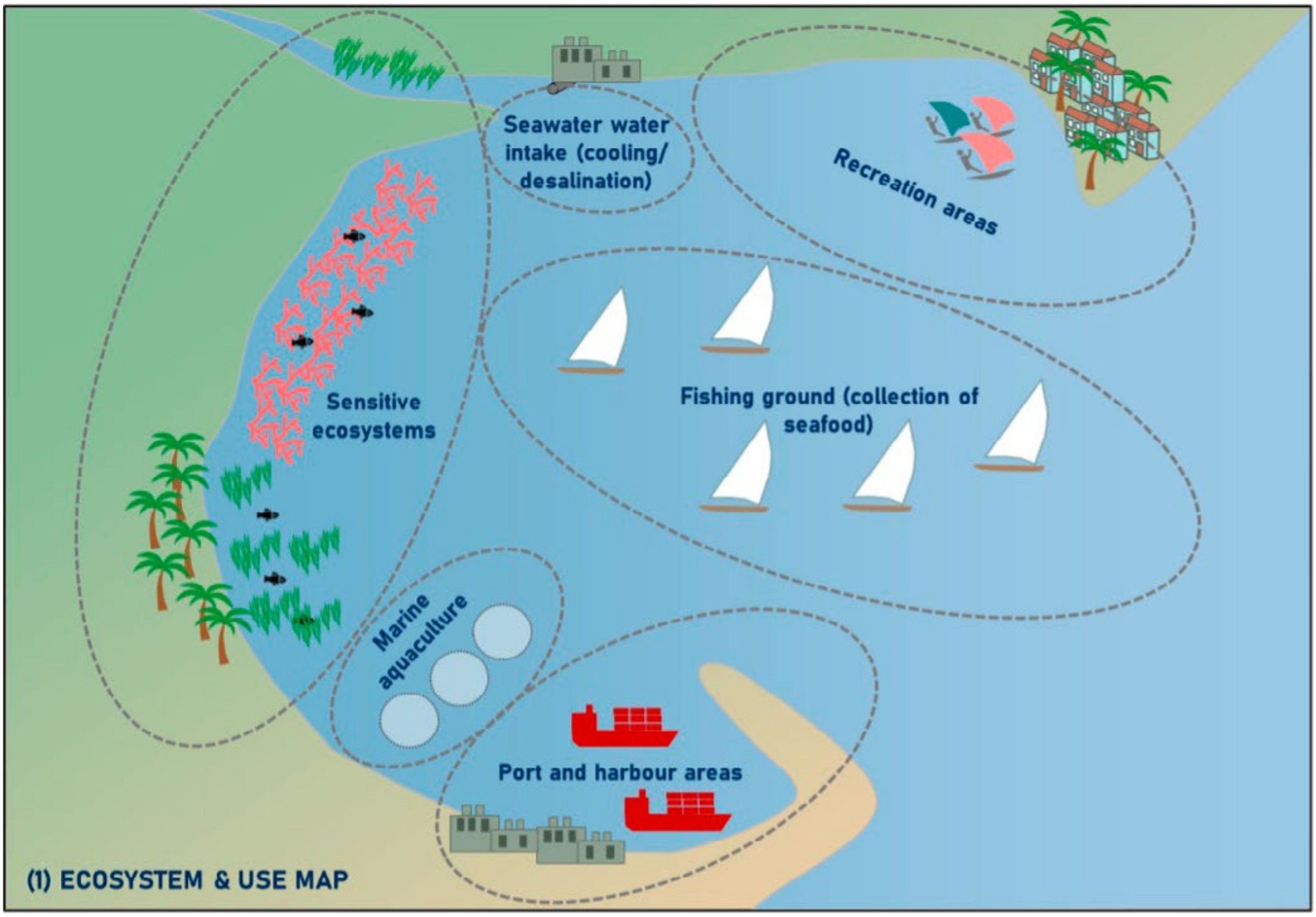
In order to provide context for testing of the interim water and sediment quality objectives and targets it is important to collate and generate related relevant information for pilot studies sites, as summarized below.

2.1 Background information

- Geographical boundaries of pollution hotspot
- Brief description of coastal and marine environment
- Socio-economic context (demographics, economic profiles, important social considerations)
- Legal framework applicable to C&MWQM
- Institutional Arrangements for C&MWQM.

2.2 Zonation of Important Ecosystems and Uses

- Location map of Important and Sensitive Ecosystems, as well as required QTs (e.g. as per Guidelines for the WIO region)
- Location map of social and economic uses (ecosystem services), as well as required QTs (e.g. as per Guidelines for the WIO region)
- Identification of Pollution Sources (Activities)



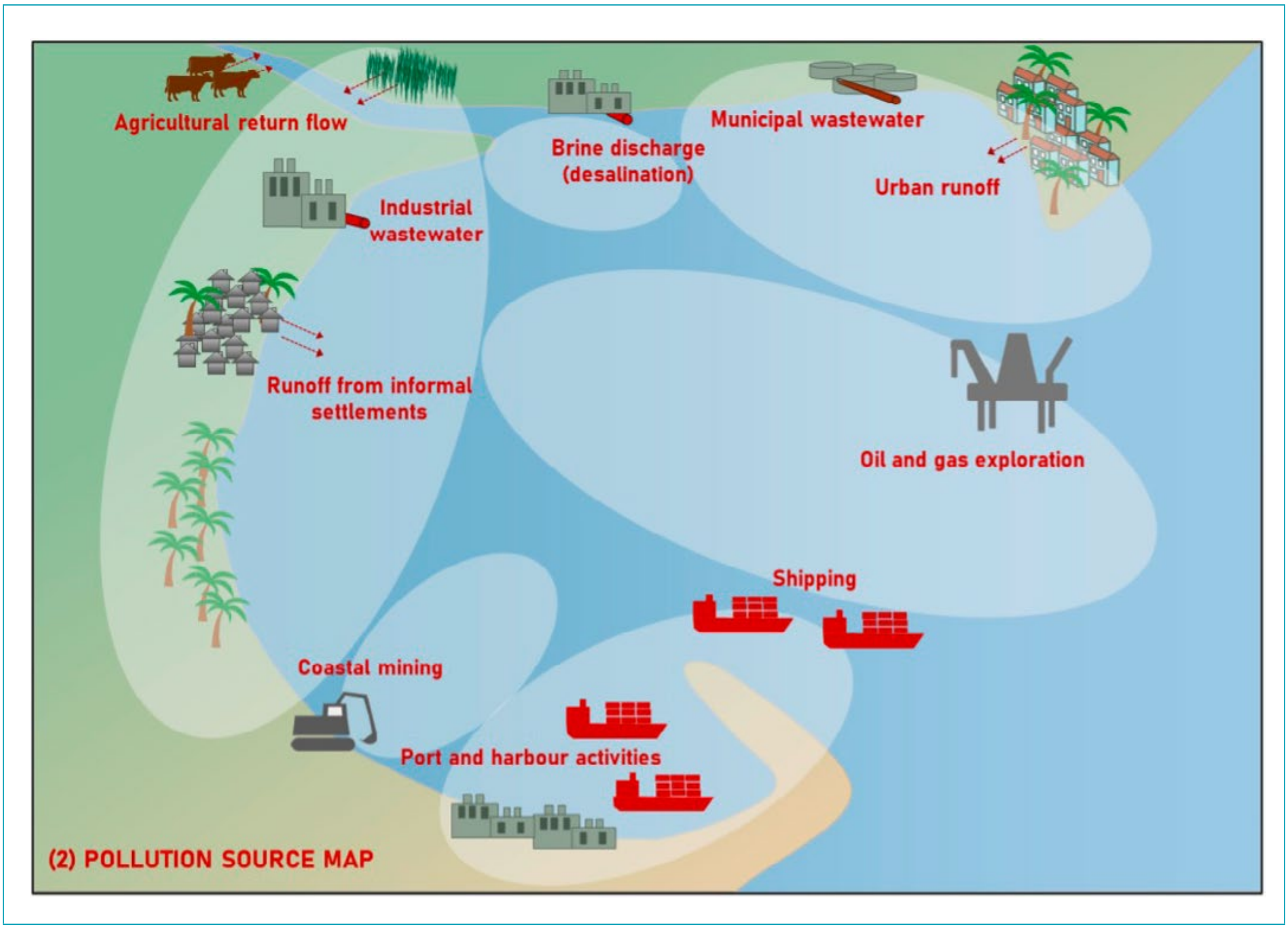
2.3 Location map of pollution sources (activities)

- Location map of pollution sources (activities)
- Description and quantification of each of the identified pollution sources (activities)

2.4 Define Relevant Quality Objectives and Targets
Based on the identified ecosystem and other beneficial uses, as well as the types of pollutants expected to affect those areas, use the Interim Water and Sediment Quality Target Report (this report) to derive QTs.

2.5 Define Relevant Quality Objectives and Targets

Based on the identified ecosystem and other beneficial uses, as well as the types of pollutants expected to affect those areas, use the regional **Water and Sediment Quality Targets**, e.g.



TYPE OF AREAS	KEY PARAMETERS	QUALITY TARGET
Sensitive aquatic ecosystem areas		
Recreation areas		
Marine aquaculture areas		
Industrial use areas		

Chapter 3:
Collate/Gather Field Measurements on Key Parameters

Source available data and information on concentrations of key parameters previously gathered from stations in the pilot study areas, e.g. scientific literature, government monitoring programmes, or any other possible sources of such data.

Where such data do not exist, start a monitoring programme to collect data on key parameters. In order to apply the Reference Method for site-specific physico-chemical and nutrient QTs, it is important to identify and monitor so-called reference sites, i.e. areas of similar characteristics but that have not been affected by pollution.

Also important is to ensure good practice in the execution of measurement programme as these are costly. Important considerations are:

- Selection monitoring parameters (motivation and frequency of sampling)
- Location of sampling stations (e.g. matched with beneficial uses areas)
- Frequency of sampling
- Sampling and in situ measurements procedures
- Laboratory analysis procedures
- Data analysis methodology

As this component of the pilot study can be costly (e.g. if field measurements needs to be undertaken) it will be important to collaborate with partners, such as local authorities, universities and other institutions with capabilities to perform water and sediment quality monitoring to develop a joint initiative.

Also, it might not be possible (due to human and financial resource constraints) to collect new data on all the key water quality parameters. In those instances, measurement programmes can start with those parameters that are easier to measure, or that are more affordable.

Chapter 4: Evaluate Water and Sediment Quality Data

Once field data on key water and sediment quality parameters at stations within the pilot study area have been collated or collected, the next step will be to compare these data to the interim QTs (see Table above) relevant to various areas in the pilot study area (see maps above).

In doing so, it will be possible to test the applicability and practicability of applying the interim QTs in pilot study areas in a particular country. Because of natural variability in some water and sediment quality parameters, where there is "non-compliance" with interim QTs it is necessary to check whether this is actually attributed to pollution, or where it is because values are naturally variable outside of QT ranges (e.g. by also looking at Reference site data).

Chapter 5:
Key Findings and Recommendations

- Summarize key findings from results, e.g. compliance/ non-compliance, trends, etc.
- Identify where refinements to the interim QTs may have to be considered, where concentrations of key parameters are naturally higher than targets, or where more studies need to be conducted to confirm.

Following the outcome of the pilot studies, the interim QTs can be refined where necessary, and can then be accepted as official water and sediment quality targets for a particular country for application in C&MWQM.

The pilot studies can also then be rolled out to full C&MWQM programmes for those particular areas, and used as templates for initiation in other marine pollution hotspots. It is also important to formalize local institutional arrangements that were established to execute the pilot studies—*moving from pilot project to institutionalized practic*e.

The Nairobi Convention, through the GEF-funded projects “Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP)” and the “Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms (SAPPHIRE)”, as well as the European Union-funded project “African, Caribbean, and Pacific (ACP) Countries Capacity Building of Multilateral Environmental Agreements (MEAs) project”, together with the Council on Scientific and Industrial Research in South Africa, have produced a suite of publications on coastal and marine water quality management—a Water Quality Situational Assessment, Water Quality Monitoring Framework and Water Quality Monitoring Guidelines in support of improved water quality in the WIO region

The participating countries in the projects include Comoros, Madagascar, Mauritius, Seychelles, Mozambique, Kenya, Tanzania, France (not a beneficiary of GEF funds), Somalia and South Africa. The goal of the WIOSAP is to: “Improve and maintain the environmental health of the region’s coastal and marine ecosystems through improved management of land-based stresses”. The goal of the SAPPHIRE project is to “achieve effective long-term ecosystem management in the Western Indian Ocean LMEs in line with the Strategic Action Programme (SAP).” The goal of the ACP-MEAs project in the Western Indian Ocean region is to “build capacity to support countries in fulfilling their obligations as parties to Multilateral Environmental Agreements (MEAs), to address the environmental challenges they face and to reap the benefits of improved environmental governance at the national and regional levels.”