Guidelines for the Establishment of Environmental Quality Objectives and Targets in the Coastal Zone of the Western Indian Ocean (WIO) Region

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EXECUTIVE SUMMARY

Introduction

The Project "Addressing Land-based Activities in the Western Indian Ocean" (WIO-Lab) is a deliberate and conscious effort of the people of the Western Indian Ocean (WIO) region (including Kenya, Tanzania, Mozambique, South Africa, Madagascar, Seychelles, Comoros and Mauritius) taken in response to a call from the 1st Meeting of the Contracting Parties to the Nairobi Convention in March 1997. The project was officially launched in Madagascar in July 2004 during the 4th Meeting of the Contracting Parties to the Nairobi Convention.

The WIO-Lab Project is aimed at addressing some of the major environmental problems and issues related to the degradation of the marine and coastal environment due to land-based activities in the region and has three main objectives:

- Reduce stress to the ecosystem by improving water and sediment quality
- Strengthen regional legal basis for preventing land-based sources of pollution
- Develop regional capacity and strengthen institutions for sustainable, less polluting development.

As part of the strategy of fulfilling the first and second objectives of the WIO-LaB Project, Protocols for the establishment of Environmental Quality Objectives and Targets (EQO/Ts) applicable to the coastal zone had to be developed for the region. Such EQO/Ts aim to protect the biodiversity of marine habitats (or ecotones) in coastal areas of the WIO region, as well as to ensure fitness for use (e.g. recreational use).

An Environmental Quality Objective (EQO) is a broad, narrative statement describing the desired quality levels (or goals) for a particular environment, in this case the coastal zone. Environmental Quality Targts (EQTs) are defined as numerical or narrative target values for water and sediment quality parameters in receiving coastal environments that will ensure compliance with EQOs.

The WIO-Lab Project Management Unit (PMU) approached the CSIR to assist in the formulation of Guidelines for the establishment of EQO/Ts for the coastal zone of the Western Indian Ocean (WIO), as presented here.

Environmental Quality Objectives and Targets in Perspective

The ultimate goal in the management of coastal systems is to keep the resource suitable for all designated uses – both existing and future uses (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning).

The uses of coastal ecosystems are typically divided into four broad categories namely:

- Protection of biodiversity and ecosystem functioning of the natural environment (conservation areas)
- Recreational use (including tourism)
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial uses (e.g. cooling water intake and water for seafood processing).

In many instances sustainable use of coastal ecosystems rely on these systems remaining functional. In turn, the integrity of coastal ecosystems depends on a number of factors, including:

- Stream flows (referring to river and groundwater inflows)
- Physical habitat (referring to water circulation processes, sediment type and climatic conditions)
- **Water and sediment quality** (referring to the biogeochemical status)
- Availability of suitable migration or recruitment routes

- Food web integrity.

Within the WIO region, as in many other coastal regions, the integrity of coastal ecosystems is increasingly degraded and threatened by an array of natural phenomena (e.g. floods, storms, cyclones, etc.) as well as anthropogenic (human) activities. The latter may include activities occurring at sea (e.g. offshore oil exploration and ship traffic) or land-based activities. Land-based activities that are of particular concern in the WIO include:

- 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
- Inappropriate disposal of waste (pollution).

In order to effectively manage coastal systems to remain suitable for designated use, objectives and measurable targets should be set for the different parameters defining the integrity of these systems, taking into account the requirements of designated uses, as well as potential threats.

In terms of setting such targets **for water and sediment quality**, Environmental Quality Objectives (EQOs), defined as broad, narrative statements describing the desired quality levels (or goals) for a particular environment - in this case geographically defined units in the coastal zone - need to be developed. From a management perspective, these goals need to be translated into measurable target values or Environmental Quality Targets (EQTs). The guidelines – as proposed here - aim at providing local managers and governing authorities with the information to set site specific EQOs and EQTs for water and sediment quality in geographically defined units, taking into account specific issues of relevance and potential concerns in their area. In other words countries need not specify and monitor for all the parameters listed here, but should be guided by the designated uses (and their quality requirements) as well as the pollution sources (and associated pollutants) within a specific areas.

As part of the guidelines, generic EQO/Ts for application in the WIO region are also recommended. Generic EQTs - usually developed on the regional or national scale - are presented either as numerical target or descriptive statements specifying the quality requirements of a coastal ecosystem (biodiversity) or designated use (e.g. recreation). To accommodate natural variability encountered in coastal ecosystems, but still minimize risk of impact, these EQTs need to be generic, but fairly conservative. Generic EQO/Ts - as recommended here - should be considered as a first phase approach in setting site-specific EQO/Ts, and depending on site-specific conditions (ecological, social and/or economic) these may have to be refined. In other words, countries should be guided by the generic EQO/Ts to prepare more specific national or local EQO/Ts.

As a result of the above, generic EQTs generally do not automatically become legally binding, although these could be used to develop legally binding standards (e.g. emission limit values [ELV] for wastewater discharges) (Ragas et al, 2005). Also, once generic EQTs have been verified and refined to accommodate site-specific needs these can become legally binding standards in themselves (e.g. those applying to coastal waters used for marine aquaculture activities).

Main Ecotones in the Coastal Zone of the WIO Region

The term ecotone as used here is not that of the traditional sense (i.e. a transitional area between two adjacent ecological communities). Rather the term refers to an ecologically distinct zone which shows some degree of ecological homogeneity rather than transition. For the purposes of this study, the main ecotones within the WIO region are considered to be sea grass beds, mangrove forests and coral reefs. Considerable thought was given to including estuaries as an additional ecotone. However, estuaries are complex systems that comprise numerous habitats and gradients in physico-chemical conditions, and are better considered here as domains (along with nearshore and offshore, for example). In addition to this, consideration of sea grass beds and mangroves allowed the two most sensitive estuarine habitat types to be included in the assessment.

Sea grass beds are a predominant feature throughout the shallow waters of the WIO region, and serve as a habitat to a wide diversity of marine organisms ranging from algae and invertebrates through to the vertebrate classes. Larger animals that are threatened species (marine turtles and dugongs) depend on these ecosystems as a source of food. These habitats are continuously degraded either by direct removal or indirect impacts of land based activities. Key taxa within sea grass ecotones are bacteria, fungi, macro and micro-algae, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (shrimp, prawns, crabs, isopods and amphipods), fish, marine turtles and dugongs.

Mangroves in the WIO region are species rich habitats that support major fisheries, particularly in the estuaries of Mozambique, Tanzania and Kenya. Ten species of mangroves exist in the WIO region, with the most extensive forests located along the Mozambican coastline. Despite the ecological value of mangroves, these habitats are facing severe degradation from human activities. Key taxa that typically associate with mangroves are bacteria, fungi, macro and micro-algae, invertebrate and vertebrate larvae, post larvae and juveniles, polychaetes, bivalves, gastropods, crustaceans (shrimp, prawns, crabs, isopods, amphipods), fish, marine turtles and dugongs.

Extensive and highly productive coral reefs fringe over 1500 km of the WIO region coastline. Besides the massive bleaching event in 1998 which brought some species to extinction, coral reefs are negatively impacted by direct and indirect anthropogenic activities. Typical fauna and flora that use coral reefs are macro and micro-algae, tunicates, sponges, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (prawns, crabs, lobsters, isopods, amphipods) and fish.

Recommended Environmental Quality Objectives and Targets

The ultimate goal in the management of coastal ecosystems is *to keep the resource suitable for all designated uses – both existing and future uses* (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning). One of the aspects to be managed, to ensure fitness-for-use is water and sediment quality. For the WIO region it is proposed that the following broad categories be recognised in terms of designated uses:

- Protection of coastal aquatic ecosystems
- Recreational use
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial use.

Translating the ultimate goal into category-specific objectives, the following generic EQOs are proposed for the WIO region (recognizing that these EQOs may have to be adapted site-specifically, based on local ecological, social and economic conditions):

Protection of coastal aquatic ecosystems	*The physical, chemical and biological conditions defining the structure of, and processes within, a particular coastal ecosystem are maintained*
Recreational use	*Environmental quality is suitable for recreational use from an aesthetic, safety and hygienic point of view*
Marine aquaculture	*Environmental quality sustains acceptable product quality and prevents any health risks to consumers*
Industrial use	*Environmental quality does not result in mechanical interferences, sustains acceptable product quality and prevents any health risks to consumers*

Protection of Coastal Aquatic Ecosystems

EQTs for coastal waters linked to the protection of coastal aquatic ecosystems are proposed for the following constituent types:

- Objectionable matter (e.g. resulting in entanglement of marine organisms)
- Physico-chemical variables
- Nutrients
- Toxic substances.

EQTs for sediments are generally only specified for the protection of aquatic ecosystems, and in particular for toxic substances. Recommended EQTs for the above-mentioned constituent categories are provided in the tables below.

Monthly data collected over a two-year period are considered to be sufficient to indicate ecosystem variability and can be used to derive EQTs for constituents that do not show large seasonal or event-scale effects. However, in ecosystems where concentrations of physico-chemical variables and nutrients (and ecological and biological responses) are influenced by 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 EQTs need to be derived for corresponding key periods.

Objectionable matter (aesthetics)

CONSTITUENT	RECOMMENDED EQT
Objectionable Matter/Aesthetics	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 variables

CONSTITUENT	RECOMMENDED EQT
Temperature	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the range defined by the 20%ile and 80%ile of the seasonal distribution for the reference system. Test data: Median concentration for the period
Salinity	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20%ile or 80%ile of the reference system(s) distribution, depending upon whether low salinity or high salinity effects are being considered. Test data: Median concentration for the period
pH	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value range should be determined as the range defined by the 20%ile and 80%ile of the seasonal distribution for the reference system. pH changes of more than 0.5 pH units from the seasonal maximum or minimum defined by the reference systems should be fully investigated. Test data: Median concentration for the period
Turbidity Suspended solids	Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline values should be determined as the 80%ile of the reference system(s) distribution. Additionally, the natural euphotic depth (Z_{eu}) should not be permitted to change by more than 10%. Test data: Median concentration for period

CONSTITUENT	RECOMMENDED EQT
Dissolved oxygen	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20%ile of the reference system(s) distribution. Where possible, the guideline value should be obtained 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 by using the lowest diurnal DO concentrations

Where the above-mentioned data are not available the following is recommended as interim EQTs:

CONSTITUENT	RECOMMENDED INTERIM EQT		
	Seagrasses	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

Nutrients

CONSTITUENT	RECOMMENDED EQT
Chlorophyll a	Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline value should be determined as the 80%ile of the reference system(s) distribution.
Dissolved oxygen	See above
Turbidity	See above
Nutrients	Nutrient concentrations in the water column should not result in chlorophyll a, turbidity and/or dissolved oxygen levels that are outside the recommended water quality guideline range (see above). This range should be established by using either suitable statistical or mathematical modelling techniques. Alternatively, where a modelling approach is difficult to implement, nutrient concentrations can be derived using the reference system data approach: Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline value should be determined as the 80%ile of the reference system(s) distribution.

Where the above-mentioned data are not available the following are recommended as interim EQTs:

CONSTITUENT	RECOMMENDED INTERIM EQT		
	Seagrasses	Mangroves	Coral reefs
Dissolved Inorganic Nitrogen-N (µg/ℓ) (NH_4-N + NO_3-N+ NO_2 –N)	500	1000	15
Dissolved inorganic phosphate-P (µg/ℓ)	50	100	5

Toxic substances (coastal waters)

CONSTITUENT	RECOMMENDED EQT (µg/ℓ)
Total Ammonia-N	910 (600 - coral reefs)*
Total Residual Chlorine-Cl	3 (0.2)
Cyanide (CN^-)	4
Fluoride(F^-)	5 000
Sulfides (S^-)	1 (0.02)
Phenol	400
Polychlorinated Biphenyls (PCBs)	0.03
Trace metals (as Total metal):	
Arsenic	As(III) - 2.3; As(V) - 4.5 (15)
Cadmium	5.5 (5)
Chromium	Cr (III) - 10; Cr (VI) - 4.4

CONSTITUENT	RECOMMENDED EQT (µg/ℓ)
Cobalt	1
Copper	1.3 (1)
Lead	4.4 (1)
Mercury	0.4 (0.3)
Nickel	70 (10)
Silver	1.4 (1)
Sn (as Tributyltin)	0.006
Vanadium	100
Zinc	15 (17)
Aromatic Hydrocarbons (C6-C9 simple hydrocarbons - volatile):	
Benzene (C6)	500
Toluene (C7)	180
Ethylbenzene (C8)	5
Xylene (C8)	Ortho - 350; Para - 75; Meta - 200
Naphthalene (C9)	70
Poly-Aromatic Hydrocarbons (< C15 - acute toxicity with short half-life in water)	
Anthracene (C14)	0.4
Phenanthrene (C14)	4
Poly-Aromatic Hydrocarbons (> C15, chronic toxicity, with longer half-life in water)	
Fluoranthene (C15)	1.7
Benzo(a)pyrene (C20)	0.4
Pesticides:	
Aldrin	(3.15)
DDT	0.001 (0.05)
Dieldrin	0.002 (0.85)
Endosulfan	(0.003)
Endrin	0.002
Lindane	(0.08)

* *Threshold levels sourced from measured data specifically relevant to the WIO region are provided in brackets*

Toxic substances (sediment)

CONSTITUENT	RECOMMENDED EQT	PROBABLE EFFECT CONCENTRATION
TRACE METALS (mg/kg dry weight)		
Antimony	-	-
Arsenic	7.24	41.6
Cadmium	0.68	4.21
Chromium	52.3	160
Copper	18.7	108
Lead	30.2	112
Mercury	0.13	0.7
Nickel	15.9	42.8
Silver	0.73	1.77
Tin as Tributyltin-Sn	0.005	0.07
Zinc	124	271
TOXIC ORGANIC COMPOUNDS (µg/kg dry weight normalized to 1% organic carbon)		
Total PAHs	1684	16770
Low Molecular PAHs	312	1442
Acenaphthene	6.71	88.9
Acenaphthalene	44	640

CONSTITUENT	RECOMMENDED EQT	PROBABLE EFFECT CONCENTRATION
Anthracene	46.9	245
Fluorene	21.2	144
2-methyl naphthalene	-	-
Naphthalene	34.6	391
Phenanthrene	86.7	544
High Molecular Weight PAHs	655	6676
Benzo(a)anthracene	74.8	693
Benzo(a) pyrene	88.8	763
Dibenzo(a,h)anthracene	6.22	135
Chrysene	108	846
Fluoranthene	113	1494
Pyrene	153	1398
Toxaphene	-	-
Total DDT	3.89	51.7
p p DDE	2.2	27
Chlordane	2.26	4.79
Dieldrin	0.72	4.3
Total PCBs	21.6	189

Recreational Use

EQTs for the Recreational use are proposed for following constituent types:

- Aesthetics
- Microbiological indicators, as related to protection of human health
- Toxic substances, as related to protection of human health.

Aesthetics

The EQTs related to the aesthetic quality of coastal area, would be similar to that described for Objectionable matter as per EQTs for the Protection of coastal aquatic ecosystems (refer to table above).

Microbiological indicators

Instead of using 'single' target values to classify recreational areas (beaches) either 'safe' or 'unsafe', a range of target values (using Enterococci as the preferred indicator organism for marine waters) is proposed corresponding to different risk levels:

RISK CATEGORY	RECOMMENDED EQT	
	95th PERCENTILE OF ENTEROCOCCI per 100 ml (estimated *E. coli* equivalent)	ESTIMATED RISK PER EXPOSURE
A	<40 (<100)	<1% gastrointestinal (GI) illness risk <0.3% acute febrile respiratory (AFRI) risk
B	40 – 200 (100 - 500)	1–5% GI illness risk; 0.3–1.9% AFRI risk
C	201 – 500 (501-1250)	5–10% GI illness risk; 1.9–3.9% AFRI risk
D	> 500 (>1250)	>10% GI illness risk; >3.9% AFRI risk

Acknowledging the potential for microbial indicator survival and regrowth in tropical coastal systems, it may be necessary to include an additional indicator organism, *Clostridium perfringens*, in tropical area where there are uncertainties whether impacts are linked to human faecal contamination. The recommended EQTfor *C. perfringens* is a geometric mean of equal or less than 5 counts/100 ml.

Toxic Substances

With reference to toxic substances, it is proposed that appropriate Drinking water quality guidelines be consulted to make preliminary risk assessments in areas where these substances are expected to be present at levels that pose a risk to human health.

Marine Aquaculture

EQTs related to marine aquaculture activities are proposed for the following aspects:

- Protection of the health of aquatic organisms cultured and harvested for seafood
- Protection of the health of human consumers
- Tainting substances affecting the quality of seafood products.

Protection of Aquatic Organism Health

With reference to the protection of aquatic organisms cultured and harvested for seafood, it is proposed that the EQTs proposed for the Protection of coastal aquatic ecosystems be applied. This simplified approach is also applied internationally, particularly where activities rely on natural stocks.

Protection of Health of Human Consumers

With reference to the protection of human consumers, it is proposed that the allowable limits of toxic substances and human pathogens be controlled through legislation, as is the norm internationally. Where such standards are currently not in place, it is recommended that the relevant Government Departments be approached to initiate such legislation.

In terms of shellfish growing areas, it is proposed that EQTs, as listed below, be applied, in conjunction with a sanitary survey, as well as acceptable quality of shellfish meat (as per the above):

INDICATOR	RECOMMENDED EQT
Faecal coliform	Median concentrations should not exceed 14 Most Probable Number (MPN) per 100 ml with not more than 10% of the samples exceeding 43 MPN per 100 ml for a 5-tube, 3-dilution method.

Tainting Substances *(estimated threshold concentrations for tainting substances for consideration in the WIO region)*

TAINTING SUBSTANCE	THRESHOLD CONCENTRATIONS ABOVE WHICH TAINTING IS LIKELY TO OCCUR (mg/ℓ)
Acenaphthene	0.02
Acetophenone	0.5
Acrylonitrile	18
Copper	1
m-cresol	0.2
o-cresol	0.4
p-cresol	0.12
Cresylic acids (meta, para)	0.2
Chlorobenzene	-
n-butylmercaptan	0.06
o-sec. butylphenol	0.3
p-tert. butylphenol	0.03
2-chlorophenol	0.001
3-chlorophenol	0.001
3-chlorophenol	0.001
o-chlorophenol	0.001
p-chlorophenol	0.01
2,3-dinitrophenol	0.08
2,4,6-trinitrophenol	0.002

TAINTING SUBSTANCE	THRESHOLD CONCENTRATIONS ABOVE WHICH TAINTING IS LIKELY TO OCCUR (mg/ℓ)
2,3 dichlorophenol	0.00004
2,4-dichlorophenol	0.001
2,5-dichlorophenol	0.023
2,6-dichlorophenol	0.035
3,4-dichlorophenol	0.0003
2-methyl-4-chlorophenol	0.75
2-methyl-6-cholorophenol	0.003
3-methyl-4-chlorophenol	0.02 – 3
o-phenylphenol	1
Pentachlorophenol	0.03
Phenol	1
2,3,4,6-tetrachlorophenol	0.001
2,4,5-trichlorophenol	0.001
2,3,5-trichlorophenol	0.001
2,4,6-trichlorophenol	0.003
2,4-dimethylphenol	0.4
Dimethylamine	7
Diphenyloxide	0.05
B,B-dichlorodiethyl ether	0.09
o-dichlorobenzene	< 0.25
p-dichlorobenzene	0.25
Ethylbenzene	0.25
Momochlorobenzene	0.02
Ethanethiol	0.24
Ethylacrylate	0.6
Formaldehyde	95
Gasoline/Petrol	0.005
Guaicol	0.082
Kerosene	0.1
Kerosene plus kaolin	1
Hexachlorocyclopentadiene	0.001
Isopropylbenzene	0.25
Naphtha	0.1
Naphthalene	1
Naphthol	0.5
2-Naphthol	0.3
Nitrobenzene	0.03
a-methylstyrene	0.25
Oil, emulsifiable	15
Pyridine	5
Pyrocatechol	0.8
Pyrogallol	0.5
Quinoline	0.5
p-quinone	0.5
Styrene	0.25
Toluene	0.25
Outboard motor fuel as exhaust	0.5
Zinc	5

Industrial Use

It is proposed that the following activities be recognised as industrial uses of coastal waters, which may have specific requirements in term of water and sediment quality:

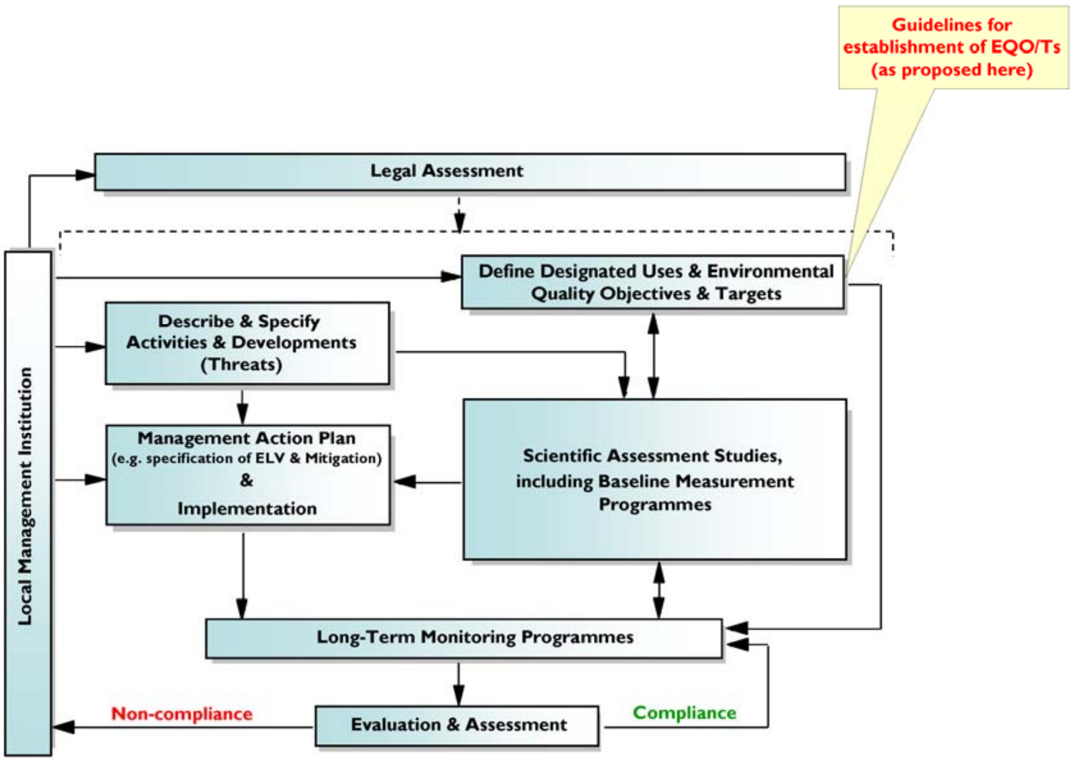
- Seafood processing industries
- Salt production
- Desalination
- Aquariums and oceanariums
- Harbours and ports
- Cooling water intake
- Ballast water intake
- Coastal mining
- Make-up water for offshore marine outfalls
- Exploration drilling
- Scaling and scrubbing.

However, as a result of the large variation in quality requirements of these activities, mainly driven by specific processes and technologies, it is further proposed that EQTs be derived site-specifically, based on specific requirements of industries in the area.

Proposed Implementation Practice

In order to effectively manage coastal systems so as to remain suitable for designated use, measurable targets should be set for the different parameters defining the integrity of these systems. In terms of water and sediment quality, generic EQO/Ts – as proposed here - are developed to provide guidance to local managers and governing authorities in setting site-specific EQO/Ts, focusing on specific issues of relevance and potential concern in their area. Thus, generic EQO/Ts should be considered as a first phase approach in setting local EQO/Ts and depending on site-specific conditions (ecological, social and/or economic) these may have to be refined and or adapted.

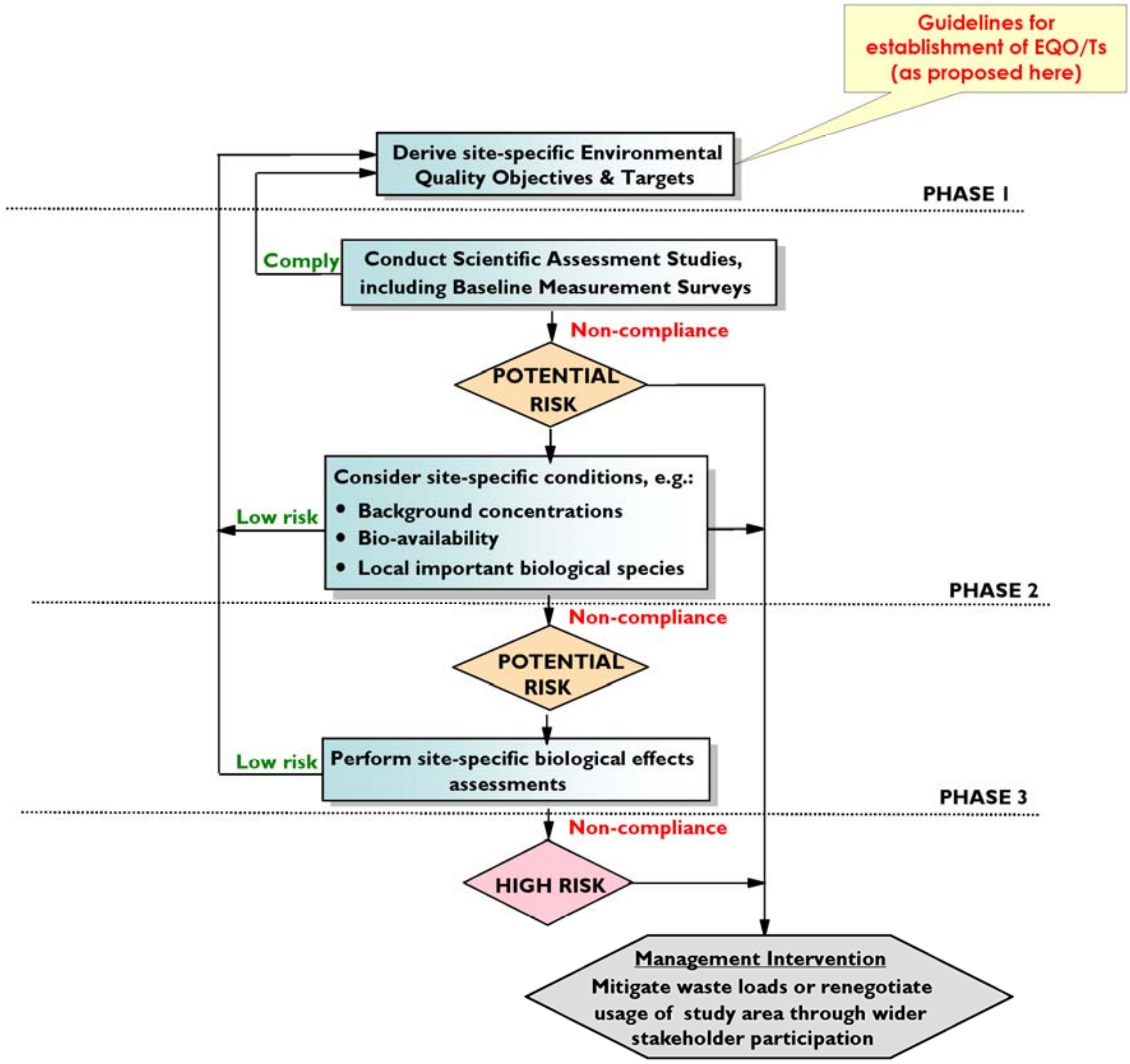
The development and implementation of EQO/Ts should not occur in an *ad hoc* manner, but rather form part of a proper management strategy or framework as proposed below:



Within the Management Framework proposed above, EQOs for coastal areas need to be determined in consultation with relevant stakeholders. Once these have been established, site specific, measurable target values need to be derived based on the generice EQTs provided as part of this document. The proposed process whereby site specific EQO/Ts can be derived for the coastal zone in the WIO region are provided in the following sections for different uses.

Protection of Coastal Aquatic Ecosystems

Following international best practice, it is recommended that generic EQO/Ts for the protection of coastal aquatic ecosystems in the WIO region be applied as benchmarks, using a risk assessment or phased approach to refine such targets as illustrated below:



Recreational Use

It is recommended that the WIO region adopt a beach classification system, rather than the traditional approach of classifying recreational waters as either safe or unsafe (based on a percentage compliance with a faecal indicator organism).

With reference to water quality, the classification should be based on both a sanitary survey, as well routine microbiological surveys. The classification rating should be re-evaluated on an annual basis. In this regard, it is recommended that a classification system be adopted as illustrated below:

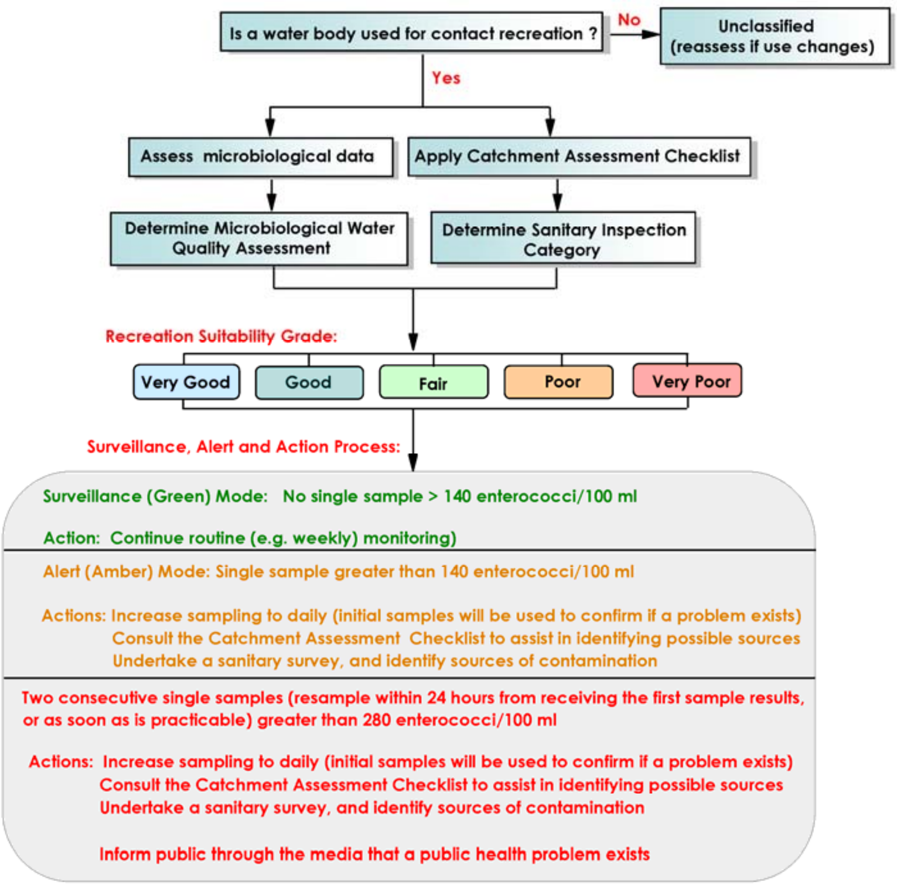
		MICROBIOLOGICAL QUALITY ASSESSMENT CATEGORY (95TH PERCENTILE ENTEROCOCCI/100 ml – refer to Table 5.7)				
		A (<40)	**B (41-200)**	**C (201-500)**	**D (>500)**	**Exceptional circumstances[3]**
SANITARY INSPECTION CATEGORY	**Very Low**	Very good	Very good	Follow-up[1]	Follow-up[1]	Action required
	Low	Very Good	Good	Fair	Follow-up[1]	
	Moderate	Good[2]	Good	Fair	Poor	
	High	Good[2]	Fair[2]	Poor	Very poor	
	Very high	Follow-up[2]	Fair[2]	Poor	Very poor	
	Exceptional circumstances[3]	Action required				

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 and a grading would not apply until the episode has abated.*

In addition to a classification system, it is also recommended that a day-to-day management system be adopted:



Marine Aquaculture

It is recommended that a classification system for shellfish growing areas be adopted for the WIO region. Major export markets may eventually dictate the approach that will have to be followed by countries in the region. To address this issue it is recommended that a regional task team (e.g. through the WIO Mariculture Forum) be convened to decide on the final approach for the classification of shellfish growing areas in the WIO region.

As an interim measure for the WIO region, unless dictated otherwise, it is recommended that the National Shellfish Sanitation Program (NSSP) approach, applied by the United States Food and Drug Administration, be followed for the classification of shellfish growing areas in the WIO region.This approach is considered to be the most practical in terms of implementation, as it classifies areas on the basis of the condition of the waters in the growing area, rather than, for example, the European Union's approach, which classifies areas on the basis of levels of contaminants in shellfish flesh. The NSSP's approach is also the most widely used internationally and also 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 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 for Sanitary Surveys that consist of:

- Identification and evaluation of all potential and actual pollution sources (Shoreline Survey) — this survey describes the studies required 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 survey refers to the measurement of faecal indicator levels in the growing areas.

Resurveys are conducted regularly to determine if sanitary conditions have undergone significant change. The proposed classification system for shellfish growing areas in the WIO region is provided below.

Recommended (interim) classification system of shellfish growing areas

CLASS	DESCRIPTION
Approved	Approved areas need to be free from pollution and shellfish from such areas are suitable for direct human consumption of raw shellfish.
Conditionally approved/restricted	Where areas are subjected to limited, intermittent pollution caused by discharges from wastewater treatment facilities, seasonal populations, non-point source pollution, or boating activity they can be classified as conditionally approved or conditionally restricted. However, it must be shown that the shellfish harvesting area will be open for the purposes of harvesting shellfish for a reasonable period of time and the factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' for harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Restricted areas are subject to a limited degree of pollution. However, the level of faecal pollution, human pathogens and toxic or deleterious substances is such that shellfish can be made fit for human consumption by either relaying or depuration.
Prohibited	An area is classified as 'Prohibited' for shellfish harvesting if no comprehensive survey has been conducted or where a survey finds that the area is: • adjacent to a sewage treatment plant outfall or other point source outfall with public health significance • contaminated by (an) unpredictable pollution source(s) • contaminated with faecal waste so that the shellfish may be vectors for disease micro-

CLASS	DESCRIPTION
	organisms • affected by algae which contain biotoxin(s) sufficient to cause a public health risk • contaminated with poisonous or deleterious substances whereby the quality of shellfish may be affected. NOTE: Where an event such as a flood, storm or marine biotoxin outbreak occurs in either 'Approved' or 'Restricted' areas, these can also be classified as temporarily 'Prohibited' areas.

Requirements associated with each class in the recommended (interim) classification system

CLASS	REQUIREMENTS
Approved	A sanitation survey must be completed according to specification to be reviewed annually. The area shall not be contaminated with faecal coliform (as listed) and shall not contain pathogens or hazardous concentrations of toxic substances or marine biotoxins (an approved shellfish growing area may be temporarily made a prohibited area, e.g. when a flood, storm or marine biotoxin event occurs). Evidence of potential pollution sources, such as sewage lift station overflows, direct sewage discharges, septic tank seepage, etc., is sufficient to exclude the growing waters from the approved category. Faecal coliform median (or geometric mean MPN or MF (mTEC) of the water sample results shall not exceed 14 per 100 ml and the estimated 90th percentile shall not exceed an MPN or MF (mTEC) of: (a) 43 MPN per 100 ml for a five tube decimal dilution test; (b) 49 MPN per 100 ml for a three-tube decimal dilution test; or (c) 31 CFU per 100 ml for a MF (mTEC) test. Total coliform geometric mean of the water sample results for each sampling station shall not exceed 70 MPN per 100 ml and the estimated 90th percentile shall not exceed an MPN of: (a) 230 MPN per 100 ml for a 5-tube, decimal dilution test; (b) 330 MPN per 100 ml for a 3-tube, decimal dilution test.
Conditionally approved/restricted	Factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. A management plan must be developed for every conditionally approved/restricted area. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' for harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Faecal coliform median or geometric mean MPN of the water sample results shall not exceed 88 per 100 ml and the estimated 90th percentile shall not exceed a MPN of: (a) 260 MPN per 100 ml for a five tube decimal dilution test; or (b) 300 MPN per 100 ml for a three-tube decimal dilution test. Total coliform geometric mean MPN of the water sample results for each station shall not exceed 700 per 100 ml and not more than 10% of the samples shall exceed an MPN of: (a) 2300 MPN per 100 ml for a 5-tube, decimal dilution test; or (b) 3300 MPN per 100 ml for a 3-tube, decimal dilution test; or (c) 1386 MPN per 100 ml for a 12-tube, single dilution test.
Prohibited area	No requirements specified

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ACRONYMS, SYMBOLS AND ABBREVIATIONS

ACR	Acute-Chronic Ratio
ANZECC	Australia and New Zealand Environment and Conservation Council
ANZFA	Australia New Zealand Food Authority
AQUIRE	Aquatic Toxicity Information Retrieval Database
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASSAC	Australian Shellfish Sanitation Advisory Committee
AWRC	Australian Water Resources Council
BCF	Bio-Concentration Factor
BCLME	Benguela Current Large Marine Ecosystem
BOD	Biochemical Oxygen Demand
CCC	Criteria Continuous Concentration
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CEC	Council of European Community
CF	Conversion Factor
CMC	Criteria Maximum Concentration
COD	Chemical Oxygen Demand
Cordio	Coral Reef Degradation in the Indian Ocean
CWA	Clean Water Act, United States
DWAF	Department of Water Affairs and Forestry (South Africa)
EC	European Community
EC_{50}	Effective concentration the dosage at which the desired response is present for 50 % of the population
ELV	Effluent limit value
EQO	Environmental Quality Objective
EQT	Environmental Quality Target
EqP	Equilibrium Partitioning
ERL	Effect Range Low
ERM	Effect Range Median
FAO	Food and Agriculture Organisation of the United Nations
FEE	Foundation for Environmental Education
GEF	Global Environmental Facility
GPA/LBA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
IUCN	The World Conservation Union
IRIS	Integrated Risk Information System
LC_{50}	Concentration that is lethal to 50% of the test organisms
LOEC	Lowest Observable Effects Concentration
MAF	Ministry of Agriculture and Fisheries (New Zealand)
MF	Membrane Filtration
MPN	Most Probable Number
MATC	Maximum Acceptable Toxicant Concentration
MoU	Memorandum of Understanding
MHSPE	Ministry for Housing, Spatial Planning and Environment, Netherlands

NHMRC	National Health and Medical Research Council (Australia)
NEPAD	New Partnership for Africa's Development
NOAA	National Oceanic and Atmospheric Administration (United States)
NOEC	No Observable Effect Concentration
NSSP	National Shellfish Sanitation Program
NZME	New Zealand Ministry of Environment
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyl
PEL	Probable Effect Level
PMU	Project Management Unit
POPs	Persistent Organic Pollutants
OECD	Organisation for Economic Co-Operation and Development
RSA	Republic of South Africa
SQG	Sediment Quality Guideline
SSM	Single sample maximum
TEL	Threshold Effect Level
UNEP	United Nations Environmental Program
US-EPA	United States Environmental Protection Agency
US-FDA	United States Food and Drug Administration
WIO-Lab	Addressing Land-based Activities in the West Indian Ocean
WQG	Water Quality Guideline
WHO	World Health Organisation
WRc	Water Research Centre
WSSD	World Summit for Sustainable Development
WWF	World Wildlife fund

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- Shamilla Pillay (CSIR, Durban, South Africa)
- Anisha Rajkumar (CSIR, Durban, South Africa)

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INTRODUCTION

General Background

The Project "Addressing Land-based Activities in the Western Indian Ocean" (WIO-Lab) is a deliberate and conscious effort of the people of the Western Indian Ocean (WIO) region (including Kenya, Tanzania, Mozambique, South Africa, Madagascar, Seychelles, Comoros and Mauritius) taken in response to a call from the 1st Meeting of the Contracting Parties to the Nairobi Convention in March 1997. The project is a direct follow-on to the 2002 World Summit for Sustainable Development (WSSD) and the related Johannesburg Plan of Implementation, which called for advanced implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA/LBA).

The WIO-Lab project makes an important contribution to the implementation of the Action Plan for the Environment Initiative of the New Partnership for Africa's Development (NEPAD) and builds upon the UNEP/GEF supported African Process for the Development and Protection of the Marine and Coastal Environment. The project was officially launched in Madagascar in July 2004 during the 4th Meeting of the Contracting Parties to the Nairobi Convention. During the course of its implementation, the project will address many of the threats identified above. The Project is implemented by the United Nations Environment Programme (UNEP), and is financed by the Global Environment Facility (GEF) and the Norwegian Government.

The WIO-Lab Project is aimed at addressing some of the major environmental problems and issues related to the degradation of the marine and coastal environment due to land-based activities in the region and has three main objectives:

- Reduce stress to the ecosystem by improving water and sediment quality
- Strengthen regional legal basis for preventing land-based sources of pollution
- Develop regional capacity and strengthen institutions for sustainable, less polluting development.

As part of the strategy of fulfilling the first and second objectives of the WIO-LaB Project, Protocols for the establishment of Environmental Quality Objectives and Targets (EQO/Ts) applicable to the coastal zone had to be developed for the region. Such EQO/Ts aim to protect the biodiversity of marine habitats (or ecotones) in coastal areas of the WIO region, and ensure fitness for use (e.g. recreational use).

An Environmental Quality Objective (EQO) is a broad, narrative statement describing the desired quality levels (or goals) for a particular environment, in this case the coastal zone. Environmental Quality Targts (EQTs) are defined as numerical or narrative target values for water and sediment quality parameters in receiving coastal environments that will ensure compliance with EQOs.

The WIO-Lab Project Management Unit (PMU) approached the CSIR to assist in the formulation of guidelines for the establishment of EQO/Ts for the coastal zone of the WIO. The CSIR has expertise on such matters. I 2006 they were commissioned to develop a common set of water and sediment quality guidelines and implementation protocols for the coastal zone of the Benguela Current Large Marine Ecosystem (BCLME) (including Angola, Namibia and South Africa) (Taljaard, 2006). Much of the learning gathered during that project was used here to formulate comparable, but appropriate EQO/Ts for application in the WIO region.

In accomplishing the proposed project, the CSIR collaborated with the WIO-LaB PMU and in particular it's Regional Working Group on Water, Sediment and Biota Quality Assessment and Monitoring (RWG). The CSIR also liaised with other key stakeholders in the region, such as WWF, IUCN and Cordio, on aspects related to the characterization and determination of pollution thresholds in different ecotones.

Scope of Work

Based on the Terms of Reference provided to the CSIR by the WIO-Lab PMU, the scope of work included the following key components:

- Based on a review of available literature, provide a brief description of the characteristics and general issues with regard to the main ecotones in the WIO region and assess their thresholds with regard to different pollutants

  The term "ecotone" in the traditional sense is defined as a transitional area between two adjacent ecological communities. For the purpose of this assignment, this definition is further refined to refer to an ecologically distinct zone which shows some degree of ecological homogeneity. In defining specific ecotones within the WIO region, we suggest adopting a hierarchical approach to deal with the main structural elements of estuarine, intertidal and subtidal ecosystem components. In the WIO region these are considered to include seagrass beds, mangroves, intertidal coastal zones (sandy beaches and rocky shores) and coral reefs.

- Propose a strategy for the development of EQO/Ts, as well as recommended, generic-type EQO/Ts for the coastal zone of WIO region, based on:
  - An international review
  - Status reports (related to land-based activities) prepared by the different countries in the WIO region
  - Regional Pollution Status Synthesis Report
  - Outcome of the ecotone assessment (see above).

- Prepare a document on *Guidelines for the establishment of environmental quality objectives and targets for the coastal zone of the Western Indian Ocean region* - this document.

As part of the project, a draft Annex on EQO/Ts for incorporation in the new Land-based Activity (LBA) Protocol of the Nairobi Convention was also prepared.

The above was developed in consultation with the Regional Working Group on water, sediment and biota quality assessment and monitoring established by the WIO-LaB Project.

Environmental Quality Objectives and Targets in Perspective

The ultimate goal in the management of coastal systems is to keep the resource suitable for all designated uses – both existing and future uses (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning).

Uses of coastal ecosystems are typically divided into four broad categories (ANZECC, 2000, RSA, DWAF, 1995, Mauritius, 2006a) namely:

- Protection of biodiversity and ecosystem functioning of the natural environment (conservation areas)
- Recreational use (including tourism)
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial uses (e.g. cooling water intake and water for seafood processing).

In many instances sustainable use of coastal ecosystems relies on these systems remaining functional. In turn, the integrity of coastal ecosystems depends on a number of factors, including:

- Stream flows (referring to river and groundwater inflows)

- Physical habitat (referring to water circulation processes, sediment type and climatic conditions)
- **Water and sediment quality** (referring to the biogeochemical status)
- Availability of suitable migration or recruitment routes
- Food web integrity.

Within the WIO region, as in many other coastal regions, the integrity of coastal ecosystems is increasingly degraded and threatened by an array of natural phenomena (e.g. floods, storms, cyclones) as well as anthropogenic (human) activities. The latter may include activities occurring at sea (e.g. offshore oil exploration and ship traffic) or land-based activities. Land-based activities that are of particular concern in the WIO include:

- Modification of stream flows, e.g. through dams an 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
- Inappropriate disposal of waste (pollution).

In order to effectively manage coastal systems to remain suitable for designated use, objectives and measurable targets should be set for the different parameters defining the integrity of these systems, taking into account the requirements of designated uses, as well as potential threats.

In terms of setting such targets **for water and sediment quality**, Environmental Quality Objectives (EQOs), defined as broad, narrative statements describing the desired quality levels (or goals) for a particular environment - in this case geographically defined units in the coastal zone - need to be developed. From a management perspective, these goals need to be translated into measurable target values or Environmental Quality Targets (EQTs). The guidelines – as proposed here - aim at providing local managers and governing authorities with the information to set site specific EQOs and EQTs for water and sediment quality in geographically defined units, taking into account specific issues of relevance and potential concerns in their area. In other words countries need not specify and monitor for all the parameters listed here, but should be guided by the designated uses (and their quality requirements) as well as the pollution sources (and associated pollutants) within a specific areas.

As part of the guidelines, generic EQO/Ts for application in the WIO region are also recommended. Generic EQTs - usually developed on the regional or national scale - are presented either as numerical targets or descriptive statements specifying the quality requirements of a coastal ecosystem (biodiversity) or designated use (e.g. recreation). To accommodate natural variability encountered in coastal ecosystems, but still minimize risk of impact, these EQTs need to be generic, but fairly conservative. Generic EQO/Ts - as recommended here - should be considered as a first phase approach in setting site-specific EQO/Ts, and depending on site-specific conditions (ecological, social and/or economic) these may have to be refined. In other words, countries should be guided by the generic EQO/Ts to prepare more specific national or local EQO/Ts.

As a result of the above, generic EQTs generally do not automatically become legally binding, although these could be used to develop legally binding standards (e.g. emission limit values [ELV] for wastewater discharges) (Ragas et al, 2005). Also, once generic EQTs have been verified and refined to accommodate site-specific needs these can become legally binding standards in themselves (e.g. those applying to coastal waters used for marine aquaculture activities).

NOTE: Generic versus site-specific EQO/Ts

Site-specific EQO/Ts are quality objectives and targets agreed among stakeholders, or set by local jurisdictions. They can be based on generic-type or recommended EQO/Ts (as proposed here), but may be modified by other inputs, such as social, cultural, economic or political constraints within a particular coastal region. The relative importance placed on the recommended EQO/Ts and these other, potentially very important but less tangible, considerations would be site-specific, and therefore would be determined on a case by case basis. Site-specific EQO/Ts are therefore established at a local level to protect and support the designated uses, and against them performance can be measured. Site-specific EQO/Ts may be adopted into legislation to become legally-binding standards.

It is very important to realise that the existence of generic EQO/Ts does not imply that environmental quality should or could automatically be degraded to those levels. A continuous effort should be made to ensure that coastal resources 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 minimisation
- Recycling and re-use
- Best available or best attainable technologies.

NOTE: Difference between Effluent Standards and EQO/Ts

The so-called Uniform Effluent Standard Approach has been followed extensively throughout the world to manage and control land-derived wastewater discharges. Uniform effluent standards or effluent limit values (ELVs) are usually industry specific and legally enforceable. Limits specify minimum concentrations or loads to which wastewater discharges must comply prior to discharging into a water resource. The ELVs, in turn, can be derived in several ways, including the Technology-based Approach and the EQO-based Approach (Ragas, et al 2005).

Although the Technology-based Approach (i.e. deriving wastewater limits based on 'Best available technology', 'Best practicable means' or 'Best available technique not encompassing excessive costs') has great value in terms of enforcing principles like 'Pollution prevention' and 'Waste minimisation' (World Bank Group, 2004), it has shortcoming when used in isolation. However, wastewater standards derived in this manner do not necessarily take into account the assimilative capacity of the receiving water environment (particularly with regard to physico-chemical variables, nutrients and other naturally occurring chemicals such as trace metals) or cumulative and synergistic effects of multiple waste discharges. Also, when such ELVs are applied to a discharge into calm, near-stagnant water bodies they could be insufficient to adequately protect the coastal environment and its uses while, when applied to a discharge into dynamic, well-flushed areas, such limits could be too stringent.

To address these shortfalls, many countries have adopted the Receiving Water Quality Objectives Approach (or EQO-based Approach) where, in short, the physical, chemical and biological processes and uses of a particular (receiving) coastal area dictate the 'limits of discharge'. This approach led to the development of generic EQO/Ts so as to assist local managers and governing authorities in setting site-specific environmental quality targets for a particular area. The EQO-based Approach has multiple uses, one of which is to set EQO-based wastewater standards (another important application is to set long-term monitoring objectives).

The EOQ-based Approach does not exclude the Technology-based Approach to set wastewater standards, but should be seen as complimentary. For example, technology-based standards are still very important in terms of controlling the discharge of hazardous chemicals that bio-accumulate in the environment with severe adverse effects on coastal ecosystems. Here the European Union is an example; in addition to managing coastal waters based on EQO-approach, they also enforce technology-based effluent standards for a number of hazardous chemicals, referred to as priority substances (CEC, 2000).

The scope of this project is to develop guidelines for the establishment of EQO/Ts — for the coastal zone of the WIO region, also recommending a set of generic EQO/Ts. It is not within the scope of the project to further elaborate on setting of effluent standards (or ELVs), although as discussed above, the EQO-based Approach can be applied to set such standards within the region.

Outline of Report

This introductory chapter is followed by:

- Chapter 1, providing and overview on the existing situation in the WIO region, identifying priority categories of water and sediment quality parameters, reviewing existing EQO/Ts (also referred to as environmental quality guidelines) applied by countries in the region, as well as any existing implementation practices

- Chapter 2, providing a review of international approaches to the development of EQO/Ts as well as international implementation practices

- Chapter 3, providing an overview of the main coastal ecotones in the WIO region, major pressures and their thresholds for pollutants, in particular the priority categories of water and sediment parameters

- Chapter 4, providing a proposed strategy (approach and methodology) for the development of EQO/Ts for water and sediment quality in the coastal zone of the WIO region

- Chapter 5, proposing a common set of generic EQO/T for the coastal zone of the WIO region, in particular for:
    - Protection of the coastal aquatic ecosystems
    - Recreational use
    - Marine aquaculture
    - Industrial use of coastal waters.

- Chapter 6, proposing a framework for successful implementation of EQO/Ts in the WIO region.

Appendices to this document include:

- Appendix I: Summary of International Marine Water Quality Guidelines (or Targets) for the Protection of Marine (coastal) Aquatic Ecosystems

- Appendix II: Summary of International Sediment Quality Guidelines (or Targets) for the Protection of Marine (coastal) Aquatic Ecosystems

- Appendix III: Summary of International Marine Water Quality Guidelines (or Targets) for Marine Aquaculture.

1. REVIEW OF EXISTING SITUATION IN WIO REGION

1.1 Identification of Priority Categories of Parameters

Degradation of the coastal (and marine) environment continues globally. The major threats to the ecological integrity and uses of coastal systems result from human activities in both coastal and inland areas. For example, some 80% of the pollution load in the oceans originates from land-based sources, including municipal, industrial and agricultural run-off, as well as atmospheric deposition. In addition, coastal habitats are increasingly being altered and destroyed, constituting the most widespread, frequently irreversible, human impact on the coastal zone (UNEP/GPA, 2006).

Recognizing the growing and serious threat from land-based activities to both human health and well-being and the integrity of coastal ecosystems, the Washington Declaration and the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) were adopted by 108 governments and the European Union in 1995 (UNEP/GPA, 2006). The GPA is mainly concerned with nine source categories:

- Sewage (introducing nutrients, organic matter, suspended solids and microbiological contaminants)
- Nutrients
- Heavy metals
- Oils (Hydrocarbons)
- Marine Litter
- Persistent Organic Pollutants (POPs)
- Radioactive substances
- Sediment mobilization (introducing turbidity and causing siltation)
- Physical Alteration and Destruction of Habitats.

Although most of these source categories arise from land-based pollution, it is important to note that, for example modification of river flows, over-exploitation of resources and infrastructure development (e.g. clearing of coastal areas for housing and agriculture) also contribute, in particular to the category: *Physical Alteration and Destruction of Habitats.*

The major sources of land-based pollution in the WIO region are associated with anthropogenic activities whose social and economic drivers are not controlled or adequately managed by the responsible authorities (UNEP/GPA, 2006). Important social and economic drivers in the WIO region are (as documented in *National Pollution Status Reports* of the individual countries):

- Poverty and inequality
- Population growth
- Urbanisation
- Tourism
- Industrialisation.

In the region major sources of pollution originating from land include (as documented in *National Pollution Status Reports* of the individual countries):

- Municipal waste (e.g. domestic sewage, contaminated urban storm water and solid waste)
- Tourist developments
- Agricultural activities
- Industrial activities (including harbour and ports)
- Mineral exploitation
- Atmospheric emissions
- Climate change.

The lack of proper sewage and storm water reticulation systems, as well as treatment facilities for municipal liquid and solid waste are identified as major causes of coastal pollution in urban centers within the WIO region. Population growth and rural-urban migration result in large, rapidly expanding coastal urban populations that produce large quantities of domestic sewage. In addition, changes in lifestyles, characterised by high consumption rates, result in increased generation of solid waste. Many coastal cities still rely on septic tank or pit latrine systems, that when overloaded, cause severe pollution of groundwater resources. Furthermore, impermeable urban surfaces generate large volumes of contaminated storm water runoff. Priority parameter categories associated with municipal waste include:

- Organic matter (or biochemical oxygen demand - BOD)
- Suspended solids
- (Low) salinity (e.g. large quantities of storm water can reduce salinity in coastal waters)
- Nutrients (e.g. nitrogen and phosphorous)
- Microbiological contaminants
- Litter (or objectionable matter).

Within the WIO region rourism form an integral part of countries' economies, if not the most important (e.g. Seychelles). Although the largest impacts of tourist developments and associated activities are usually reflected in the category: *Physical destruction and alterations of coastal habitats*, these developments also pose pollution risks. They generated large quantities of liquid (sewage) and solid waste. Many of tourist resorts also house large golf courses that use large quantities of fertilizers which could leach into sheltered coastal areas posing eutrophication risks. The discharge of chlorinated swimming pool water into coastal areas is also seen as a growing problem - although individually small, their cumulative impacts can be considerable (UNEP, 1998) (e.g. bleaching of coral and lower salinities). Priority parameter categories associated with tourism development include:

- Organic matter (or BOD)
- Suspended solids
- (Low) salinity
- Nutrients (e.g. nitrogen and phosphorous)
- Microbiological contaminants
- Litter (or objectionable matter)
- Chlorine (discharging of chlorinated swimming pool water).

In many of the WIO countries agriculture is the most significant economic activity, both as a foreign exchange earner and the mainstay of rural farmers and inhabitants. Commercial farming is an important activity in most of the river drainage basins and contributes heavily to land degradation that results in increasing soil erosion due to inappropriate farming practices. Agriculture, in particular commercial farming, contributes to pesticide residues and fertilizers, which leach into rivers and ultimately reach coastal areas (UNEP/GPA, 2006). Priority parameter categories associated with agricultural activities include:

- Suspended solids or turbidity (associated with soil erosion)
- Nutrients (e.g. nitrogen and phosphorous)
- Persistent organic pollutants (POPs).

Industrial activities in the WIO region are mainly concentrated in the large urban centers and are dominated by food and beverage processing and textile manufacturing, and to a lesser extent chemical manufacturing, oil refineries and cement factories. Harbour and port activities are also major sources of land-based (industrial) pollution in the region. Priority parameter categories associated with industrial waste are obviously strongly dependent on the type of industry, but generally include:

- Organic matter (e.g. food processing industries)
- Suspended solids
- Trace metals (e.g. chemical manufacturing and oil refineries)
- Oils (Hydrocarbons) (e.g. oil refineries and harbours and ports).

Mineral exploitation activities in the WIO region include sand mining (for building purposes) and mining of precious and semi-precious stones (e.g. Madagascar). Although impacts of mineral exploration are primarily linked to the physical destruction and alteration of coastal habitats, these activities can also introduce pollution to coastal areas, in the form of increased suspended solid loads.

Atmospheric emissions in the WIO region are mainly associated with traffic, wood fuel burning (for domestic energy needs) and emissions from industries. Priority parameter categories associated with atmospheric emissions are obviously strongly dependent on the source, but parameters that pose risks to coastal pollution generally include:

- Suspended solids
- Nutrients (nitrogen from nitrous oxide)
- Trace metals
- Oils (Hydrocarbons).

Climate change, argued to be a cumulative effect of numerous land-based activities (e.g. deforestation, atmospheric emissions, etc), also poses a serious (pollution) risk to coastal ecosystems in the WIO region, where increases in temperatures are resulting in coral bleaching (UNEP/GPA, 2006).

A summary of the priority parameter categories associated with each of the major sources of land-based pollution in the WIO region, as discussed above, is provided in Table 1.1.

TABLE 1.1: Summary of priority parameter categories associated with each of the major sources of land-based pollution in the WIO region

PRIORITY PARAMETER CATEGORIES	MAJOR SOURCES OF LAND-BASED POLLUTION						
	Municipal waste	Tourist development	Agriculture	Industry	Mineral exploration	Atmospheric emissions	Climate change
Organic matter (BOD)	X	X		X			
Suspended solids/turbidity	X	X	X	X	X		
Salinity (reduction)	X	X					
Temperature				X			X
Nutrients	X	X	X			X	
Chlorine		X					
Trace metals				X		X	
POPs			X				
Oils (hydrocarbons)				X		X	
Litter (Objectionable matter)	X	X					
Microbiological contaminants	X	X					
Radio-active substances							

NOTE:

The marine waters off the coast of East Africa are one of the major transportation routes for oil from the Middle East to Europe and the Unites States of America (UNEP, 1998) As a result maritime transportation poses an equally serious threat to the coastal environment of WIO region, if not greater than some of the sources listed above. However these activities are not considered to be land-based and are therefore not discussed further here.

1.2 Existing Water and Sediment Quality Objectives and Targets

Only Mauritius and South Africa currently have official EQO/Ts pertaining to coastal waters, based on the information contained in the *National Pollution Status Reports*. These are briefly discussed below.

1.2.1 Mauritius

The *Guidelines on Coastal Water Quality* (Government Notice No 620 of 1999) form part of the secondary legislation issued under the Environmental Protection Act of 2002 (Republic of Mauritius, 2006a). These guidelines identify different categories for which coastal waters can be used, each with their own EQO/Ts:

- Category A: Conservation (distinguishing between coral communities and other natural areas)
- Category B: Recreation (distinguishing between primary and secondary contact recreation)
- Class C: Fisheries (distinguishing between harvesting of marine life and shellfish culture)
- Category D: Industrial uses and other remaining coastal area (note that is this context industrial uses refers to discharges from industries and not industry's use of coastal waters, e.g. cooling water intakes)

The approach and methodology used in the development of these EQO/Ts are not clear.

In addition to *Guidelines on Coastal Water Quality*, the Government of Mauritius also issued secondary legislation (or Regulations) under the Environmental Protection Act of 2002 on *Standards for effluent discharge into the Ocean* (Government Notice No 45 of 2003*)* (Republic of Mauritius, 2006a). Furthermore, effluent standards specifically pertaining to discharges from the sugar industry, namely the *Effluent Limitations for the Sugar Industry Regulations* (Government Notice No.34 of 1997) have also been issued under the Environmental Protection Act of 2002. From the available information it is not clear whether a Technology-based Approach and the EQO-based Approach (Ragas, et al 2005) was used to derive these ELVs,

A summary of the Mauritian EQTs for coastal waters specifically linked to conservation (protection of coastal aquatic ecosystems) and fisheries (marine aquaculture) is provided in Appendices I and III, respectively.

1.2.2 South Africa

The *South African Water Quality Guidelines for Coastal Marine Waters* were published by the country's Department of Water Affairs and Forestry in 1995, which at the time was (and currently still is), responsible for the management and control of land-based wastewater discharges to the marine (coastal) environment. The guidelines include recommended target values for the following use categories (RSA DWAF, 1995b):

- Natural environment (referring to the Protection of aquatic ecosystems)
- Recreational use
- Mariculture
- Industrial use.

The recommended EQTs for coastal waters specifically linked to the protection of the marine aquatic ecosystems, however, are still largely based on the initial set of values that were derived by an *ad hoc* working committee in 1984 (Lusher, 1984). In the belief that simplicity is more likely to succeed in practice, only those physico-chemical properties that have the most marked importance to marine communities were considered (Lusher, 1984). In the absence of any documented evidence of harmful effects of nutrients along the South African coast (at the time), narrative target values governing nutrient concentrations, rather than numerical levels, were proposed (Lusher, 1984). In the case of toxic substances (i.e. trace metals), the Maximum Allowable Toxicant Concentration (MATC) was selected as the guideline value, where a reasonable set of reliable chronic toxicity data were available from studies on marine organisms (chronic toxicity is defined as an observable toxic effect after exposure for an extended period of time equal to the lifespan of the organism or the span of more than one generation). Where data appeared unreliable, a more conservative level was selected, with guidance from available international guidelines (Lusher, 1984).

The South African water quality guidelines for coastal marine waters do not provide EQTs for sediments. Currently such EQTs are typically determined from site-specific field measurements and numerical modelling output. Other sediment quality targets include those of the country's Department of Environmental Affairs, which provide suggested levels of Annex I and Annex II substances under the London Convention (unpublished documentation from the Department of Environmental Affairs, Cape Town). Currently, these guidelines are particularly aimed at areas that require dredging (e.g. ports).

A summary of the existing South African EQTs for coastal waters linked to the protection of marine aquatic ecosystems and marine aquaculture is provided in Appendixes I-III. The Department of Environmental Affairs, however, is in the process of revising *South African Water Quality Guidelines for Coastal Marine Waters.*

1.3 Existing Implementation Practices

Countries in the WIO region attribute fragmented legislation as a key stumbling block, among others, to effective management of coastal ecosystems. This is also considered one of the main reasons for the lack of effective integrated coastal management programmes (including the implementation of EQO/Ts) in the region, together with constraints posed by limited (experienced) human and financial resources.

In its *White Paper on National Environment Policy*, Mauritius identified the absence of an integrated Coastal Zone Management (ICZM) Plan as an important issue that needs to be addressed in order to protect the island's coastal resources (Republic of Mauritius, 2006b). One of the objectives in the White Paper is therefore to promote sustainable use and development of the coastal zone through Integrated Coastal Zone Management targeting multiple objectives (e.g. tourism, fisheries, conservation). To this end the government is planning to establish a comprehensive ICZM framework for the planning of the coastal zone.

Although South Africa's legislation pertaining to these matter is also fragmented, the Department of Water Affairs and Forestry, in 2004, took the initiative to provide a best practice guide to disposal of land-derived waste and wastewater to the marine environment (under the National Water Act [36 of 1998] this Department is currently responsible for such activities, although this may change pending the outcome of a new National Environmental Management: Integrated Coastal Bill). In collaboration with other (national, provincial and local) government authorities, the *Operational Policy for the Disposal of Land-derived Waste and Water containing Waste to the Marine Environment of South Africa* was adopted (RSA DWAF 2004a-c).

In addition to stipulating a clear goal, the basic underpinning principle and a number of ground rules, the operational policy also includes a framework within which to implement an ecosystem-based coastal management progamme (including the implementation of EQO/Ts) (Figure 1.1). Detailed guidance on the implementation of this framework is also provided as part of a series of documents on the operational policy (RSA DWAF, 2004b).

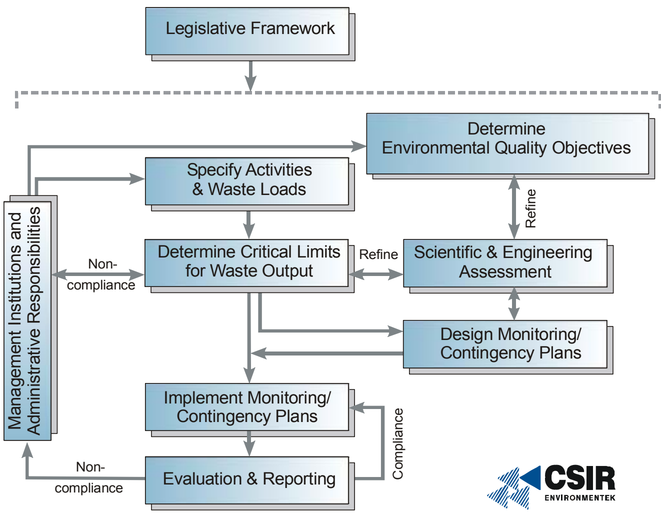


Figure 1.1: A management framework for the implementation of the Operational policy for the disposal of land-derived wastewater to the marine environment of South Africa (taken from RSA DWAF, 2004a)

2. REVIEW OF INTERNATIONAL ENVIRONMENTAL QUALITY OBJECTIVES AND TARGETS FOR COASTAL AREAS

For the purposes of this project, EQO/Ts for coastal water and sediment quality from the following countries and organizations, considered to be the global leaders in this regard, were reviewed:

- Australia and New Zealand
- United States of America
- European Community
- Canada
- World Health Organisation.

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).

2.1 Protection of Coastal Aquatic Ecosystems: Water

EQO/Ts for coastal waters (or water quality guidelines) specifically linked to the protection of coastal aquatic ecosystems from the following countries and regions were included in the review:

Australia and New Zealand

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) provide comprehensive information and procedures for setting water guideline values. In the case of these two countries, water quality guideline values are defined as the concentration of biogeochemical variables below which there is a *low risk that adverse biological effects* will occur.

NOTE:

To assist regional groups in setting environmental values and water quality targets for their catchments/region, Water Quality Targets: A Handbook was published by Environment Australia in 2002 (www.environment.gov.au/water/publications/quality/index.html). The handbook outlines the steps to be followed in setting default targets derived from the published guidelines in The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. When used in conjunction with Water Quality Targets: On Line (www.environment.gov.au/water/publications/quality/index.html), this handbook simplifies the task of setting water quality targets. It is not prescriptive and is intended as a tool for assisting the planning process.

United States of America

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, 1986a; 2001; 2002a). Their criteria provide guidance to States and Tribes in adopting their own water quality standards under Section 303(c) of the CWA.

The US-EPA water quality guidelines, 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 categories of variables - e.g. physico-chemical variables, nutrients and toxic substances, 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 distill the approach and methodology used in deriving criteria for each and every variable listed in their guideline document. However, where a generic approach and methodology have been provided for a category of variables (e.g. trace metals), these are discussed in further detail.

The US-EPA does, however, follow a generic process when developing new criteria for a specific variable or re-assessing an existing criterion, which is as follows (US-EPA, 1999):

- Undertake a comprehensive review of available data and information
- Publish a notice in the Federal Register and on the internet announcing its assessment or reassessment of the pollutant for public comment
- Utilise information obtained from the review and the public to develop draft recommended water quality criteria
- Conduct peer review of the draft criteria as well as publish a notice in the Federal Register and on the internet of the availability of the draft water quality criteria and solicit public comment
- Prepare a response document for the record
- Revise the draft criteria as necessary, and announce the availability of the final water quality criteria in the Federal Register and on the internet.

Canada

In 1987, the Canadian Council of Resource and Environment Ministers (CCREM) published the Canadian Water Quality Guidelines (CCREM, 1987). In 1999, the Canadian Council of Ministers of the Environment published the Canadian Environmental Quality Guidelines, which integrated national environmental quality guidelines for all environmental media, including water (drinking water, recreational water, water for aquatic life, irrigation water, and livestock water), soil (agricultural, residential/ parkland, commercial, and industrial land uses), sediment, tissue residue (for wildlife consumers of aquatic biota), and air (for human health, vegetation, animals, materials, and aesthetic atmospheric properties) (CCME, 1999b). The Canadian protocol for the derivation of water quality guidelines for the protection of aquatic life is described in CCME (1999a).

A summary document of the Canadian Environmental Quality Guidelines (as revised in 2002) has been consulted to obtain specific guideline values for different substances (CCME, 2002).

European Community

In October 2000, 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 variables 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).

This Water Framework Directive repealed and will be repealing a number of other Directives, including Council Directive on Water pollution by discharges of certain dangerous substances (CEC, 1976b). In the interim Directive on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community (CEC, 2006a) lays down harmonised rules to protect the aquatic environment against the discharge of dangerous substances: it stipulates that all discharges of certain substances should be authorised, sets emission ceilings for these substances and compels the Member States to improve the quality of their water. This Directive will be repealed by the Framework Directive on water as from the end of 2013.

In addition to providing general guidance on setting environmental quality standards, the Water Framework Directive also identifies a list of priority (toxic) substances for which the Council is responsible for setting specific environmental quality standards for the protection of aquatic ecosystems. Such standards have been derived for about 18 priority substances. The approach and methodology followed in deriving such standards are comprehensively discussed in the EC Directives on the particular substance or suite of substances (CEC, 1983, 1984a, 1984b, 1986, 1988, 1990).

2.1.1 Approaches and Methodologies

The approach and methodologies applied by the international community to derive EQO/Ts for coastal waters (or water quality guidelines) linked to the protection of aquatic ecosystems appear to be different for the different sub-categories of substances, namely:

- Objectionable matter
- Physico-chemical variables
- Nutrients
- Toxic substances.

For this reason, the approach and methodologies for the different sub-categories are discussed separately.

Water quality guideline values for the protection of coastal aquatic ecosystems, as recommended by the countries and organisations included in this review, are summarised in Appendix I.

Objectionable matter

Although guidelines related to the presence of objectionable matter are typically linked to recreational waters (in which case they are referred to as Aesthetic guidelines) (RSA DWAF, 1995b; ANZECC, 2000a; CEC, 2002; CMNHW, 1992), the presence of objectionable matter can also be a concern in terms of the protection of coastal aquatic organisms, for example, litter and other plastic pollution. EQTs related to objectionable matter or aesthetic issues are usually narrative and typically require that areas be free from:

- Objectionable floating matter or oily films
- Non-natural matter that will settle to form objectionable deposits on the seabed
- Submerged objects and other subsurface hazards that arise from non-natural origins and which would be a danger to recreational users
- Objectionable smells or odours.

Currently, it is only South Africa in the WIO region that explicitly lists recommended targets for objectionable matter relating to the protection of marine aquatic ecosystems (DWAF, 1995b). These are:

- Water should not contain 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 putrescence.

- 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 variables

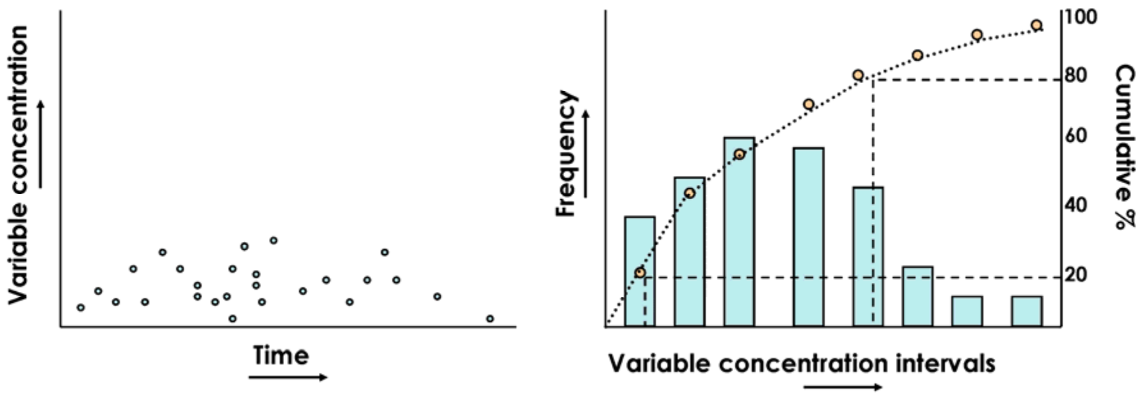
Physico-chemical variables typically include temperature, salinity, pH, dissolved oxygen, turbidity and suspended solids. Different approaches have been used to derive EQTs for these variables, including (ANZECC, 2000):

- *Biological and ecological effects data*, obtained from biological effects tests using local biota and local waters. Ecological effects data are obtained through site- or ecosystem-specific laboratory and field experiments. Such data can also be derived from relevant scientific literature
- *Reference system data*, obtained from either the same (undisturbed) ecosystem or from a regional reference ecosystem
- *Predictive modelling*, which is particularly useful for certain variables whose disturbance occurs through transformation in the environment. In these cases, because of other factors involved, there may not be a direct relationship between the ambient concentration of the variable and the biological response, but there is often a relationship between flux and biological response
- *Professional judgement* is used in cases in which there are insufficient data to derive quality guidelines. Such judgement should be supported by appropriate scientific information.

In many instances, the guideline documents from the different countries are not explicit about the approach that was followed but, based on the rationale or motivations provided for setting a particular value, it appears as if the biological and ecological effects data and the reference system data routes are mostly applied in the case of physico-chemical variables (ANCEZZ, 2000; CCREM, 1987; CEC, 2000; US-EPA, 2000a, 2002a). The Australian and New Zealand document provided the most useful (and practical) guidance in this regard (ANCEZZ, 2000).

The physico-chemical characteristics of coastal waters are usually site-specific and often subject to large natural variability. Water quality target values therefore need to be as specific as possible to each ecosystem. This, in turn, requires site-specific data on the statistical distribution of a physico-chemical variable, obtained from a specific site (or an appropriate reference site), as well as information on the ecological and biological effects of such physico-chemical variables. Target values therefore need to take into account natural variability as well ecological or biological effects (e.g. meaningful changes to the biology or ecology should not occur).

However, where there is insufficient information on biological and ecological effects to determine an acceptable change from the reference condition, it is recommended that an appropriate percentile of data collected on a physico-chemical variable from a specific site (or an appropriate reference site) be used to derive the target values (the percentile represents a measure that can be applied to data whether they be normally or non-normally distributed). ANCEZZ (2000) recommended that the target concentrations be determined as either the 20th or the 80th percentile of the reference system(s) distribution, or as the range defined by these percentiles, depending on whether trigger values need to be set for a low concentration limit, a high concentration limit or both. This choice of the percentile values was arbitrary, but considered to be reasonably conservative. This concept is graphically illustrated below:



Monthly data collected over a two-year period were considered to be sufficient to indicate ecosystem variability and can be used to derive target values for variables that do not show large seasonal- or event-scale effects. However, in ecosystems where concentrations of physico-chemical variables and the ecological and biological responses are influenced by strong seasonal- or event-scale effects, it will be necessary to monitor (or model) so as to detect these seasonal influences or events. Therefore, where seasonal- or event-driven processes dominate, data need to be grouped and target values need to be derived for corresponding key periods. As an interim measure, where few reference data are available and seasonal and event influences are poorly defined, single target values could be derived from available data based on professional judgement.

Nutrients

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 the 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 time-scales - 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 (ANZECC, 2000).

As a result, predictive modelling (dynamic simulation) has become a very useful tool for deriving water quality target values for nutrients, in addition to the other approaches, e.g. Biological and ecological effects data and Reference system data approaches (ANZECC, 2000; CEC, 2000; US-EPA, 2001).

Although ANZECC (2000) recognises the advantages of using predictive modelling in setting water quality target values for nutrients, the Reference system data approach is still applied. It is recommended that, where an appropriate local reference system(s) is available, the target value for the causative (e.g. inorganic nitrogen and phosphate) as well as response (e.g. Chlorophyll a) variables be determined as the 80^{th} percentile of the reference system(s) distribution. Where possible, the target value should be obtained for that part of the seasonal or flow period when the probability of aquatic plant growth is most likely.

In terms of using the modelling approach, 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 approach put forward by the US-EPA consists of a number of key steps, which can be summarised 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 are capable of addressing 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 water quality guidelines – the US-EPA requires that proposed guidelines 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.

Toxic Substances

Toxic substances can typically be categorised into:

- General toxicants (including substances such as ammonia, chlorine, sulphide, phenol cyanide and fluoride)
- Trace metals (including arsenic, cadmium, chromium, lead, mercury, nickel, vanadium and zinc)
- Volatile organic carbons (e.g. benzene, ethyl-benzene, toluene and xylene)
- Poly-aromatic hydrocarbons
- Poly-chlorinated biphenyls (PCBs)
- Pesticides.

In setting target values for toxic substances, the Ecological and biological effects data approach is mainly used (ANZECC, 2000, CCME, 1999; CEC, 1983, 1984a, 1984b, 1986, 1988, 1990; Russo, 2002). For the purposes of this review, the focus will be on the approach and methodologies followed in Australia and New Zealand (ANZECC, 2000), US- EPA (Russo, 2002) and Canada (CCME, 1999a).

NOTE:

No-Observable-Effects Concentration (NOEC) is the highest test concentration that does not cause a significant effect while the Lowest-Observable-Effects Concentration (LOEC) is the lowest test concentration that does cause an effect. Although NOEC and LOEC figures are dependent on the choice of the tester, overall, NOECs are broadly around 2.5 times lower than LOECs (ANZECC, 2000).

For the development of national water quality target values, toxicological databases - of which the US-EPA's AQUIRE (Aquatic Toxicological Information and Retrieval Database) (now part of their ECOTOX database) appears to be the most popular - are regularly used to obtain relevant data (US-EPA, 2007; ANZECC, 2000; Russo, 2002).

A minimum set of aquatic toxicological data is required to set water quality target values for toxic substances. The specific data requirements tend to vary from one country to another. Furthermore, because the quality and type of toxicity data varied greatly from one substance to another, the reliability of the guideline values varied. Depending on the quality and type of data available, Australia and New Zealand, for example, categorised their target (or guidelines) values into (1) high reliability, (2) moderate reliability, and (3) low reliability, while Canada distinguished between (1) full and (2) interim guidelines (ANZECC, 2000; CCME, 1999a). Although the EC Directives and US-EPA do provide guidance on minimum data requirements, they do not make allowance for different categories of 'confidence' (CEC, 2000; Russo, 2002).

NOTE:

Data collated in preparation for deriving water quality target values for toxic substances for Australia and New Zealand included (ANZECC, 2000):

- ***Overseas criteria documents, particularly those produced by the United States (US-EPA 1986a), Canada (CCREM 1987), the Netherlands (MHSPE 1994), Denmark (Samsoe-Petersen and Pedersen 1995), United Kingdom (e.g. Mance et al. 1984a-c, 1988a-e, Mance and Yates, 1988a-b) and the previous ANZECC (1992) guidelines***
- ***US-EPA's Aquatic Toxicology Information and Retrieval database (AQUIRE) now part of ECOTOX (US-EPA, 2007), which at the time of the preparation of the ANZECC (2000) guidelines had more than 100 000 entries***
- ***Papers containing field mesocosm, chronic NOEC and LOEC data and those papers containing LC50 data on the same species***
- ***Data on the Australasian Ecotoxicology Database (Warne et al. 1998) which contained around 3500 entries***
- ***Reviews on ecotoxicology of a particular chemical***
- ***Data on physico-properties, especially KOW values, and bio-concentration factor (BCF) data.***

The minimum toxicological data requirements specified by the different countries and organisations are summarised in Table 2.1. Stringent data evaluation procedures apply which are too comprehensive to discuss in detail as part of this review, but can be obtained from the literature listed in Table 2.1.

The approach and methodology that is followed in Australia and New Zealand to derive water quality targets for toxic substances are schematically illustrated in Figure 2.1.

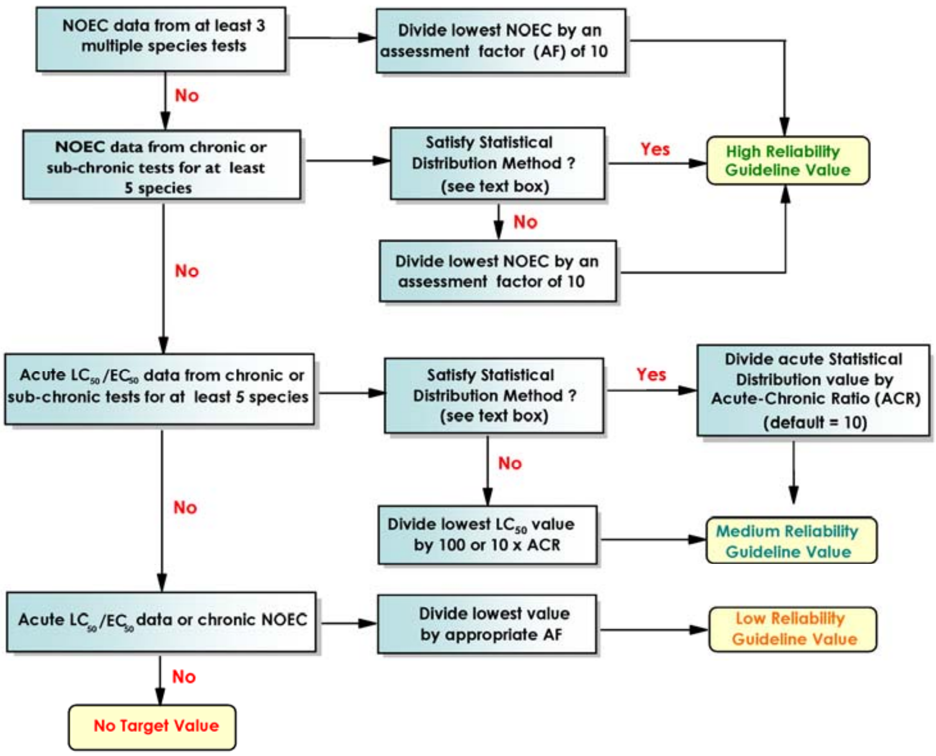


Figure 2.1: Schematic illustration of the procedures followed by Australia and New Zealand to derive water quality targets (or guidelines) for toxic substances (adapted from ANZECC, 2000)

TABLE 2.1: Summary of the minimum toxicological data requirements for the derivation of water quality targets for toxic substances for the protection of marine aquatic ecosystems: Toxic substances

COUNTRY	CONFIDENCE CATEGORY	MINIMUM TOXICOLOGICAL DATA REQUIREMENTS
Australia and New Zealand[1]	High Reliability	No-Observable-Effect Concentration (NOEC) data of suitable quality from chronic or sub-chronic tests for 5 or more species belonging to at least four different taxonomic groups. Alternatively, NOEC data from at least 3 well-conducted field or mesocosm studies that: • Include fish and shellfish or data related to these • Include components that represent basic properties of ecosystems (e.g. nutrient cycling, trophic structures) • Are of sufficient duration to account for life-history of organisms and fate of the toxic substance • Have rigorous experimental design with adequate controls and exposure/effect data (i.e. at least 3 treatments plus control) • Have sufficient replication to give adequate statistical power
	Medium Reliability	LC_{50} or EC_{50} of suitable quality for 5 or more species belonging to at least four different taxonomic groups.
	Low Reliability	At least 3 chronic NOEC values or at least 3 acute LC_{50} or EC_{50} values. Alternatively, use freshwater quality guideline, where available
Canada[2]	Full	• At least 3 studies on 3 or more temperate marine fish species, including at least 2 chronic • At least 2 chronic studies on 2 or more temperate marine invertebrate species from different classes • At least 1 study on a temperate marine vascular plant or marine algal species
	Interim	• At least 2 acute and/or chronic studies on 2 or more marine fish species, one of which is a temperate species • At least 2 acute and/or chronic studies on 2 or more marine invertebrate species from different classes, one of which is a temperate species • (Where toxicity data indicate that a plant species is most sensitive, then that data must be included) In addition, data on the fate and behaviour of the substance are required, such as: • Mobility of substance and the components of the aquatic environment where it is like to be distributed • Kinds of chemical and biological reactions that take place during transport and after deposition • Eventual chemical form • Persistence of substance in water, sediment and biota It is not required to have information on all of the above, but the intent is to determine the major environmental pathways of the variable in the aquatic environment

TABLE 2.1: ***continued…***

COUNTRY	CONFIDENCE CATEGORY	MINIMUM TOXICOLOGICAL DATA REQUIREMENTS
US-EPA[3]	No level specified	• Acute toxicity test results with at least 1 animal species in at least 8 different families so as to include 2 families in the phylum Chordata, 1 family in a phylum other than Arthropoda or Chordata, either the Mysidae or Penaeidae family, 3 other families not in Chordata, and any other family • Acute-chronic ratios with species in aquatic families in at least 3 different phyla, one fish, one invertebrate and one in an acutely sensitive saltwater species (the other 2 may be freshwater) • At least one acceptable toxicity test on 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
European Community[4]	No level specified	Where possible, both acute and chronic data shall be obtained for the taxa set out below that are relevant for the water body type concerned, as well as any other aquatic taxa for which data are available. The 'base set' of taxa is: • algae and/or macrophytes • daphnia or representative organisms for saline waters • fish

1: For details refer to ANZECC, 2000

2: For details refer to CCME, 1999a

3: For details refer to US-EPA (1985) and Russo (2002)

4: For details refer to CEC, 2000

Recommended Application Factors (AF) for deriving low reliability target values, based on those proposed by the OECD (1992), are as follows (ANZECC, 2000):

- Apply an assessment factor of 1000 to the lowest acute LC50 or EC50 value within a dataset on only one or two aquatic species or a factor of 200 to limited chronic data
- Apply a factor of 100 to the lowest acute LC50, EC50 value within a data set comprising, at a minimum, algae, crustaceans and fish
- Apply a factor of 20 (OECD (1992) recommends a factor of 10) to the lowest chronic NOEC value within a dataset comprising, at a minimum, algae, crustaceans and fish.

It has been recommended that, in cases in which toxicity data or target values were missing for marine waters but available for fresh water, managers may use freshwater figures as tentative working levels (OECD 1992), taking into account any known salinity effects.

NOTE: STATISTICAL DISTRIBUTION METHOD

The statistical distribution method that was used by the Australians to determine high reliability guideline trigger values is schematically illustrated below:

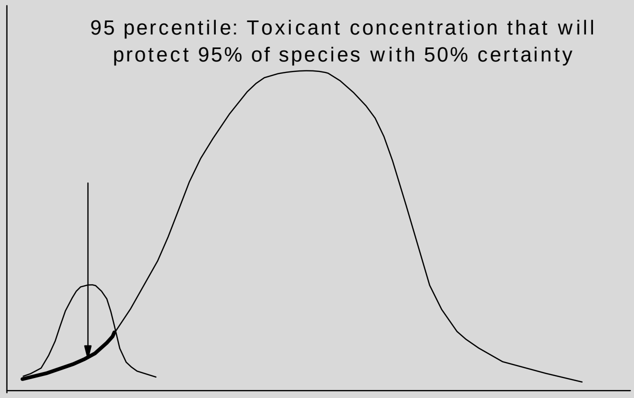


Figure 2.2 schematically illustrates the US-EPA approach and methodology to derive water quality targets for toxic substances.

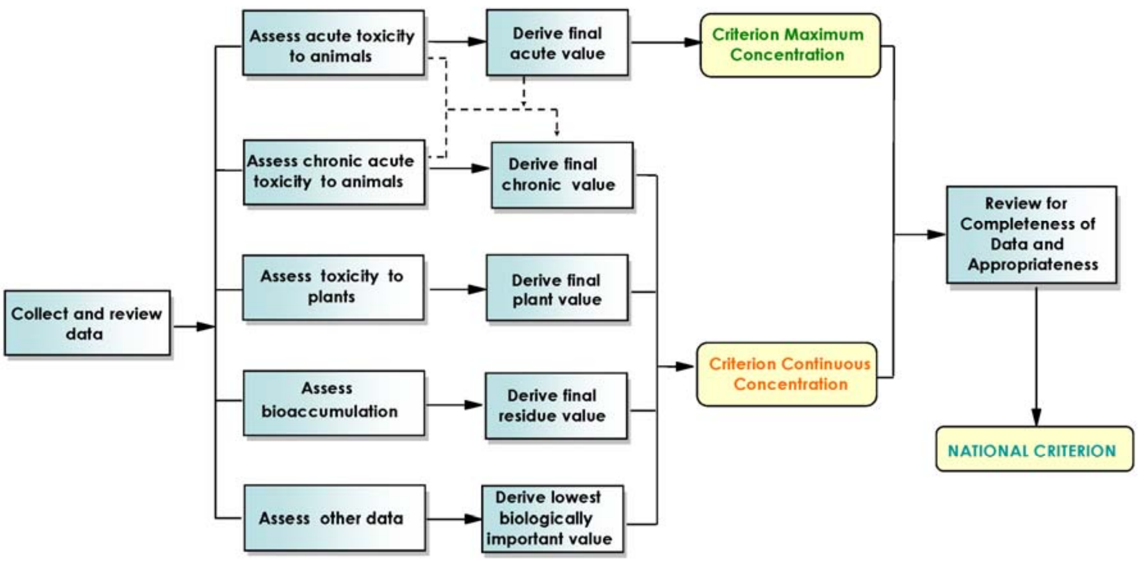


Figure 2.2: **Schematic illustration of the procedures followed by the US-EPA to deterime water quality targets (criteria) for toxic substances (adapted from Russo, 2002)**

Final values referred to in Figure 2.2 are calculated as follows:

- Final acute values are calculated as an estimate of the concentration of the substance corresponding to a cumulative probability of 0.05 in the acute toxicity data from the genera with which acceptable tests have been conducted (if the acute value for a commercially or recreationally important species is lower than the calculated value, then the value for that species is accepted as the final value)
- Final chronic values are calculated as the geometric mean of the Lowest-Observable-Effects Concentration (LOEC) and the No-Observable-EffectsConcentration (NOEC) from the chronic data sets
- Final plant values are calculated as the lowest result from a 96-h test conducted with an alga or a chronic test conducted on an aquatic vascular plant
- Final residue values are calculated by dividing the maximum permissible tissue concentration (e.g. a US Food and Drug Administration action level for fish oil or the edible portion of fish or shellfish) divided by an appropriate bio-concentration factor (BCF).

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

- 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 = one 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 = lowest of the final chronic value, final plant value and final residue value.

Note that the US-EPA water quality targets for trace metals, as revised in 2002 – listed in Appendix A – are expressed as dissolved metal concentrations in the water column. These concentrations were calculated from the aquatic life criteria (US-EPA, 1986a), 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, 2002a).

The procedures for the derivation of water quality targets for toxic substances followed in Canada are illustrated in Figure 2.3. Target values are derived from the lowest-observable-effect concentration (LOEC) from a chronic study, using a non-lethal endpoint for the most sensitive life stage of the most sensitive aquatic species investigated. The most sensitive LOEC is multiplied by a safety factor of 0.1 to arrive at a target value. This safety factor has been chosen to account for differences in sensitivity to a variable due to differences in species, laboratory versus field conditions, and test endpoints.

Where the above-mentioned data are not available, target values can be derived from acute studies by converting short-term median lethal or median effective concentrations (LC_{50}, EC_{50}) to long-term no-effect concentrations. Acute/chronic ratios (ACRs) are used to convert the median lethal results of a short-term study to an estimated long-term no-effect concentration. An ACR is calculated by dividing an LC_{50} or EC_{50} by the no-observed-effect concentration (NOEC) from a chronic exposure test for the same species. In the event that ACRs are not available, the alternate method of choice for deriving a target value from an acute study is to multiply the LC_{50} or EC_{50} value by a universal application factor. The application factor (AF) for non-persistent variables ($t_{1/2}$ in water < 8 weeks) is 0.05; for persistent variables, the AF is 0.01.

Unless otherwise specified, a target value for toxic substances refers to the total concentration in an unfiltered sample. Total concentrations will apply unless it can be demonstrated that (a) the relationship between variable fractions and their toxicity is firmly established, and (b) analytical techniques have been developed that unequivocally identify the toxic fraction of a variable in a consistent manner using routine field-verified measurements (CCME, 1999a).

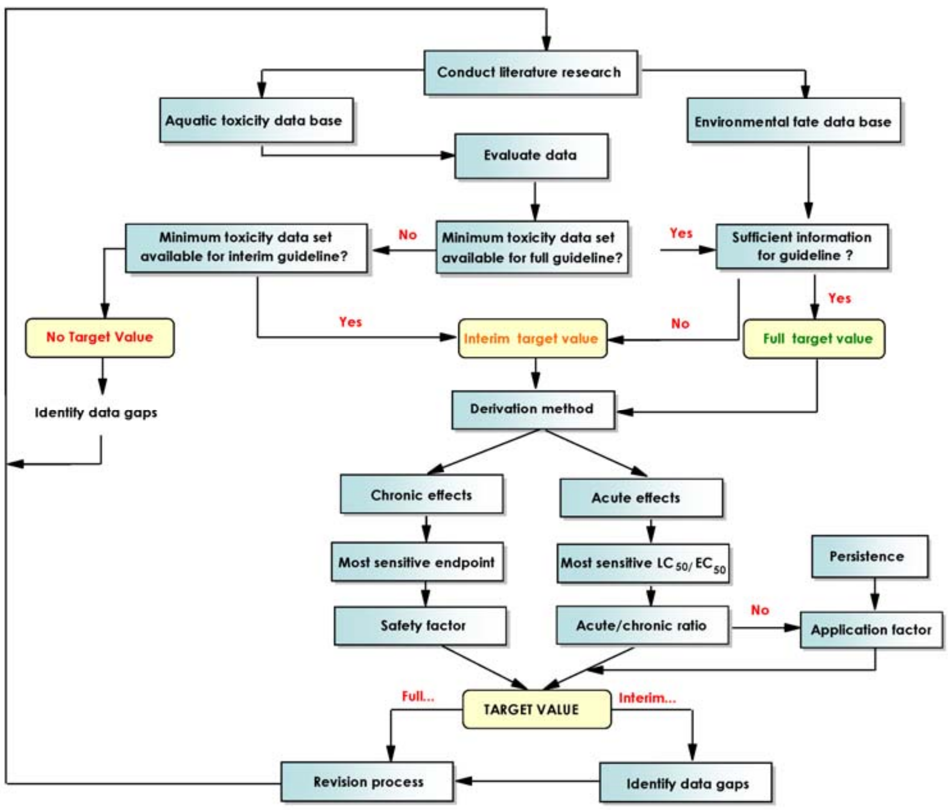


Figure 2.3: **Schematic illustration of the procedures for the derivation of water quality targets for toxic substances followed in Canada (adapted from CCME, 1999a)**

In the European Union, the ultimate aim of the Water Framework Directive is to achieve the elimination of priority hazardous substances and contribute to achieving concentrations in the marine environment of near background values for naturally occurring substances. Thirty-three substances or groups of substances are currently on the list of priority substances, including biocides, metals and other groups like polyaromatic hydrocarbons (PAH). The complete list is given below and can also be accessed on http://ec.europa.eu/comm/environment/water/water-framework/priority_substances.htm:

PRIORITY SUBSTANCES		
Alachor	Fluoranthene	Pentachlorobenzene
Anthrene	Hexachlorobenzene	Pentachlorophenol
Atraziner	Hexachlorobutadiene	Polyaromatic hydrocarbons
Benzene	Hexachlorocyclohexane	(Benzo(a)pyrene
Brominated diphenylethers	(gamma-isomer, Lindane)	Benzo(b)fluoroanthene
Cadmium and its compounds	Isoproturon	Benzo(g,h,i)perylene
C10-13 chloroalkanes	Lead and its compounds	Benzo(k)fluoroanthene
Chlorfenvinphos	Mercury and its compounds	Indeno(1,2,3-cd)pyrene
Chlorpyrifos	Naphthalene	Simazine
1,2-Dichloroethane	Nickel and its compounds	Tributyltin compounds
Dichloromethane	Nonylphenols	Tributyl-cation
Di(2-ethylhexyl)phthalate	4-(para)-nonylphenol	Trichlorobenzene
Diuron	Octylphenols	Trichloromethane (chloroform)
Endosulfan	(para-tert-octylphenol)	Trifluralin
(apha-endosulfan)		

It is the responsibility of the Council to specify emission limit values and EQO/Ts for these priority substances. Such limits and EQO/Ts have already been set for 18 substances in five specific directives, also called 'daughter' directives:

- Council Directive on limit values and quality objectives for mercury discharges by the chlor-alkali electrolysis industry (CEC, 1982)
- Council Directive on limit values and quality objectives for cadmium discharges (CEC, 1983)
- Council Directive on limit values and quality objectives for mercury discharges by sectors other than the chlor-alkali electrolysis industry (CEC, 1984a)
- Council Directive on limit values and quality objectives for the discharges of hexachlorocyclohexane (CEC, 1984b)
- Council Directive on limit values and quality objectives for discharges of certain dangerous substances in List I of the Annex to Directive 76/464/EEC (CEC 1976b, 1986, 1988 and 1990).

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 bioaccumulable organic toxic substances
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 applies to the setting of a maximum annual average concentration (further details are provided in CEC [2000] and CEC [2006a]):

- 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.

2.1.2 Implementation Practices

EQO/Ts are not designed to be used as 'magic numbers' or threshold values at which an environmental problem is inferred if they are exceeded, i.e. they are usually NOT standards (legally enforceable values). EQO/Ts are primarily used to set target values within broader management objectives and strategies, so as to sustain marine aquatic health in the long term. They can also be used as benchmarks for water quality data obtained either through monitoring programmes or simulated through modelling studies (e.g. to asses potential impacts from future developments).

Generic EQO/Ts are usually set at a national or regional level to provide guidance to local managers and responsible authorities to derive site-specific environmental quality objectives and target values focusing on specific issues of relevance and potential concern in their area. The aim is to set generic EQTs at reasonably conservative levels, so that adverse biological affects are not expected when the concentrations are below or at the target value. The potential for adverse biological effects is recognised when guideline values are exceeded (CCME, 1995). Generic EQTs are typically based on bio-available concentrations, and hence are relatively conservative when compared with total concentrations in the marine environment (comparing <u>total</u> concentrations with guideline values, is therefore seen as a simple and low-cost point of departure).

Refinement of generic EQO/Ts can occur on different levels (ANZECC, 2000):

- Values can be adjusted and refined upfront, based on site-specific information on key physical and chemical variables in the marine environment. For example, the toxicity and bioavailability of some metals (e.g. copper, zinc and cadmium) are strongly influenced by water quality characteristics such as dissolved organic matter and pH and the toxicity of different metal species.
- After continuous and extensive monitoring show that exceedances of a guideline value are consistently assessed as posing no risk to the ecosystem.
- Where it is shown that natural background concentrations of a particular variable exceed the guideline values.

Internationally, a risk assessment or phased approach is typically followed: Where EQO/Ts are exceeded, this triggers the incorporation of additional information or further investigation to determine whether or not a real risk to the ecosystem exists and, where possible, to adjust the guideline values for site-specific conditions (ANZECC, 2000).

This is illustrated by the Australian and New Zealand approach (Figure 2.4). ANZECC (2000) recommends that, for these assessments, target values be compared with the <u>median</u> or <u>average</u> (whichever is considered most appropriate) of the measured or simulated data set. Statistically, the median usually represents the most robust descriptor of the test site data.

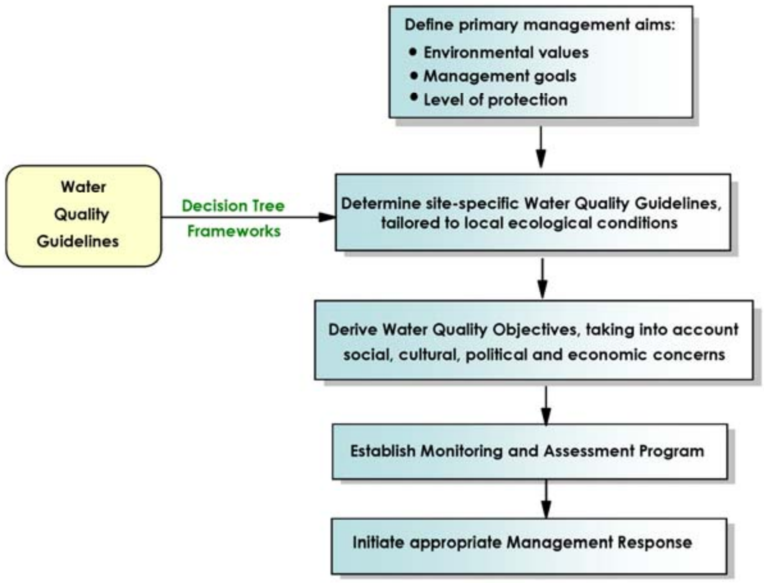


Figure 2.4: Implementation of generic EQO/Ts for coastal waters (water quality guidelines) in the broader water quality management framework (adapted from ANZECC, 2000)

To adapt water quality target values for a particular site, a risk assessment approach, using decision tree frameworks is used (example illustrated in Figure 2.5).

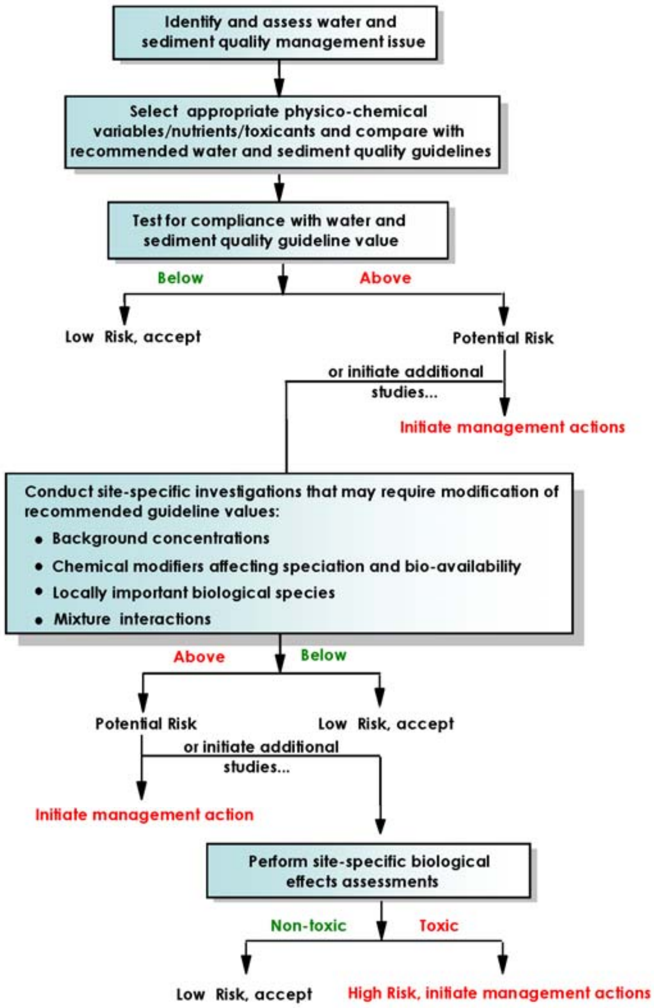


Figure 2.5: Decision tree framework to generic-type EQO/Ts for a particular site (ANZECC, 2000)

In these frameworks, exceedance of recommended water quality target values 'triggers' further investigation. The subsequent investigation then aims to assess whether exceedances will result in adverse biological effects by accounting for site-specific environmental factors that can modify the effect of the variable. Although in some cases this will require more work, it will result in much more realistic goals for management and therefore has the potential to reduce both costs and confrontation. These frameworks provide a structured approach within which to reduce the amount of conservatism necessarily incorporated in the target values, and so produce values more appropriate to a particular environment (ANZECC, 2000).

Similar to the Australian approach, the Canadian water quality target values are also not used as blanket values for national water quality, as variations in environmental conditions will affect water quality in different ways and many of the target values may need to be modified according to local conditions, such as assimilative capacity, sensitivity of endangered species, and habitat (Figure 2.6). Using the generic water quality target values to set site-specific water quality targets requires an understanding of the physical and biological characteristics of the water body and an understanding of the behaviour of a substance once it is introduced into the aquatic environment (CCME, 1999a).

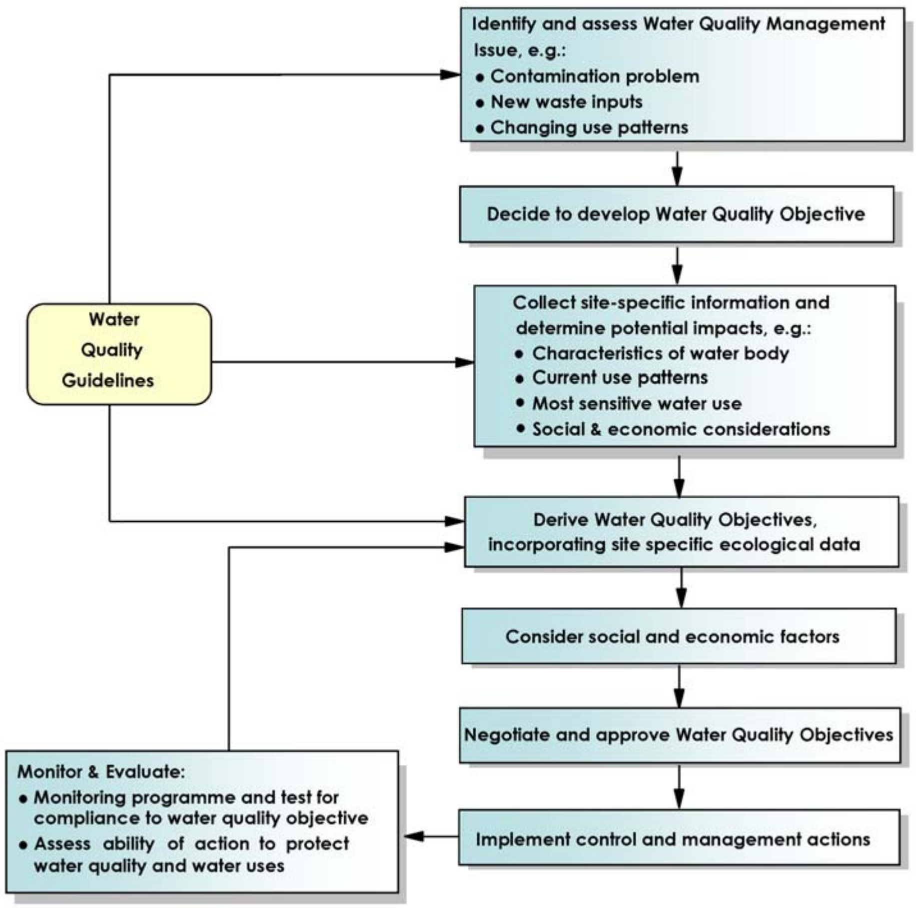


Figure 2.6: Implementation of water quality target (guidelines) in Canada (adapted from CCME, 1999a)

Section 304(a)(1) of the Clean Water Act (USA) requires that the EPA develop criteria for water quality that accurately reflect the latest scientific knowledge (US-EPA, 2004). These criteria are based solely on data and scientific judgements on pollutant concentrations and environmental or human health effects. Section 304(a) also provides guidance to states and tribes in adopting water quality standards. Criteria are developed for the protection of aquatic life as well as for human health. States and authorised tribes adopt water quality criteria with sufficient coverage of parameters and of adequate stringency to protect designated uses.

In adopting such criteria, States and Tribes may (US-EPA, 2004):

- adopt the criteria that EPA publishes under section 304(a) of the Clean Water Act
- modify the section 304(a) criteria to reflect site-specific conditions, or
- adopt criteria based on other scientifically-defensible methods.

The US-EPA therefore also recognises that generic water quality target values are recommended numerical and descriptive values for assisting states and tribes in developing site-specific water quality standards by taking local conditions into account.

In the European Union waters (including marine waters), the use of water determines the level to which quality of water needs to be protected (CEC, 2003). In contrast to some uses for which water is protected only in specified areas (e.g. recreation or culture of shellfish), ecological protection should apply to all waters: The central requirement of the European Treaty is that the natural environment (aquatic ecosystems) be protected to a high level in its entirety.

To protect aquatic ecosystems, it was realised that no quality standards can be set which apply across the Community. Therefore, to cover all surface waters, the Water Framework Directive introduced a concept of setting a general requirement for ecological protection, and a general minimum chemical standard (CEC, 2000).

Good ecological status is defined, in Annex V of the Water Framework Directive, in terms of the quality of the biological community, the hydrological characteristics and the physico-chemical characteristics. In this regard, members need to set site-specific standards that will ensure that conditions defined as indicative of a 'good eclogical status' are attained.

Good chemical status, in turn, is defined in terms of compliance with all the quality standards established for substances (toxic) at European level. In this regard, some numerical chemical standards are provided at European level (in so-called 'daughter' directives [CEC, 1982, 1983, CEC, 1984a, CEC, 1984b, CEC 1976b, 1986, 1988 and 1990]), while for others Annex X of the Water Framework Directive provides guidance on how such standards should be determined.

2.2 Protection of Coastal Aquatic Ecosystems: Sediment

Sediments are an important component of coastal aquatic ecosystems and provide a habitat for many benthic (and epibenthic) organisms. In addition, sediment found in depositional areas tends to integrate (or accumulate) contaminant inputs over time - many toxic and accumulative substances form associations with particulate matter (either biogenic or lithogenic), which eventually becomes incorporated into bed sediments. Consequently, sediments can also act as a long-term source of toxic substances to the aquatic environment, not only to benthic organisms, but also to overlying waters.

EQTs for sediments (or sediment quality guidelines) linked to the protection of marine aquatic ecosystems from the following countries and regions were included in the review:

United States of America

The National Oceanic and Atmospheric Administration (NOAA) in the United States developed a set of sediment quality target values that was 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, NOAA, 1999). 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). They expanded the saltwater database that was originally used by Long and co-workers with additional data on saltwater. The procedures that were developed as part of these two studies currently form the basis for the derivation of sediment quality target values worldwide, e.g. Australia and New Zealand (ANZECC, 2000), and Canada (1995).

To assist regulatory authorities in making decisions concerning contaminated sediments, the US-EPA also embarked on studies to develop sediment quality targets, primarily for non-ionic organic compounds. From the available literature, guidance in this regard has been documented for dieldrin, endrin and a mixture of PAHs (US-EPA 2003c, d and e).

Australia and New Zealand

Few reliable data on sediment toxicity are available for either Australia or New Zealand from which to derive sediment quality guidelines. With little likelihood of further data forthcoming in the immediate future, these countries opted to use best available overseas target values (or guideline values) and to refine them with local knowledge of local baseline concentrations, as well as by using local effects data, as and when such data become available (ANZECC, 2000). The interim sediment quality guideline values adopted by Australia and New Zealand are based primarily on the approach followed by NOAA (USA) (NOAA, 1999; Long et al., 1995).

Canada

In 1988, Environment Canada commissioned a study to review and evaluate available approaches used to develop sediment quality guidelines in the world (CCME, 1995). This resulted in the development of a formal protocol for the development of sediment quality guidelines, which is based primarily on the approach and methodology used by MacDonald et al. (1996) in the derivation of sediment quality target values for the State of Florida (USA).

A summary document of the Canadian EOTs (as revised in 2002) has been consulted to obtain the target values for different substances (CCME, 2002). Unless otherwise specified, sediment quality targets refer to the total concentration of the substance in surficial sediments (e.g. upper few centimetres).

2.2.1 Approaches and Methodologies

Ideally, sediment quality targets should be developed from detailed dose-response data that describe the acute and chronic toxicity of individual substances in sediments to sensitive life stages of sensitive aquatic organisms. Such data should be generated in controlled laboratory studies in which the influence of important environmental variables affecting bioavailability (and toxicity) are identified and quantified. Subsequently, the results from the laboratory studies should be validated in field trials to ensure that any guideline value derived from such data will be applicable to a broad range of locations. A detailed understanding of site-specific factors that influence bioavailability and toxicity (e.g. total organic carbon, sediment grain size and acid volatile sulphide) is also required so as to define and predict the extent to which such modifiers will affect toxicity under field situations.

However, in most countries, such detailed data are usually not available and are also very costly to collate. In response to the identified need for sediment quality targets, numerous approaches were investigated worldwide, taking into account practicality, scientific defensibility and wide applicability.

EQTs for sediments linked to the protection of marine aquatic ecosystems, as recommended by the countries and organisations included in this review are summarised in Appendix II.

Generic EQTs for sediments are generally only specified for the protection of aquatic ecosystems, in particular for toxic substances. Approaches that have been documented as being used in the derivation of sediment quality guidelines for toxic substances include:

Effects range approach. The effect range approach involves the use of large effects databases, for which concentrations have been measured in sediment and the biological effects simultaneously recorded. Such data can be obtained through field, laboratory and/or modelling studies. Sediment quality guideline values are then derived using statistical analyses of matching sediment chemistry and biological effects data.

This approach requires sufficient amounts of matching sediment chemistry and biological effects data, collected from sediments with different physical and geo-chemical characteristics and from numerous locations so as to provide a basis for establishing guideline values that should be widely applicable. The use of data collated through field studies, in which mixtures of substances occur within samples, is also considered to maximise applicability to most real-world situations. Furthermore, data from a variety of toxicological end-points are also likely to broaden the applicability of guideline values derived through this approach (Long and McDonald, 1998).

The effects-based approach is also thought to be the most ecological relevant and scientifically defensible approach as it relies directly on observed biological effects of sediment associated substances (whereas , for example, equilibrium partitioning models are based only on indirect biological effects – see later) (CMME, 1995).

Screening level concentrations. This approach uses field data and patterns of co-occurrence in sediments of specific contaminant concentrations and specific benthic biota. For a particular species, the screening level concentration is estimated as the concentration which co-occurs with 95% of a particular organism. Sediment quality guideline values are then derived by determining screening level concentrations for a number of species (ANZECC, 2000).

Apparent effects threshold. The apparent effects threshold is defined as the sediment concentration above which statistically significant ($p < 0.5$) biological effects are always observed for a given data set. The approach involves collection of matched biological effects data from tests carried out on sub-samples from the same field sample. Impacted and non-impacted sites are measured and the statistical significance of adverse biological effects is tested (ANZECC, 2000).

Sediment quality triad. This approach involves data from three separate measurements: sediment chemistry, sediment bioassays, and *in situ* biological effects and is conducted at the community or ecosystem level. Chemical (and physical) measurements are also taken to assess the level of contamination, as well as other parameters which may influence the abundance of biota. The bioassay data provide information on the toxicity of the contaminants, while the *in situ* biological measurements assess histopathological abnormalities, community structure and other parameters that can be related to sediment chemistry (ANZECC, 2000).

Spiked sediment toxicity tests. The spiked sediment toxicity approach involves the mixing and equilibration of sediments with a contaminant spike, added either to sediment slurry or to overlying water. The information generated provides precise dose-response data on specific toxic substances, as well as quantitative data on interactive effects of substances. This approach can also account specifically for factors influencing toxicity of substances in sediments.

Although results obtained from such controlled laboratory tests have a high degree of precision, they require field validation. This approach is therefore usually best applied in combination with, for example, the effects range approach, and are typically included in databases used in the effects range approach (CCME, 1995; ANZECC, 2000).

Equilibrium partitioning models. The equilibrium partitioning (EqP) approach primarily derives sediment quality guideline values by defining the contaminant concentration in the sediment that is in equilibrium with the quality guideline value of the particular contaminant in the pore water. In most cases, the (surface) water quality guideline value (as discussed earlier) is applied. This approach is most widely applied to non-ionic organic compounds primarily because it is well-established that the partitioning is dominated by sediment organic carbon (this approach is less advanced in terms of trace metals, as metal bioavailability is often dependent on more than one phase in the sediments) (ANZECC, 2000).

Where this approach is applied to non-ionic organic compounds (e.g. PAHs), the sediment/pore water partitioning coefficient, KD, needs to be related to the organic carbon partitioning coefficient, KOC and fOC, the fraction by weight of organic carbon:

$$K_D = K_{OC} f_{OC}$$

The sediment quality target (SQT) value can therefore be calculated from a water quality target value (WQT) value as follows:

$$SQT = K_{OC}f_{OC} * WQT$$

Although the approach is attractive to many regulators, it is important to realise that partitioning coefficients are dependent on sediment type (% fine fraction) and this needs to be taken into consideration when applying guidelines derived though EqP models. Also, this approach assumes that benthic organisms are as sensitive to toxic effects from a particular substance as water column organisms (water quality target values are based on their sensitivity) (ANZECC, 2000).

Outputs from EqP models are therefore also best applied in conjunction with, for example, the effect range approach. Data generated from EqP models for non-ionic organic compounds are also incorporated in databases used in the effect range approach (ANZECC, 2000).

The effects range approach is currently the most widely accepted approach for sediment guideline development, often utilising data generated through some of the other approaches (CCME, 1995; MacDonald et al., 1996; NOAA, 1999; ANZECC, 2000). In this regard, the National Status and Trends Program approach of NOAA is most widely applied throughout the world. This approach is discussed in greater detail in the following sections. The equilibrium partitioning (EqP) approach, which is primarily applied by the US-EPA, is also discussed.

National Status and Trends Program Approach (effects range approach)

Long and his co-workers were the first to investigate and implement the effects range approach on a comprehensive level (Long and Morgan, 1990, revised by Long et al., 1995 using only salt-water data). The approach was originally developed to provide a means of interpreting sediment monitoring data collected throughout the United States as part of the National Status and Trends Program of the National Oceanic and Atmospheric Administration in the United States – known as the National Status and Trends Program Approach (NOAA, 1999). For this project, an extensive data set on matching sediment chemistry and biological effects was collated into a database, derived from field, laboratory and modelling studies performed on sediments with different physical and geo-chemical characteristics and from numerous locations so as to provide a basis for establishing target values that should be widely applicable throughout North America.

The majority of data used to derive the target values were from field studies in which a mixture of substances occurred in the samples, thus maximising the applicability for the guidelines to most real-world situations (Long and MacDonald, 1998). Data on each substance were organised into an ascending data table, for both effect data (i.e. data for which end-points showed adverse biological effects) and no-effect data (i.e. data for which end-points showed no adverse biological effects).

From the ascending data tables, threshold values were calculated from the effect data (i.e. excluding no-effect data) as follows:

- Effect Range-Low (ERL) value: 10th percentile of the effect data, representing a threshold value below which adverse effects are unlikely to occur
- Effect Range-Median (ERM) value: 50th percentile of the effect data, representing a threshold value above which adverse effects frequently occur.

In the late 1990s, MacDonald and co-workers put forward an alternative method to the original National Status and Trends Program Approach when they developed a set of saltwater sediment quality targets for the Florida (USA) Department of Environmental Protection (MacDonald et al., 1996). They expanded the original database with additional data on saltwater and also revised the database by carefully screening data (the updated database is referred to as BEDS (Biological Effects Database for Sediments) (CCME, 1995).

Strict criteria are also applied in the quality control of data for inclusion in BEDS (CCME, 1995).

NOTE:

Each BEDS record included information on (CCME, 1995):

- ***Location***
- ***Concentration of (expressed as total of on a dry weight basis)***
- ***Biological response observed***
- ***Test duration***
- ***Species tested or benthic community assessed***
- ***Information on factors that could influence bioavailability, e.g. total organic carbon, grain size and acid volatile sulphide)***

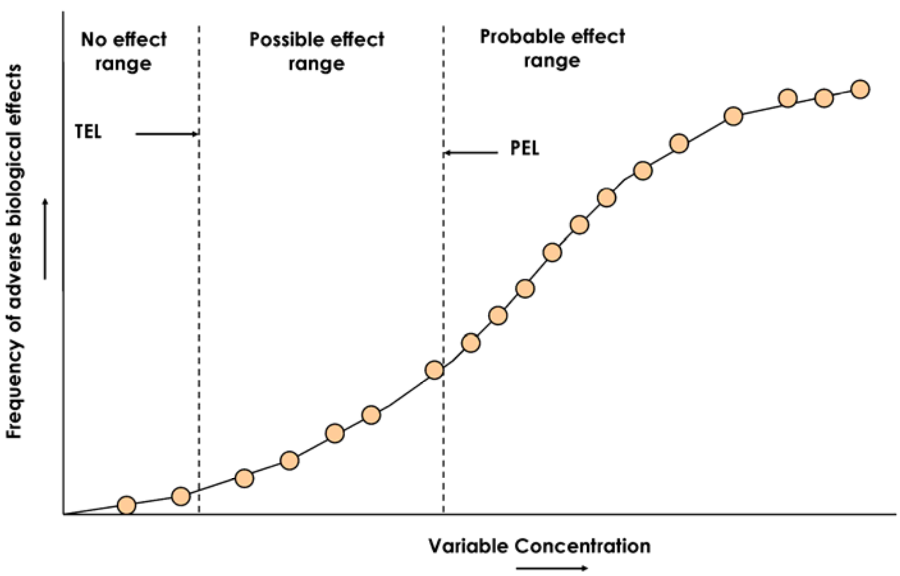
The threshold values calculated by MacDonald et al. (1996) differed from those calculated earlier in that no-effect data were used rather than effect data:

- Threshold effect level (TEL): Calculated as the square root of the product of the lower 15th percentile of the effect data and the 50th percentile of the no-effect data, representing a threshold value below which adverse biological affects are unlikely to occur (i.e. represents no significant hazard to aquatic organisms)
- Probable effect level (PEL): Calculated as the square root of the product of the lower 50th percentile of the effect data and the 85th percentile of the no-effect data, representing a threshold value above which adverse biological affects usually or always occur

However, a comparison of the threshold values from the two studies of 'unlikely occurrence of adverse biological effects' (ERL and TEL) and 'adverse biological effects usually or always occurring' (ERM and PEL) showed remarkable similarity (on average they vary within a factor of 2) even though they were derived differently (ANZECC, 2000; CCME, 1995; Long and MacDonald, 1998).

Furthermore, studies on the reliability and predictability of these thresholds found that ERL and TEL values provided reliable and predictive tools for identifying concentrations of chemicals in sediments that are unlikely to be associated with adverse biological effects (to test predictability large independent data sets compiled from studies of the Atlantic, Gulf and Pacific coasts were used). It was concluded that these target values provided 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: By deriving two threshold values, i.e. a 'low' (ERL/TEL) and a 'median' (ERM/PEL), three ranges of concentration are defined, namely, those that are rarely, occasionally and frequently associated with adverse biological effects, as illustrated below (CCME 1995, Long and MacDonald, 1998):



Canada, Australia and New Zealand opted for the National Status and Trends approach, after a critical review of international approaches (CCME, 1995; ANZECC, 2000).

As few reliable data on sediment toxicity were available for either Australia or New Zealand, it was decided to adopt the ERL/ERM values as applied in the National Status and Trends Program (NOAA, 1999; Long et al., 1995). The 'low' value corresponds to the ERL of the NOAA listing, while the 'high' value corresponds to the ERM value. The 'low' or ERL value is used at the 'trigger value'. For substances that were considered important, but for which the National Status and Trends Program did not propose target values, other international sources were used. For example, guidelines for tributyltin were estimated on the basis of equilibrium partitioning, based on data summarised from the US-EPA (ANCEZZ, 2000), while values for lindane were taken from MacDonald et al. (1996).

To provide a standardised approach to the derivation of EQTs for sediments, the Canadians developed a formal protocol, with the National Status and Trends Program Approach forming an integral part (CCME, 1995) (Figure 2.7). This protocol has also been adopted by Australia and New Zealand for any future revision of their EQTs for sediments (ANZECC, 2000).

In applying this protocol, the following are important considerations to take into account:

- In deriving EQTs for sediments linked to the protection of an aquatic ecosystem, all components (e.g. bacteria, algae, macrophytes, invertebrates and fish) need to be considered, if data are available, focusing on ecologically relevant species
- EQTs for sediments are to be refined as new and relevant scientific data become available (following the Adaptive Management Approach)
- Interim EQTs for sediments are developed where insufficient data are available.

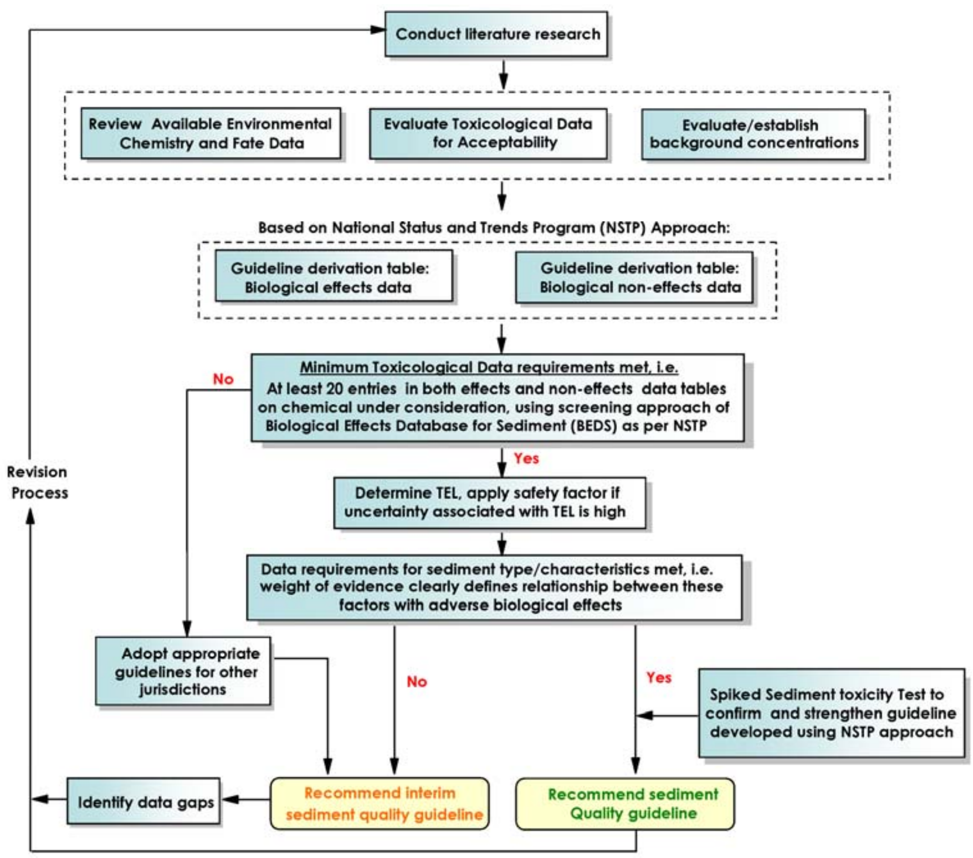


Figure 2.7: Canadian protocol for the derivation of EQTs for sediments (adapted from CCME, 1995)

Where insufficient data are available to derive EQTs for sediments, suitable interim quality targets should be derived from other jurisdictions, using the following default process that gives preference to biological effect-based values (CCME, 1995):

- Select the lowest quality targets that incorporate data on effects of sediment-associated substances on sediment dwelling organisms (e.g. effects range approach, screening level concentrations, apparent effects threshold or sediment quality triad)
- For non-ionic organic compounds select the lower value obtained using the EqP and water quality tartget value (if a water quality target exists and if no biological effect based values are available).

Select the upper background limit (at a particular site) if an interim quality target cannot be derived using the above procedures or if the value obtained through the above procedures is below the upper background concentration of the substance at the particular site

NOTE:

An important aspect that is clearly highlighted in the Canadian protocol is the consideration of background concentrations of naturally occurring chemicals, e.g. in the case of trace metals. This information should be considered in the site-specific application of sediment quality guidelines, since generically determined sediment quality targets may be lower than the respective naturally occurring substances at a particular site. This is therefore an important component that needs to be considered when deriving (site-specific) target values for a particular site from generic EQTs. A method that is commonly used to distinguish between the probable origin of trace metals (i.e. natural versus anthropogenic) involves the determination of the ratio of trace metal concentrations to that of a reference element at a number of uncontaminated sites (such ratios are relatively constant in the earth's crust). Elements that are typically used in this regard are aluminium, iron and lithium. The relationship between the trace element and reference element is typically linear. Usually anthropogenic enrichment of the trace element is suspected when the trace element to reference element (e.g. aluminium) at a site exceeds the upper 95% confidence limit, calculated from a simple linear regression (CCME, 1995). Note that where the (linear) relationship between trace elements and the reference element is very strong (e.g. r^2>9), target values derived in this manner may actually be too strict.

Currently, most of the sediment quality targets for Canada are interim values, derived from other jurisdictions. The target values adopted are those put forward by MacDonald et al. (1996) using the PEL/TEL approach rather than the ERL/ERM approach (CCME, 2002).

Target values developed in terms of the National Status and Trends Program Approach does have a number of limitations that should be taken into account (Long and MacDonald, 1998), namely:

- There are many substances that could be highly toxic for which SQG are currently not available
- These targets do not address bioaccumulation pathways
- These targets are not toxicity thresholds, i.e. there is no certainty that they will always correctly predict toxicity or non-toxicity
- These targets are best applied in conjunction with measures such as toxicity tests and/or benthic community surveys and/or bioaccumulation tests, particularly in sediments showing intermediate concentrations
- Care should be taken when using these sediment quality targets to identify the contaminants that are actually causing toxicity in sediments with complex mixtures of chemicals. Other, more precise methods, such as spiked sediment toxicity tests, should rather be applied to confirm which chemicals actually warrant the greatest concern.

Equilibrium Partitioning Approach (US-EPA)

To assist regulatory authorities in making decisions concerning contaminated sediments, the US-EPA embarked on studies to develop defensible equilibrium partitioning sediment benchmarks (i.e. sediment quality guidelines based on the EqP approach), primarily for non-ionic organic compounds. From the available literature, guidance in this regard has been documented for dieldrin, endrin and a mixture of PAHs (US-EPA 2003c, d and e).

The US-EPA also highlights the limitations of using this approach, namely:

- EqP models derive sediment guideline values from water quality guideline values and the partition coefficient between sediment/pore water, assuming that the level of protection provided by the water quality guideline for a particular substance is similar to that required by benthic organisms. These guidelines are therefore not considered suitable where locally important benthic species are very sensitive or where sediment organic carbon is less than 0.2%, the reason being that, at such low organic carbon concentrations, second-order effects such as particle size and adsorption to non-organic mineral fractions become more important (US-UPA, 2003e, ANZECC, 2000)
- Antagonistic, additive or synergistic effects of other sediment contaminants in combination with the specific substance are not addressed
- Potential for bioaccumulation and trophic transfer is not addressed.

As a result, guidelines derived from EqP models should not be used as stand-alone or pass-fail criteria for all applications but, rather, exceedances of these values could trigger collection of additional assessment data.

2.2.2 Implementation Practices

EQTs for sediments are primarily used to set targets for sediment quality within broader management strategies, so as to sustain marine aquatic health in the long term. They can also be used as benchmarks for sediment chemistry data, either obtained through monitoring programmes or simulated through modelling studies (e.g. to asses potential impacts from future developments).

Generic EQO/Ts are usually set at a national or federal level to provide guidance to local managers and responsible authorities to derive site-specific quality objectives or benchmarks. The aim is to set generic EQTs at reasonably conservative levels, so that adverse biological affects are not predicted when the concentration of a sediment-associated toxic substance is below or at the target value. The potential for adverse biological effects is recognised when guideline values are exceeded (CCME, 1995).

Still, generic EQTs for sediments are NOT standards (i.e. legally enforceable numbers) and it is essential to further investigate site-specific factors, for example, site background concentrations, bio-availability of toxic substances, and susceptibility of local biological communities to the toxic effects of a toxic substance.

In essence, generic EQTs for sediments (like EQTs for coastal waters) are a means of dealing with a complex issue (i.e. the aquatic marine ecosystem) in a phased approach, their application being the first phase.

In a recent review of international sediment quality criteria, Burton (2002) also emphasised the limitation of sediment quality targets and concluded that such targets should be used only in a “screening” manner or in a “weight-of-evidence” approach. Aquatic ecosystems (including sediments) must be assessed in a ‘holistic’ manner, in which multiple other components are assessed (e.g., habitat, hydrodynamics, resident biota, toxicity and physico-chemistry) by using integrated approaches.

The above-mentioned caution is echoed in the implementation of generic sediment quality target values worldwide (CCME, 1995; ANZECC, 2000), as illustrated by the Canadian approach (Figure 2.8) (CCME, 1995).

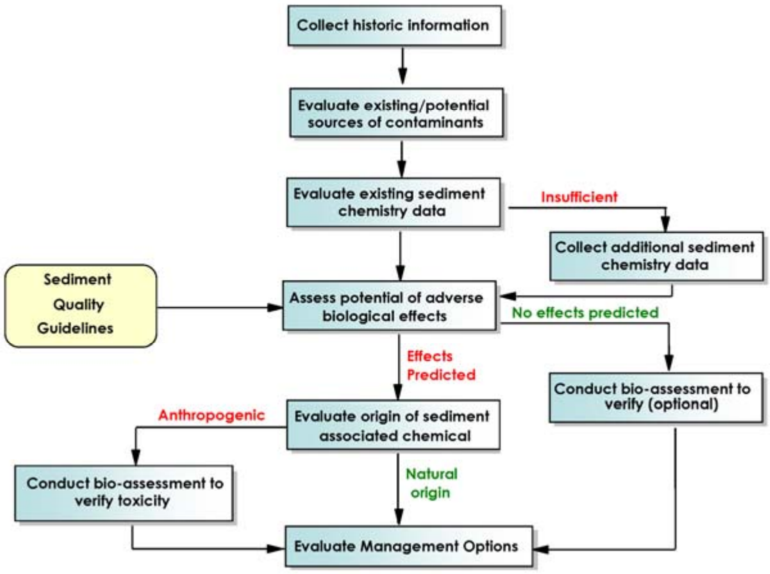


Figure 2.8: Implementation of EQTs for sediments in Canada (adapted from CCME, 1995)

Whilst the Australian and New Zealand approach is focused mainly on the use of sediment quality target values as a benchmark for assessing monitoring data, it also highlights the importance of taking local biogeochemical and ecological factors into account (Figure 2.9)

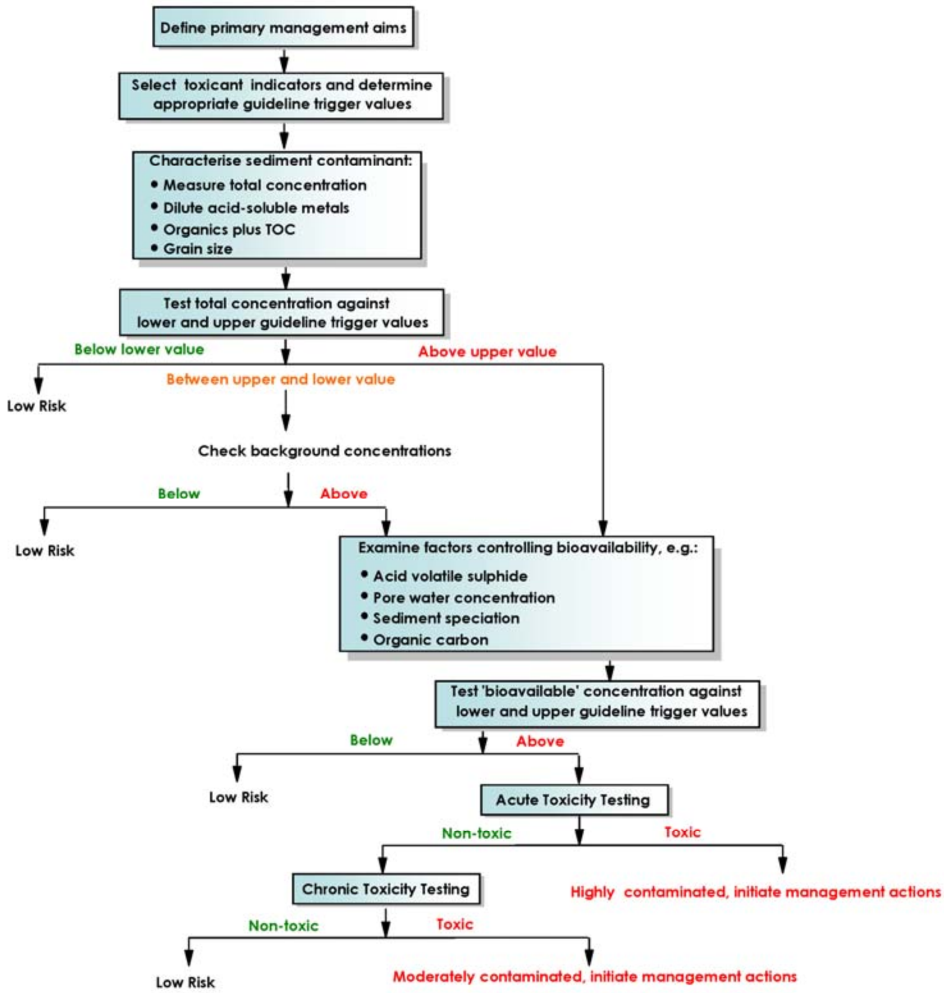


Figure 2.9: Application of EQTs for sediments in Australia and New Zealand as part of monitoring programmes (ANZECC, 2000)

2.3 Recreational use

EQO/Ts (or water quality guidelines) linked to recreational use of coastal waters have received much attention worldwide. For the purpose of this review, the criteria and guidelines from the following countries and organisations were reviewed:

World Health Organisation

The World Health Organisation (WHO) published a document entitled *Guidelines for Safe Recreational Water Environments* (WHO, 2003). These guidelines are intended to be used as the basis for the development of international and national approaches (including standards and regulations) to manage recreational water environments.

New Zealand

New Zealand has recently updated its microbiological water quality guidelines for recreational areas (NZME, 2003). The new approach largely adopted the revised WHO approach as documented in 'Annapolis Protocol' (WHO, 1999) and the *Guidelines for Safe Recreational Water Environments* (WHO, 2003).

Australia

Australia is in the process of revising its water quality guidelines for recreation in alignment with recent developments put forward by the WHO (1998, 2003). Until these revised guidelines are endorsed, water quality guidelines in recreational waters will be applied as per ANZECC (2000).

European Union

In the European Union, the management of bathing water quality is addressed in European environmental legislation, namely the Council Directive concerning the management of bathing water quality (CEC, 2006b) that repeals the previous directive (CEC, 1976).

The EU does not distinguish between different recreational categories and focuses mainly on the protection of human health in terms of *microbiological contaminants*. The 2006 Directive lays down two parameters for analysis; intestinal enterococci and *Escherichia coli* (*E. coli*) (instead of nineteen in the 1976 Directive). Other parameters that may possibly be taken into account include the presence of cyanobacteria or microalgae.

Canada

In preparing the Canadian water quality guidelines for recreational water quality, a working group thoroughly reviewed the existing (international) criteria, current indicators of hygienic quality, water quality data from recreational areas in various parts of Canada and pertinent epidemiological studies (CMNHW, 1992).

United States

In terms of recreational use, the US-EPA water quality guidelines focus on microbiological parameters, in particular for primary contact recreation (US-EPA, 1986b, 2002b). The US-EPA also provides limited guidance on setting target values for toxic substances for recreational waters (US-EPA, 2000b).

2.3.1 Approach and Methodologies

Recreational use of coastal waters fits into different categories, based on the degree of water contact, (ANZECC, 2000; RSA DWAF, 1995b; WHO, 2003) namely:

- Whole-body (or primary) contact—recreational activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wetted by spray, and where it is likely that some water will be swallowed, e.g., swimming, diving.
- Incidental (or secondary) contact—recreational activity in which only the limbs are regularly wetted and in which greater contact (including swallowing water) is unusual, e.g. boating, fishing, wading.
- No contact—recreational activity in which there is normally no contact with water (e.g. angling from shore), or where water is incidental to enjoyment of the activity (such as sunbathing on a beach).

In terms of water quality, the following key aspects are important in relation to recreational use of coastal waters:

- Aesthetics
- Protection of human health relating to toxic substances
- Protection of human health relating to microbiological contaminants.

Aesthetics (Objectionable matter)

EQTs for recreational waters related to aesthetic issues are usually narrative and typically require that areas be free from (RSA DWAF, 1995b; ANZECC, 2000a; CEC, 2006b; CMNHW, 1992):

- Objectionable floating matter or oily films
- Non-natural matter that will settle to form objectionable deposits on the seabed
- Submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger to recreational users
- Objectionable smells or odours.

Such EQTs usually apply to all the categories of recreational uses, as described above.

Examples of available EQTs that are recommended for the aesthetic quality of recreational waters are summarised in Table 2.2.

TABLE 2.2: Summary of available EQTs recommended for aesthetic quality of coasta waters

COUNTRY	RECOMMENDED EQT
Australia	Natural visual clarity should not be reduced by more than 20%. Natural hue of the water should not be changed by more than 10 points on the Munsell Scale Natural reflectance of the water should not be changed by more than 50%. Horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m. Macrophytes, phytoplankton scums, filamentous algal mats, sewage fungus, leeches, etc. should not be present in excessive amounts. Direct contact activities should be discouraged if algal levels of 15 000–20 000 cells/mℓ are present, depending on the algal species. Oil and petrols should not be noticeable as a visible film on the water nor should they be detectable by odour
Canada	Turbidity and colour should not be so intense as to impede visibility in areas used for swimming e.g. 100 platinum-cobalt (Pt-Co) units or 50 Nephelometric Turbidity Units (NTU). Water should be sufficiently clear that a Secchi disc is visible at a minimum depth of 1.2 m. Water should be as free as possible from nuisance organisms that could affect swimmers. Nuisance is defined as something that can cause harm or is annoying, unpleasant, or obnoxious Water should be free from substances attributable to wastewater or other discharges in amounts that would interfere with the existence of life forms of aesthetic value a) materials that will settle to

COUNTRY	RECOMMENDED EQT
	form objectionable deposits b) floating debris, oil, scum, and other matter c) substances producing objectionable colour, odour, taste, or turbidity d) substances and conditions or combinations thereof in concentrations that produce undesirable aquatic life. Oil or petrols should not be present in concentrations that: a) can be detected as a visible film, sheen, or discolouration on the surface b) can be detected by odour c) can form deposits on shorelines and bottom sediments that are detectable by sight or odour.
EC	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 macro-algae 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.
South Africa	Water should not contain 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 putrescence. 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.

Toxic Substances

Although international guidance on setting quality targets for toxic substances in recreational waters is available, e.g. US-EPA (2002b), the WHO, in its studies, concluded that the concentrations in which these substances occur, generally do not seem to represent a serious health risk for recreational users (WHO, 2003). In most cases, the concentrations of contaminants are found to be below drinking-water target values. The WHO therefore recommends that, as long as care is taken in their application, the WHO Guidelines for Drinking-water Quality (WHO, 2004) can be used as a starting point for 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. A similar approach is recommended in the Australian guidelines, in which the 1987 drinking water guidelines for toxic substances were applied (NHMRC and AWRC, 1987). However, those guidelines have since been revised and updated (NHMRC and ARMCANZ, 1996 updated 2001).

Water quality target values for toxic substances typically apply to the category: Primary Contract Recreation and to a lesser extent to the Category: Secondary Contact Recreation.

Microbiological contaminants

The most important (and most researched) aspect of water quality guidelines for recreation waters relates to the selection of microbiological indicators that have the most appropriate 'quantifiable relationship between the density of an indicator in the water and the potential human health risks involved in the water's recreational use' (US-EPA, 1986a).

In this regard, most countries found enterococci to be the most suitable indicator for marine waters (ANZECC, 2000; CMNHW, 1992; US-EPA, 1986a; US-EPA, 2002b; WHO, 2003, NZME, 2003) (Table 2.3). A number of deficiencies with using faecal coliform as indicator organism of health risks in marine waters have been documented (McBride et al., 1991) and recent epidemiological studies also showed poorer relationships between faecal coliform densities and illness rates in bathers than are obtained using enterococci (Cabelli 1983a and 1983b, Cabelli et al. 1982 and 1983). Furthermore, there is now considerable evidence that faecal coliforms die off faster than pathogens under certain circumstances and may, therefore, go undetected during beach monitoring programmes, resulting in the disease risks being underestimated (CMNHW, 1992).

TABLE 2.3: Summary of microbiological EQTs recommended for coastal recreational waters

COUNTRY	RECOMMENDED EQT
US-EPA	35 counts/100 ml (enterococci), based on the <u>geometric mean</u> of at least 5 samples, taken during a period not to exceed 30 days. Single sample maximum (SSM) should not exceed: • 104 for designated beach area (75%ile) • 158 for moderate full body recreation (82%ile) • 276 for lightly used full body contact (90%ile) • 501 for infrequent full body contact (95%ile)
Australia	<u>Primary contact</u>: 35 counts/100 ml (enterococci) based on the <u>median</u> concentration over bathing season (maximum number in any sample: 60–100 counts/100 ml), alternatively… 150 counts/100ml (faecal coliform) based on the median concentration over the bathing season (minimum of 5 samples taken at regular intervals not exceeding 1 month, 4 out of 5 samples containing less than 600 counts/100 ml) <u>Secondary contact</u>: 230 counts/100 ml (enterococci) based on the median concentration over bathing season (maximum number in any 1 sample: 450–700 counts/100 ml), alternatively… 1000 counts/100ml (faecal coliform) based on the median concentration over bathing season should not exceed 1000 counts/100 ml (minimum of 5 samples taken at regular intervals not exceeding 1 month, 4 out of 5 samples containing less than 4000 counts/100 ml NOTE: Although the Australian guideline also recommends limits for faecal coliform, enterococci is the preferred indicator for marine waters (ANZECC, 2000a)
Canada	35 counts/100 ml (enterococci) based on the geometric mean of at least 5 samples, taken during a period not to exceed 30 days. Resample if any sample exceeds 70 counts/100ml. If it can be demonstrated that either faecal coliform or *E. coli* are suitable indicators: 200 counts/100ml (faecal coliform) based on the geometric mean of at least 5 samples, taken during a period not to exceed 30 days. Resample if any sample exceeds 400 counts/100 ml
WHO	Refer to Table 2.4
New Zealand	
EC	Refer to Table 2.5
Mauritius	Total coliform: Direct contact recreation areas: 1000 CFU/100 ml Secondary contact recreation areas: 5000 CFU/100 ml Faecal coliform: Direct contact recreation areas: 200 CFU/100 ml Secondary contact recreation areas: 1000 CFU/100 ml
South Africa	Maximum acceptable count per 100 ml of faecal coliforms: 100 in 80 % of samples 2000 in 95 % of samples (if exceeded apply the same target values to *E. coli*)

The enterococci target recommended by the US-EPA was originally based on a series of epidemiological studies conducted by the UP-EPA, based on an ('acceptable') illness rate of 19 illnesses per 1000 for marine waters (this criterion is primarily aimed at protecting recreational users from acute gastrointestinal illness and may not provide protection against other waterborne diseases, such as eye, ear, skin, and upper respiratory infections, nor illnesses that may be transmitted from swimmer to swimmer) (US-EPA, 1986a; US-EPA, 2002b). This target value has also been adopted by other countries, e.g. Australia and Canada (ANZECC, 2000; CMNHW, 1992), with some modifications (Table 3).

The potential for indicator microbial survival and regrowth (both *E. coli* and enterococci) in tropical areas has resulted in doubts concerning the interpretation of indicator microbiological concentrations in tropical environments, especially given that the studies used to establish the US-EPA guidelines were conducted in Boston Harbor, MA, New York City, NY, and New Orleans, LA, which are not representative of tropical regions. In these situations, indicator microbiological 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). Given this problem, the State of Hawaii (USA) currently utilizes *Clostridium perfringens*, a spore-forming obligate anaerobe, to supplement its microbiological monitoring programme. *C. perfringens* is not capbable of regrowth in aerobic environments but persists for long periods of time and, its detection may therefore not be an indicator of recent sewage contamination (Hawaii Department of Health, 2000). The additional EQT proposed for *C. perfringens* is:

- *Geometric mean of equal or less than 5 counts/100 ml.*

The WHO in their studies (WHO, 2003; Kay et al., 2004) concluded that in marine waters only intestinal enterococci (faecal streptococci) showed a dose–response relationship for both gastrointestinal illness (GI) and acute febrile respiratory illness (AFRI). Instead of using 'single' target values that classify a beach either as 'safe' or 'unsafe', the WHO opted for a range of target values corresponding to different levels of risk. The target values for different risk levels were derived from a number of key studies and are based on exposure of healthy adult bathers to marine waters in temperate north European waters (WHO, 2003) (Table 2.4).

TABLE 2.4: The World Health Organisation microbiological target values recommended for recreational waters (representing different risk levels) (WHO, 2003)

CATEGORY	95th PERCENTILE OF ENTEROCOCCI per 100 ml	ESTIMATED RISK PER EXPOSURE
A	<40	<1% gastrointestinal (GI) illness risk <0.3% acute febrile respiratory (AFRI) risk
B	40 – 200	1–5% GI illness risk 0.3–1.9% AFRI risk
C	201 – 500	5–10% GI illness risk 1.9–3.9% AFRI risk
D	> 500	>10% GI illness risk >3.9% AFRI risk

The above approach has also been adopted by New Zealand (NZME, 2003).

NOTE:

It has been noted that faecal coliform and* E. coli*, although not well correlated with health risks, may be used as indicators in addition to enterococci in environmental 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 a waste stabilisation pond (WSP). Enterococci are damaged in WSP, whereas faecal coliform 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 faecal coliforms (NZME, 2003).

Also, while it is correct to infer that water exceeding the 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. 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 is capable of destroying pathogenic micro-organisms. Also, wastewater plants may not always operate 100% of the time (e.g. during high water flows) (NZME, 2003).

The European Union identifies different categories of water quality, each with a corresponding target values for intestinal enterococci and *E. coli* (CEC, 2006b) (Table 2.5)

TABLE 2.5: The European Union microbiological target values recommended for recreational waters (representing different risk levels) (CEC, 2006b)

PARAMETER	WATER QUALITY CATEGORY (cfu per 100 ml)		
	Excellent	Good	Sufficient
Intestinal Enterococci	100*	200*	185**
E. coli	250*	500*	500**

* *Based upon a 95 percentile evaluation;* ** *Based upon a 90 percentile evaluation*

South Africa still uses faecal coliform as a broad-spectrum indicator of faecal pollution and the sanitary quality of water – at the time considered the most appropriate for their situation (RSA DWAF, 1992; RSA DWAF, 1995b) (Table 2.3). Potential shortcomings of using faecal coliform as indicator, however, were realised and as a result additional tests (including enterococci, human viruses and/or coliphages) were also recommended where inspection of beaches suggested potential health risks.

2.3.2 Implementation Practice

Throughout the world, the implementation of EQO/Ts for beaches is tending to move away from the traditional approach of classifying recreational waters as either safe or unsafe (based on a percentage compliance with a faecal indicator organism) to an approach of ranking recreational waters, i.e. recognising a gradient of health risks with increasing faecal pollution of human and animal origin. This approach requires that a range of water quality categories be defined and that individual locations be classified according to the level of potential health risks.

Both the World Health Organisation and the European Union are in support of using such a holistic approach, with countries like New Zealand and, soon, Australia following suit (WHO, 2003, CEC, 2006b; ANZECC, 2000; New Zealand Land Ministry of Environment, 2003). The Blue Flag Initiative (FEE, 2004) and Canada (CMNHW, 1992) also propose a more holistic approach to the management of recreational area, but do not necessarily allow for different classes associated with different risk rates.

World Health Organisation and New Zealand

Where the traditional approach for managing beach water quality is primarily based on microbiological quality, the WHO's new approach is more holistic (WHO, 2003). It recognises that potential risks or hazards associated with recreational water environments comprise different categories, namely:

- physical hazards (leading, for example, to drowning or injury)
- cold, heat and sunlight
- (microbiological) water quality
- contamination of beach sand
- algae and their toxic products
- chemical and physical agents (e.g. toxic substances)
- presence of dangerous aquatic organisms.

With reference to microbiological quality, classification or ranking is primarily based upon a combination of:

- degree of influence of (human) faecal material (sanitary inspection)
- counts of faecal bacteria (microbiological quality assessment).

The aim of the sanitation inspection is to identify all sources of faecal pollution (particularly human faecal pollution). 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 river is receiving sewage discharges)
- contamination from bathers (e.g. excreta)
- shipping and boating activities (e.g. inappropriate sewage disposal practices).

The Recreational Classification of a beach is based on the Sanitary Inspection Category and Microbiological Quality Assessment Category (using the microbiological guideline values as provided in Table 2.4) and is derived as illustrated in Table 2.6. The recreational beach grading process of the WHO is summarised in Figure 2.10.

TABLE 2.6: The World Health Organisation Recreational Classification system

<table>
<tr><th colspan="2"></th><th colspan="5">MICROBIOLOGICAL QUALITY ASSESSMENT CATEGORY
(95TH PERCENTILE ENTEROCOCCI/100 ml)</th></tr>
<tr><th colspan="2"></th><th>A
(<40)</th><th>B
(41-200)</th><th>C
(201-500)</th><th>D
(>500)</th><th>Exceptional circumstances</th></tr>
<tr><th rowspan="6">SANITARY INSPECTION CATEGORY</th><th>Very Low</th><td>Very good</td><td>Very good</td><td>Fair</td><td>Follow-up</td><td rowspan="5">Action required</td></tr>
<tr><th>Low</th><td>Very Good</td><td>Good</td><td>Fair</td><td>Follow-up</td></tr>
<tr><th>Moderate</th><td>Good</td><td>Good</td><td>Fair</td><td>Poor</td></tr>
<tr><th>High</th><td>Good</td><td>Fair</td><td>Poor</td><td>Very poor</td></tr>
<tr><th>Very high</th><td>Follow-up</td><td>Fair</td><td>Poor</td><td>Very poor</td></tr>
<tr><th>Exceptional circumstances</th><td colspan="5">Action required</td></tr>
</table>

NOTE

In the microbial water quality assessment, the sampling programme should be representative of the range of conditions in the recreational water environment while it is being used, and a sufficient number of samples should be collected. The precision of the estimate of the 95th percentile is higher when sample numbers are increased. For example, the number of results available can be increased significantly by pooling data from multiple years, unless there is reason to believe that local (pollution) conditions have changed. For practical purposes, data on at least 100 samples from a 5-year period and a rolling 5-year data set can be used for water quality assessment purposes.

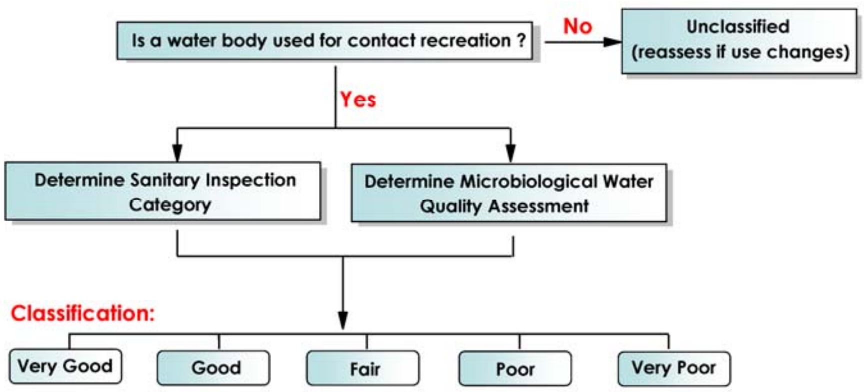


Figure 2.10: The recreational beach grading process of the WHO (adapted from WHO, 2003)

In terms of day-to-day management, this approach also provides a means of assessing whether immediate actions need to be implemented to reduce exposure. For example, managers can identify periods when water quality is poor and then ensure that advisory notices are put out warning the public of increased risk. The management component of this approach has been further developed as part of the New Zealand guidelines (see below).

In essence, this approach is seen to have the benefit of protecting public health, but also of providing the potential both to improve the classification of a location through low-cost measures as well as to enable the safe use of areas for certain periods that might otherwise be considered inappropriate for recreational use.

New Zealand also applies the WHO approach with some modifications. In the case of New Zealand, recreational areas are also classified in terms of a qualitative risk grading of the catchment (sanitary survey), supported by the direct measurement of appropriate faecal indicators (microbiological quality assessment) (NZME, 2003).

In addition, alert and action target levels are used for surveillance throughout the bathing season (i.e. for the day-to-day management). The 'Suitability for Recreation Grade' is allocated to a site through a risk assessment approach, by combining historical microbiological results and sanitary inspection information, which provide an assessment of the condition at any given time. Single samples are used to identify any immediate health risk as part of the day-to-day management of recreational beaches. For New Zealand, the grading, surveillance, alert and action process is illustrated in Figure 2.11.

A detailed Catchment Assessment (or Sanitary Survey) checklist is provided in the New Zealand Guideline Document (NZME, 2003).

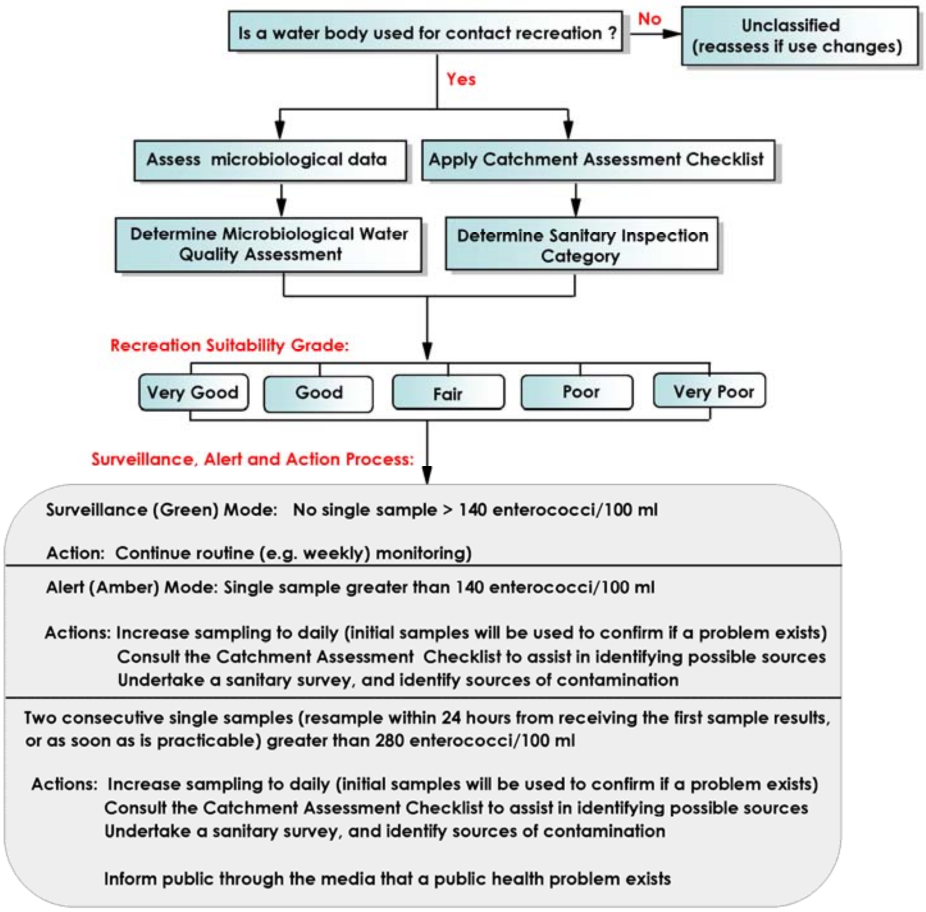


Figure 2.11: New Zealand grading and surveillance, alert and action process for the management of recreational use of marine waters (adapted from NZME, 2003)

European Union

The EU requires member state to conduct a bathing water quality assessment comprising (CEC, 2006b):

- Comparison to microbiological target values (Table 2.7); and
- Bathing beach profile (reviewed at regular intervals as specified in the Directive).

The bathing water quality assessment should be done at the end of every season on the basis of the information gathered during that season and the three preceding ones in principle. Following the assessment, bathing waters are classified in one of four quality levels: poor, sufficient, good or excellent according to specific criteria (Table 2.7). The category "sufficient" is the minimum quality threshold to be attained by the end of the 2015 season at the latest.

NOTE

The bathing water profile for the Europena Union is to consist 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;***
- ***An assessment of the potential for proliferation of macro-algae 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,***
- ***Location of the monitoring point.***

TABLE 2.7: Bathing water classification system of the European Union (CEC, 2006b)

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 2.5) 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 • the 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 2.5) 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 • the 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,

QUALITY LEVEL	SPECIFICATION
	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 2.5) 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 • the 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 2.5).

Blue Flag Campaign

The Blue Flag campaign is an international initiative that was started in the mid-1980s to encourage local authorities to provide clean and safe beaches for local populations and tourists (UNEP, 1996). It is a voluntary and non-punitive scheme and is targeted at local authorities, the general public and the tourism industry. The main objectives of the Blue Flag campaign are to:

- improve understanding of the coastal environment
- promote the incorporation of environmental issues in the decision-making processes of local authorities and their partners.

In essence, beaches that meet specific criteria are annually awarded a Blue Flag, which can be used as part of the local tourism marketing strategy. Areas for which specific criteria are assigned are:

- water quality
- beach management and safety
- environmental information and education.

Although not legally required, South Africa (through its Department of Environmental Affairs and Tourism) initiated the Blue Flag Campaign to encourage socio-economic development and to improve coastal livelihoods through better management of marine and coastal-related resources. Detailed criteria differ slightly from one region to another (FEE, 2004).

Canada

The holistic approach followed by Canada in assessing and managing the quality of recreational waters includes the following (CMNHW, 1992):

- Environmental health assessments. An annual assessment is carried out prior to the bathing season in order to identify all potential sources of contamination and physical hazards that could affect the recreational area.
- Epidemiological evidence. Wherever possible, surveillance for bather illness or injuries is established, which can either be comprehensive epidemiological studies or formal and informal reporting from physicians and hospital emergency departments.
- Indicator organism monitoring. Routine microbiological monitoring of a recreational area is carried out, the frequency of which is determined by the usage of the area, the environmental health assessment, and epidemiological evidence.

- Presence of pathogens. Tests for pathogenic organisms are carried out when there have been reports of illnesses, when there is suspected illness of undetermined cause, or when levels of an indicator organism demonstrate a continuous suspected hazard.

2.4 Marine Aquaculture

Marine aquaculture refers to the farming of marine (or estuarine) organisms, either in off-stream (land-based) facilities or in-stream in marine and estuarine environments. 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.

In terms of setting water quality guideline values for marine aquaculture, current practice in the following countries was reviewed:

European Union

In terms of water quality management, the focus within the European Union is primarily on shellfish. Water quality requirements are documented in two main directives, namely:

- EC Directive (CEC, 2006c) - stipulating quality required for shellfish waters and that replaces the EC Shellfish Waters Directive (CEC, 1979)
- EC Shellfish Hygiene Directive (CEC, 1991) – providing limits for substances in shellfish flesh and a means of classifying shellfish growing areas.

Australia and New Zealand

The Australian and New Zealand water quality guidelines provide general guideline values for the protection of local aquaculture species in Australia and New Zealand (ANZECC, 2000).

The Shellfish Industry in Australia and New Zealand is controlled and managed in terms of the Australian Shellfish Quality Assurance Program and the New Zealand Shellfish Quality Assurance Circular. These include the classification of safe shellfish-growing areas to permit commercial harvesting for domestic and/or export markets. The classification is based on a sanitary survey and a microbiological survey (Australian Shellfish Quality Assurance Advisory Committee, 2002; MAF, 1995).

United States

The US-EPA's ambient water quality criteria provide targets aimed at minimising the risk of adverse effects occurring to humans from chronic (lifetime) exposure to substances through consumption of organisms obtained from surface waters (US-EPA, 2000b; US-EPA, 2002a).

The National Shellfish Sanitation Program (NSSP) of the United States Food and Drug Administration also requires that shellfish growing areas be classified on the basis of a sanitary survey (documenting all factors that have a bearing on water quality in a shellfish growing area). This includes microbiological surveys (US-FDA, 2007).

Canada

In Canada, the Department of Fisheries and Ocean is the leading federal agency for aquaculture and acts as both a regulator and enabler of the aquaculture sector (www.dfo-mpo.gc.ca/aquaculture/main_e.htm). The Canadian Shellfish Sanitation Program (CSSP) is jointly administered by the Department of Fisheries and Oceans, Canadian Food Inspection Agency, and Environment Canada. Its primary objective is to protect the public from the consumption of contaminated shellfish by controlling the recreational and commercial harvesting of all shellfish within Canada (CFIA, DFO and EC, 2004). The Canadian Shellfish Sanitation Program follows closely the United States National Shellfish Sanitation Program (US-FDA, 2007).

2.4.1 Approach and Methodologies

In terms of water quality requirements for marine aquaculture, the key issues to consider are:

- Protection of the health of the aquatic ecosystem so as to ensure sustainable production and quality of products
- Protection of the health of human consumers
- Tainting of seafood products.

Protection of Aquatic Organism Health

It can generally be accepted that the health of organisms used for aquaculture purposes will be protected if the water quality meets EQTs as recommended for the protection of aquatic ecosystems (particularly where the activity relies on natural stocks) (RSA DWAF, 1995; ANCEZZ, 2000).

Although countries like Australia and New Zealand do specify separate water quality targets for marine aquaculture, these are provided as a general guide for the protection of local aquaculture species (ANZECC, 2000, also summarised in Appendix C). The targets are based primarily on available international information relating to aquaculture, as well as on personal experience of local industry specialists. Their guidelines, however, do recommend that, for aquaculture species for which targets are not available or where such activities rely on wild populations of fish, crustaceans or shellfish species, EQTs for the protection of aquatic ecosystems be consulted.

At present, the European Union also specifies separate water quality targets (or limits) for physico-chemical variables and toxic substances related to the protection of organisms in shellfish waters (no details were provided on the approach and methodology that were followed in setting these target values) (CEC, 2006c, also summarised in Appendix C). The European Union, however, envisages that water quality target values related to the health of aquatic organisms will eventually be consolidated in the Water Framework Directive, which requires the establishment of a comprehensive chemical and biological monitoring system for coastal waters (CEC, 2000; CEC, 2002).

Protection of Health of Human Consumers

To protect human consumers, the allowable limits of toxic substances and human pathogens in seafood are usually legislated (i.e. limits are specified as legally enforceable standards). Therefore, even though water quality target values may be recommended for marine aquaculture (e.g. as in the US-EPA, 2002a), the legally binding limits set for toxic substances and human pathogens ultimately need to be complied with – water quality target values should therefore be applied together with such legislation.

NOTE:

An approach to link the concentration in organisms (as specified in legislation) to a recommended guideline value for surface waters (or sediments), the bioaccumulation approach, is sometimes also applied: Where the uptake of a chemical is not controlled by the organism's metabolism, a concentration of the chemical in the organism will be proportional to the concentration of the chemical in the water or food (or sediment). This can be calculated by applying known bio-concentration factors (BCF) (ANZECC, 2000)

In South Africa, for example, the legal limits for chemical and human pathogens in seafood are specified under the Foodstuffs, Cosmetics and Disinfectants Act (No. 54 of 1972) and are provided in (Table 2.8):

- Regulation - Marine food (Department of Health, 1973)
- Regulations related to metals and foodstuffs (Department of Health, 1994)

TABLE 2.8: South African legal standards for chemical and microbiological constituents in the flesh of shellfish and fish used for human consumption

PARAMETER	STANDARD	
	Shellfish	Fish
Aesthetic characteristics	No decomposition shall have occurred	
Arsenic	3 µg/g (wet mass)	1 µg/g (wet mass)
Antimony	1 µg/g (wet mass)	1 µg/g (wet mass)
Cadmium	3 µg/g (wet mass)	1 µg/g (wet mass)
Copper	50 µg/g (wet mass)	30 µg/g (wet mass)
Lead	4 µg/g (wet mass)	1 µg/g (wet mass)
Mercury (as methyl mercury)	1 µg/g (wet mass)	0.5 µg/g (wet mass)
Tin	40 µg/g (wet mass)	40 µg/g (wet mass)
Zinc	300 µg/g (wet mass)	40 µg/g (wet mass)
E. coli Type I	500 per 100 g (uncooked) 1 000 per 100 g (cooked)	
Salmonella	0 (uncooked and cooked)	
Shigella	0 (uncooked and cooked)	
Vibrio sp.	0 (uncooked and cooked)	
Staphylococcus aureus (coagulate +)	10 per g (uncooked and cooked)	
Antibiotics	None shall be present	

Another example is formed by the requirements of the European Union, as set out in the Shellfish Hygiene Directive (Table 2.9) (CEC, 1991).

TABLE 2.9: EC Requirements concerning live bivalve molluscs (CEC, 1991)

Live bivalve molluscs intended for immediate human consumption must comply with the following requirements:

1. **The possession of visual characteristics associated with freshness and viability, including shells free of dirt, an adequate response to percussion, and normal amounts of intravalvular liquid.**
2. **They must contain less than 300 faecal coliforms or less than 230 E. Coli per 100 g of mollusc flesh and intravalvular liquid based on a five-tube, three-dilution MPN-test or any other bacteriological procedure shown to be of equivalent accuracy.**
3. **They must not contain salmonella in 25 g of mollusc flesh.**
4. **They must not contain toxic or objectionable compounds occurring naturally or added to the environment such as those listed in the Annex to Directive 79/923/EEC in such quantities that the calculated dietary intake exceeds the permissible daily intake, or that the taste of the molluscs may be impaired. (The Commission shall determine the testing methods for checking the chemical criteria and the limit values applicable.)**
5. **The upper limits as regards the radionuclide contents must not exceed the limits for foodstuffs as laid down by the Community.**
6. **The total Paralytic Shellfish Poison (PSP) content in the edible parts of molluscs (the whole body or any part edible separately) must not exceed 80 microgrammes per 100 g of mollusc flesh in accordance with the biological testing method - in association if necessary with a chemical method for detection of Saxitoxin - or any other method recognized in accordance with the procedure laid down in the Directive. If the results are challenged, the reference method shall be the biological**

method.

7. The customary biological testing methods must not give a positive result to the presence of Diarrhetic Shellfish Poison (DSP) in the edible parts of molluscs (the whole body or any part edible separately).

8. In the absence of routine virus testing procedures and the establishment of virological standards, health checks must be based on faecal bacteria counts.

When there is scientific evidence indicating the need to introduce other health checks or to amend the parameters in this Chapter for the purpose of protecting public health, such measures must be adopted in accordance with the procedure laid down in the Directive.

Similar standards, applying elsewhere in the world, include:

- Australia and New Zealand Food Standards Code (ANZFA, 2007)
- United States Food and Drug Administration's website on Seafood Information and Resources (US-FDA, 2009), as well as the National Shellfish Sanitation Program (US-FDA, 2007)
- The US-EPA (2002a) also provides guidelines for toxic substances in waters in which organisms are collected for human consumption (summarised in Appendix C). These target values were primarily derived using the Methodology for deriving ambient water quality criteria for the protection of human health (US-EPA, 2000b)
- Canadian Food Inspection Agency, which specifies action levels for different seafood products (Canadian Food Inspection Agency, 2004).

NOTE:

Shellfish imported to the European Union must comply with the standards laid down in the Shellfish Directive (CEC, 1991).

In the USA, shellfish imports must meet both Federal and State requirements to gain free access to US markets. In addition, fresh and fresh frozen molluscan shellfish products must meet the specific temperature, microbiological, and identification standards contained in the NSSP. The NSSP standards have been adopted into state law and are enforced by both federal and state officials. The NSSP standards apply equally to both domestic and imported fresh and frozen shellfish (US-FDA, 2007).

The protection of the health of consumers 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, which often accumulate to high concentrations in their tissue, not only toxic substances, but also pathogenic organisms.

As human pathogenic organisms (such as bacteria, protozoa and viruses) are usually very expensive to measure on a routine basis, most countries opted 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).

Faecal coliform is universally used at the indicator organism for detecting risk to human consumers in shellfish waters. The USA, Canada, Australia and New Zealand and Mauritius all use the same target value, namely:

Median faecal coliform concentration should not exceed 14 Most Probable Number (MPN) per 100 ml with not more than 10% of the samples exceeding 43 MPN per 100 ml for a 5-tube decimal dilution test

(49 MPN for a 3-tube decimal dilution test; 28 MPN per 100 ml for a twelve-tube single dilution test; 31 CFU per 100 ml for a MF [mTEC] test – US-FDA, 2007).

This target value appears to originate from the 1986 Water Quality Criteria published by the US-EPA (Gold Book) (US-EPA, 1986a). At the time, it was accepted through international agreement that the microbiological criterion for shellfish water should be 70 total coliforms per 100 ml, using a median MPN with no more than 10% of the values exceeding 230 total coliforms (no evidence of disease outbreaks from consumption of raw shellfish grown in water meeting this criterion could be demonstrated). This criterion was considered to be a practical limit when supported by a sanitary survey, acceptable quality of shellfish meat and good epidemiological evidence (US-EPA, 1986a). Furthermore, the National Shellfish Sanitation Program initiated studies through which total coliform data could be related to numbers of faecal coliforms. These studies showed that the total coliform count should be set equivalent to a faecal coliform count.

Interestingly, the target value of the European Union refers to the cocentrations in shellfish flesh (CEC, 2006c):

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.

Tainting of Seafood Products

Tainting substances refer to a large variety of chemicals, usually organics, which 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 aquaculture and wild-capture fishing industries.

Estimated threshold concentrations above which tainting of aquatic food can be expected have been provided for South Africa, Australia and New Zealand and by the US-EPA (RSA DWAF, 1995b; ANZECC, 2000; US-EPA, 2002a) and are similar throughout. These are summarised in Appendix III.

2.4.2 Implementation Practices

The protection of the health of consumers is mainly a concern with shellfish farming or where these organisms are harvested from natural stocks. An approach that is increasingly being implemented as part of the management and control of shellfish industries, in particular, shellfish growing areas, is the classification approach (CEC, 1991; Australian Shellfish Quality Assurance Advisory Committee, 2002; MAF, 1995; US-FDA, 2007).

National Shellfish Sanitation Program 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, 2007).

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 NSSP approach largely forms the basis of the classification approaches applied in Australia, New Zealand and Canada (Australian Shellfish Quality Assurance Advisory Committee, 2002; MAF, 1995; CFIA, DFO and EC, 2004).

Although there are some minor differences in the classification sub-categories proposed by different countries, these generally include:

CLASS	DESCRIPTION
Approved	Approved areas need to be free from pollution, and shellfish from such areas are suitable for direct human consumption of raw shellfish.
Conditionally approved/restricted	Where areas are subjected to limited, intermittent pollution caused by discharges from wastewater treatment facilities, seasonal populations, non-point source pollution, or boating activity [the area can be classified as conditionally approved or conditionally restricted. However, it must be shown that the shellfish harvesting area will be open for the purposes of harvesting shellfish for a reasonable period of time and the factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' to harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Restricted areas are subject to a limited degree of pollution. However, the level of faecal pollution, human pathogens and toxic or deleterious substances are at such a level that shellfish can be made fit for human consumption by either relaying or depuration.
Prohibited	An area is classified as 'Prohibited' for shellfish harvesting if no comprehensive survey has been conducted or where a survey finds that the area is: • adjacent to a sewage treatment plant outfall or other point source outfall with public health significance • contaminated by (an) unpredictable pollution source(s) • contaminated with faecal waste so that the shellfish may be vectors for disease micro-organisms • affected by algae which contain biotoxin(s) sufficient to cause a public health risk • contaminated by poisonous or deleterious substances which may detrimentally affect the quality of shellfish. NOTE: Where an event such as a flood, storm or marine biotoxin outbreak occurs in either 'Approved' or 'Restricted' areas, these can also be classified as temporarily 'Prohibited' areas.

The general, water quality-related requirements pertaining to each of these classes are summarised in Table 2.10 (distilled from Australian Shellfish Quality Assurance Advisory Committee, 2002; MAF, 1995; CFIA, DFO and EC, 2004).

TABLE 2.10: Summary of National Shellfish Sanitation Program classification approach for shellfish growing areas (US-FDA, 2007)

CLASS	REQUIREMENTS[3]
Approved	A sanitation survey must be completed according to specification to be reviewed annually. The area shall not be contaminated with faecal coliform (as listed) and shall not contain pathogens or hazardous concentrations of toxic substances or marine biotoxins (an approved shellfish growing area may be temporarily made a prohibited area, e.g. when a flood, storm or marine biotoxin event occurs). Evidence of potential pollution sources, such as sewage lift station overflows, direct sewage discharges, septic tank seepage, etc., is sufficient to exclude the growing waters from the approved category. Systematic Random Sampling Strategy[1]: Faecal coliform median (or geometric mean MPN or MF (mTEC) of the water sample results shall not exceed 14 per 100 ml and the estimated 90th percentile shall not exceed an MPN or MF (mTEC) of: (a) 43 MPN per 100 ml for a five tube decimal dilution test; (b) 49 MPN per 100 ml for a three-tube decimal dilution test; or (c) 31 CFU per 100 ml for a MF (mTEC) test. Total coliform geometric mean of the water sample results for each sampling station shall not exceed 70 MPN per 100 ml and the estimated 90th percentile shall not exceed an MPN of: (a) 230 MPN per 100 ml for a 5-tube, decimal dilution test; (b) 330 MPN per 100 ml for a 3-tube, decimal dilution test. Adverse Pollution Sampling Strategy[2]: The fecal coliform median (or geometric mean MPN or MF (mTEC) of the water sample results shall not exceed 14 per 100 ml and the estimated 90th percentile shall not exceed an MPN or MF (mTEC) of: (a) 43 MPN per 100 ml for a five tube decimal dilution test; (b) 49 MPN per 100 ml for a three-tube decimal dilution test; or (c) 31 CFU per 100 ml for a MF (mTEC) test. Ttotal coliform geometric mean of the water sample results for each sampling station shall not exceed 70 MPN per 100 ml and the estimated 90th percentile shall not exceed an MPN of: (a) 230 MPN per 100 ml for a 5-tube, decimal dilution test; (b) 330 MPN per 100 ml for a 3-tube, decimal dilution test.
Conditionally approved/restricted	Factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. A management plan must be/shall be developed for every conditionally approved/restricted area. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' to harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Systematic Random Sampling Strategy and Adverse Pollution Sampling Strategy: Faecal coliform median or geometric mean MPN of the water sample results shall not exceed 88 per 100 ml and the estimated 90th percentile shall not exceed a MPN of: (a) 260 MPN per 100 ml for a five tube decimal dilution test; or (b) 300 MPN per 100 ml for a three-tube decimal dilution test. Total coliform geometric mean MPN of the water sample results for each station shall not exceed 700 per 100 ml and not more than 10% of the samples shall exceed an MPN of: (a) 2300 MPN per 100 ml for a 5-tube, decimal dilution test; or (b) 3300 MPN per 100 ml for a 3-tube, decimal dilution test; or (c) 1386 MPN per 100 ml for a 12-tube, single dilution test.
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 the adverse pollution conditions described in the growing area management plan

3: The implementation and interpretation of the microbiological limits is subject to some understanding of statistical shortcomings which are discussed in further detail in US-FDA (2007)

European Union's Approach

The classification approach applied by the European Union, as set out in the Shellfish Hygiene Directive (CEC, 1991), differs from that of the NSSP (US-FDA, 2007) in that it classifies shellfish growing areas on the basis of the limits of constituents in shellfish flesh. The classification systems consist of 3 classes (Table 2.11)

TABLE 2.11: EC: Classification of shellfish growing areas

Class A	Life bivalve molluscs from these areas must meet the requirements as set out in Table 2.9 and can be sold direct for consumption
Class B	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three-dilution MPN-test of 6 000 faecal coliforms per 100 g of flesh or 4 600 *E. Coli* per 100 g of flesh in 90 % of samples. Organisms can be collected but only placed on the market for human consumption after treatment in a purification centre, after relaying. After purification or relaying, all the requirements set out Table 2.9 must be met.
Class C	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three-dilution MPN-test of 60 000 faecal coliforms per 100 g of flesh. Organisms can be collected but placed on the market only after relaying over a long period (at least two months), whether or not combined with purification, or after intensive purification for a period to be fixed in accordance with the Directive. After purification or relaying, all the requirements set out Table 2.9 must be met.
Waters below Class C are prohibited for Shellfish harvesting.	

2.5 Industrial Use

EQO/Ts for industrial uses of coastal marine water, other than marine aquaculture, do not seem to be addressed explicitly in other international guideline documents. The South African guidelines do provide limited targets for some industrial uses, realising that these are very much dependent on the type of industry (DWAF, 1995b). The South African guidelines recognise the following activities as industrial (beneficial) uses of marine water that require an acceptable water quality:

- Seafood processing
- Salt production
- Desalination
- Aquariums and oceanariums
- Harbours and ports
- Cooling water intake
- Ballast water intake
- Coastal mining
- Make-up water for offshore marine outfalls
- Exploration drilling
- Scaling and scrubbing.

The EQO/Ts for these uses are mainly focused on water quality matters related to industrial processes, i.e. where water quality may interfere with the mechanical operations or with the industrial processes. In the industrial uses of seawater, additional factors may also be of importance, e.g. human health aspects where the products will be used for human consumption, or biological health, where marine organisms are included in the process.

ANZECC (2000) concluded, after extensive consultation with representative industrial groups, that no specific guidance for industrial water use will be provided, because industrial water requirements are so varied (both within and between industries) and sources of water for industry have other coincidental environmental values that tend to drive management of the resource. However, industrial water use continues to be a recognised environmental value that has high economic benefit and must therefore be given adequate consideration during the planning and management of water resources.

3. ASSESSMENT OF MAIN ECOTONES IN THE WIO REGION

3.1 Introduction

Globally at least 40% of the world's population lives in coastal areas and coastal cities have expanded rapidly over the past decade (Creel, 2003). The WIO region has been no exception and has been subject to rapidly increasing populations, urbanization and industrialization. This region comprises ten countries along the east African coast, from South Africa to Somalia. Eight of these countries are participating in the WIO-LaB project. Four are coastal states (South Africa, Mozambique, Kenya and Tanzania) and the others are island states (Comoros, Mauritius, Seychelles and Madagascar). Coastal zones in these states support over 11000 species of plants and animals from a diverse range of habitats. In most of these countries large segments of coastal communities are heavily dependent on marine resources for food and as a source of revenue. As a result of poverty, pollution and the mismanagement of these resources, the marine and coastal environments here are becoming increasingly degraded.

This report describes the main ecotones of the WIO region and reviews the pressures on these ecosystems, with emphasis on those arising from land-based activities. The sensitivity of these ecotones and key species which inhibit them is assessed from available literature. This is done with a view to prepare EQO/Ts for the coastal zone of the WIO region.

3.2 Main Ecotones within WIO Region

The term ecotone as used here is not that of the traditional sense (i.e. a transitional area between two adjacent ecological communities). Rather the term refers to an ecologically distinct zone which shows some degree of ecological homogeneity rather than transition. For the purposes of this study, the main ecotones within the WIO region are considered to be sea grass beds, mangrove forests and coral reefs. Considerable thought was given to including estuaries as an additional ecotone. However, estuaries are complex systems that comprise numerous habitats and gradients in physico-chemical conditions, and are better considered here as domains (along with nearshore and offshore, for example). In addition to this, consideration of sea grass beds and mangroves allowed the two most sensitive estuarine habitat types to be included in the assessment.

Sea grass beds are a predominant feature throughout the shallow waters of the WIO region, and serve as a habitat to a wide diversity of marine organisms ranging from algae and invertebrates through to the vertebrate classes. Larger animals that are threatened species (marine turtles and dugongs) depend on these ecosystems as a source of food (Richmond, 2002). These habitats are continuously degraded either by direct removal or indirect impacts of land based activities. Key taxa within sea grass ecotones are bacteria, fungi, macro and micro-algae, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (shrimp, prawns, crabs, isopods and amphipods), fish, marine turtles and dugongs.

Mangroves in the WIO region are species rich habitats that support major fisheries, particularly in the estuaries of Mozambique, Tanzania and Kenya. Ten species of mangroves exist in the WIO region, with the most extensive forests located along the Mozambican coastline (Richmond, 2002, Figure 3.1). Despite the ecological value of mangroves, these habitats are facing severe degradation from human activities. Key taxa that typically associate with mangroves are bacteria, fungi, macro and micro-algae, invertebrate and vertebrate larvae, post larvae and juveniles, polychaetes, bivalves, gastropods, crustaceans (shrimp, prawns, crabs, isopods, amphipods), fish, marine turtles and dugongs.

Extensive and highly productive coral reefs fringe over 1500 km of the WIO region coastline (Figure 3.1). Besides the massive bleaching event in 1998 which brought some species to extinction, coral reefs are negatively impacted by direct and indirect anthropogenic activities. Typical fauna and flora that use coral reefs are macro and micro-algae, tunicates, sponges, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (prawns, crabs, lobsters, isopods, amphipods) and fish.

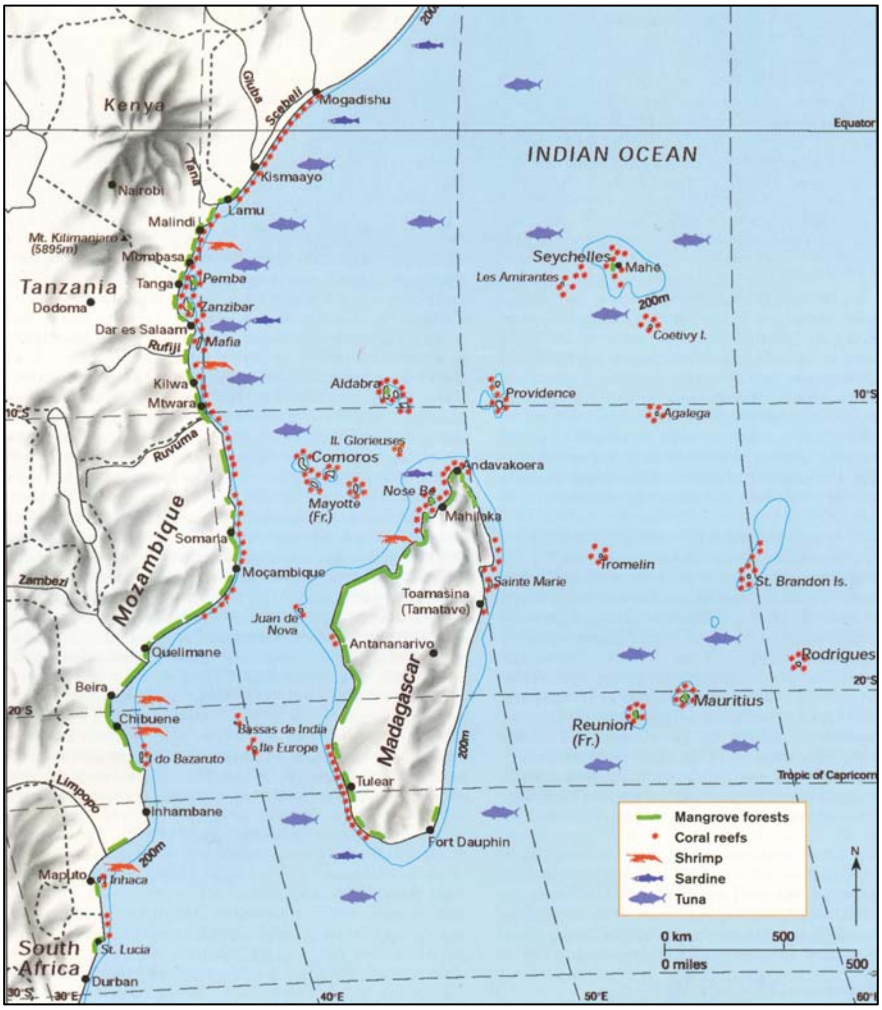


Figure 3.1: Distribution of mangroves and coral reefs within the WIO region (from Richmond, 2002)

3.2.1 Sea grasses

Sea grasses are marine angiosperms that cover large areas called sea grass meadows or beds. These plants are the only true marine vascular plants. Sea grasses occur on soft substrates (sandy or muddy sediments) and adapted to intertidal through to substidal habitats. They are usually found in estuarine and sheltered marine waters (den Hartog, 1979; Richmond, 2002) and create highly productive ecosystems that serve key functions (Duarte, 2002). They are important habitats and nursery areas for numerous organisms including crustaceans (crabs, shrimp and lobster), echinoderms (sea urchins and sea cucumbers), molluscs (bivalves and gastropods) and fish. Other organisms such as macroalgae, epiphytes, fungi, sea anemones and a few sponge species are often associated with sea grasses. These plants are a vital source of food for invertebrates and fishes, as well as for dugongs and marine turtles (Orth, 1984; Duarte, 2002). Other functions of sea grass ecosystems included:

- Provision of oxygen to waters and sediments
- Sediment stabilization
- Shoreline protection
- Trapping and cycling of nutrients

Sea grasses cover approximately 0.1 - 0.2% of the global ocean (Duarte, 2002). There are at least 45 species that are distributed mainly in tropical and subtropical regions. Eleven species from three different families have been identified in the WIO region: *Cymodocea rotundata*, *C. serrulata*, *Enhalus acoroides*, *Halodule uninervis*, *H. wrightii*, *Halophila ovalis*, *H. stipulacae*, *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Syringgodium isoetifolium* and *Zostera capensis* (Richmond, 2002). Sea grass beds are a common feature in all of the WIO countries (Table 3.1) with *Thalassia*, *Halodule*, *Syringgodium*, *Halophila* and *Cymodocea* being the most dominant genera (Richmond, 2002).

TABLE 3.1: Occurrences of sea grass beds in the WIO region (sources: Fagoonee, 1990; Ramessur, 2002; Richmond, 2002; UNEP/GPA and WIOMSA, 2004a, 2004b)

COUNTRY	LOCALITIES OF HIGHEST OCCURRENCES
South Africa	Warm temperate eastern Cape estuaries, Kosi Bay, St Lucia Estuary and Mhlathuze Estuary
Mozambique	Bazaruto Archipelago
Tanzania	Tanzanian bays, particularly on the west side of Pemba, Kilwa, Tanga, Mohoro, Unguja and Mafia
Kenya	Mombasa, Diani, Mida, Gazi, Kilifi, Tudor and Malindi
Seychelles	Platte, Coetivy and Aldabra
Comoros	Shallow lagoons around the island
Madagascar	Shallow coast areas and lagoon throughout the island
Mauritius	Most coastal lagoons around the island

Global pressures threatening sea grasses

Sea grass ecosystems are primarily limited by light, inorganic nutrients and turbidity as sunlight and nutrient minerals are essential for photosynthesis and plant growth (Fourqurean et al., 1992). Therefore physical disturbances such as increased wave action and turbidity as a result of rough weather conditions have severe impacts on sea grass ecosystems. Sea grass beds are facing a global decline largely due to anthropogenic impacts (Duarte, 2002). Mechanical damage due to destructive fishing methods result in sea grass loss and sediment erosion (Duarte, 2002). Construction of harbours, jetties and other coastal developments that require dredging and land filling, also increases erosion, turbidity and sediment deposition in coastal waters. These activities result in mass destruction of sea grass areas. Associated with development, sand extraction is commonly practiced in shallow coastal waters that are prime habitats for sea grass colonies (Duarte, 2002).

Pollution associated with coastal development has caused increased nutrient levels and inputs of toxic substances into the marine environments, with consequent deterioration in water quality and eutrophication (Lapointe and Clark, 1992; Schaffelke et al, 2005). In addition to marine pollution and direct damage from anthropogenic activities, sea grasses are faced with threats from global warming and a rising sea level, as increasing water temperatures and exposure to UV radiation affects biological plant processes such as reproduction, growth, nutrient uptake and photosynthesis (Duarte, 2002).

General issues threatening sea grass beds in the WIO region

Destructive fishing practices

Exploitation of fin- and shellfish resources has directly or indirectly caused major losses of sea grasses in the WIO region. Mechanical damage from clam digging, boating and anchoring activities have been particularly destructive (Duarte, 2002; Richmond, 2002). Dynamite fishing, although banned in most countries, is still common throughout much of the WIO region particularly in Tanzania, Mauritius, Seychelles and Kenya (Fagoonee, 1996; McClanahan, 2002; Richmond, 2002). The underwater shock wave generated by explosives, causes rupture of fishs' swim bladders and this either immobilises or kills them. As a result the fish float to the surface for easy collection. Explosives and the raw materials for preparing explosives such as fertilizers and sugar are inexpensive and easily available (Richmond, 2002). Besides killing both targeted and untargeted species, the explosions can produce craters on the seafloor, destroying entire sea grass communities. Even if not practised directly in sea grass habitats, this type of fishing increases turbidity which results in smothering of these habitats.

Bottom-dragging nets such as beach seines and shallow trawls are also destructive to sea grasses. Such fishing gear is commonly used in Mozambique, Tanzania and Kenya. Such destructive fishing practices impact on untargeted species and crush or uproot sea grass beds (Richmond, 2002). In addition, these fishing methods cause re-suspension of sediment particles in the water column and the subsequent deposition result in smothering of sea grasses and other associated benthic organisms (Richmond, 2002).

Coastal degradation, erosion and increased sediments

Land clearance, forest removal, aquaculture, salt production, mining and urban developments are major contributors to increased sediments in coastal waters. These sediments decrease light availability for photosynthesis, results in mechanical abrasion of sea grass leaves and smother sea grass communities. As a result these activities have all caused major losses of sea grass loss in the WIO region (Richmond, 2002; Duke et al., 2005, Schaffelke et al., 2005).

Optimum locations for ports are often in estuaries and calm water embayments and port development and harbour activities have resulted in sea grass losses throughout the WIO region. South Africa and Mozambique in particular have experience a dramatic increase of port construction and expansion in recent years. Sedimentation from port activities, dredging and dredge spoil disposal heavily impact on sea grass beds in proximity to harbours. Sea grass beds near ports in Zanzibar and Dar es Salaam have been completely destroyed due to increased ship traffic and high turbidity.

Land reclamation is commonly practiced in Zanzibar, Seychelles and Mauritius due to increased demand for development. This often results in sea grass loss through smothering and/or direct sea grass removal (Richmond, 2002). In Seychelles, land reclamation has been taking place since the 1970's, resulting in sea grass beds from being completely destroyed (UNEP/GPA and WIOMSA, 2004a, 2004b). In addition, sand extraction causes the suspension of fine particles in the water column and concomitant increases in turbidity and reduction in light penetration. This is the case in Mauritius where sand mining has led to severe ecosystem destruction and the re-suspension of silt has destroyed sea grass beds. Kenya and Mozambique have several mineral deposits along the coastline, and extensive mining has caused land degradation, erosion and severe siltation of shallow waters (UNEP/GPA and WIOMSA, 2004a, 2004b). Many tourist areas have had entire sea grass beds uprooted to make beaches more appealing to bathers as done in Grand Bay in Mauritius (UNEP/GPA and WIOMSA, 2004a).

Sewage and domestic waste water discharge

Water quality is a major contributor to the decline of sea grass ecosystems. Excessive nutrients derived from sewage and domestic wastewater discharge theoretically promote sea grass productivity as these ecosystems are nutrient limited. However, such increases in nutrients also increase phytoplankton biomass, epiphytes and macroalgae, which results in a decrease of light available for photosynthesis (Lapointe and Clark, 1992; Schaffelke et al., 2005). This together with excessive concentrations of some nutrients such as nitrates and ammonia, which are toxic or limiting to sea grasses at such levels, has had negative impacts on these ecosystems (Duarte, 2002).

Sea grass sediments also trap and accumulate organic compounds resulting in organic-rich sediments which promotes microbial activity (Duarte, 2002). Several studies have found that such activities can lead to oxygen depletion and excessive bacterial growth which releases toxic metabolic by-products like sulphide and methane, and also contributes to plant loss (Schaffelke et al, 2005). Human population growth in WIO countries, particularly in coastal regions, has increased the volume of discharged sewage and domestic wastes (Richmond, 2002; UNEP/GPA and WIOMSA, 2004). In 1990 the coastal waters and ecosystems of Port Louis (Mauritius) suffered from severe eutrophication as a result of nutrient enriched runoff and sewage effluent, as did sea grass beds in Bain des Dames and Point Moyenne (Ramessur, 2002).

Industrial and agricultural discharge

Agriculture is a key contributor to the economy of WIO countries and growth in this sector has been achieved through increased area put to agriculture as well as the use of modern agrochemicals. As a result, pollution derived from fertilisers and pesticides is increasingly affecting ecosystem health. Fertilisers have a high nitrogen and phosphorus content and in marine environments can cause eutrophication, habitat smothering and shading of the water column. Pesticides and herbicides from leached agrochemicals and storm water effluent have negative effects on sea grasses as these substances can inhibit photosynthesis, reproduction and growth (Duarte, 2002).

Heavy metals from industrial discharges have been shown to accumulate in sea grass tissue through foliar uptake. (Schaffelke et al, 2005). Heavy metals, particularly chromium (from dye factories), zinc and lead (from industrial effluent and land runoff) are prevalent in Mauritian coastal waters (Ramessur, 2002), Various industries on the island such as steel mills, galvanizing, electroplating and battery factories release their wastes directly into rivers (Grand River North West and St. Louis River) which empty into marine systems. Estuarine habitats such as Tombeau Bay and Poudre d'Or estuary have been exposed to such untreated industrial wastes since 1970 (Ramessur, 2002). A consequence of such long-term water quality deterioration is severe degradation and destruction of marine and estuarine ecosystems in these areas.

Petroleum and oil pollution

Common sources of petroleum and oil in coastal waters are run-off from land based activities, storm water drains, bilge water discharges from ships, port activities and illegal discharges. These substances are toxic to biota and smother sea grass communities. The main consequence of oiling on sea grass habitats is complete smothering of these benthic plants, as well as their associated organisms (Abuodha and Kairo, 2001). To exacerbate the problem, dispersants which are commonly used to clean up oil spills contain toxic solvents which penetrate the protective waxy cuticles of sea grass blades. Studies have shown such actions effect the biological functioning of cellular membranes and chloroplasts, thereby causing plant loss and as well as harmful effects in other benthic biota (Ellison and Farnsworth, 1996; Abuodha and Kairo, 2001).

There have been numerous major oil spills in the WIO region due to increases in port development and shipping traffic to- and from major harbours and refineries, and which have negatively affected sea grass ecosystems (Richmond, 2002). Sea grass communities in Maputo Bay and Mombasa have been destroyed by oiling (Munga, 1993; Richmond, 2002).

3.2.2 Mangroves

Mangroves are woody trees that grow along sheltered shores and within estuarine and brackish waters of tropical and subtropical regions (Abuodha and Kairo, 2001). They thrive in sedimentary lagoons, bays, estuaries and tidal creeks, and have adapted unique physiological and morphological characteristics to survive in environments with high salinity, wave action and anaerobic soils. Such adaptations include aerial roots for gaseous exchange, lateral roots for extra anchorage, tidal dispersal of propagules, rapid canopy growth and efficient nutrient uptake (Alongi, 2002). Mangrove forests are extremely productive ecosystems that support complex food webs consisting of both terrestrial and aquatic organisms, and are vital spawning and nursery grounds for numerous invertebrates, fish, reptiles and birds (Abuodha and Kairo, 2001; de Boer, 2002). Seeing as mangrove sediment is continuously submerged and eroded by wave action, the root system of mangroves provides a habitat for epiphytic communities such as macroalgae and bacteria. In addition to these functions, mangrove systems also provide other ecosystem goods and services, including:

- Visual amenity and shoreline aesthetics
- Shoreline protection by mangrove tree and root structure, which reduces severe wave action and erosion
- Sediment trapping which reduces the turbidity of coastal waters
- Nutrient uptake, fixation, trapping and turnover.

Mangrove forests occur on approximately two-thirds of tropical shorelines worldwide (Sumich, 1992) covering over 18 million hectares in 112 different countries. In the WIO region, they occur from the coast of South Africa to southern Somalia (Table 3.2).

TABLE 3.2: Area of mangrove forests in the WIO region (Sources: FAO, 2005; Republic of Mauritius, Ministry of Environment and NDU, 2007)

COUNTRY	AREA (ha)	LOCALITIES OF HIGHEST OCCURRENCES
Comoros	2 600	Grande Comoro, Moheli
Kenya	51 600	Lamu Archipelago, Tana Delta
Madagascar	314 000	West coast at Mahajanga bay, Nosy Be, and Hahavavy
Mauritius	23	Mathurin Bay, Rodrigues
Mozambique	390 500	Zambezi Delta
Seychelles	1 900	Aldabra Atoll
Somalia	7 500	Juba/Shebele Estuary
South Africa	667	St Lucia
Tanzania	164 200	Rufiji Delta, Tanga, Kilwa , Pangani

Ten species of mangroves are commonly found in the Western Indian Ocean (UNEP/GPA and WIOMSA, 2004b). The most dominant species found throughout the region are *Bruguiera gymnorrhiza*, *Ceriops tagal* and *Rhizophora mucronata* (UNEP/GPA and WIOMSA, 2004b), but others include *Avicennia marina*, *Avicennia officionalis*, *Heritiera littolaris*, *Lumnitzera racemosa*, *Sonneratia alba*, *Xylocarpus granatum* and *Xylocarpus moluccensis*.

Global pressures threatening mangroves

Despite their ecological value, mangroves are being destroyed on a global scale (Alongi, 2002; de Boer, 2002). Habitat destruction through development encroachment is one of the main contributors of mangrove decline (Abuodha and Kairo, 2001) as these trees are continuously removed to accommodate coastal development, industrialisation, agriculture and pond aquaculture. Due to their proximity to coastal developments, another key concern is anthropogenic impacts on mangrove systems. Previous studies on such impacts have identified sewage, domestic and industrial discharge and agrochemicals as key sources of pollutants that contribute to massive mangrove dieback (Schaffelke et al., 2005).

Mangrove ecosystems are vulnerable to several natural influences such as storms, severe flooding and cyclones, particularly in the tropics (Alongi, 2002). Out-breaks of natural diseases on mangrove systems have been known to cause growth retardation in trees, as well as severe tree mortality (Alongi, 2002). Climate change has the potential to have significant effects on mangrove ecosystems (Ellison and Farnsworth, 1996). Global warming and concomitant increases in mangrove soil temperature will promote an increase in the release of toxic metabolic by-products such as methane and sulphide. Rise in sea levels will influence mangrove distribution as the trees will display an inland migration and there will be a dieback of trees that border the coastline (Ellison and Farnsworth, 1996). Although the increase in CO2 levels that is associated with climate change will increase mangrove production and growth, the effects of sea flooding will out-weigh the benefits of mangrove growth enhancement (Ellison and Farnsworth, 1996). In addition, the increase in UV radiation will result in a decrease in growth due to retardation of photosynthetic and other biochemical processes.

General issues threatening mangroves in the WIO region

Destructive fishing practices

Destructive fishing methods are used throughout the WIO region, but are most common in Tanzania, Mauritius, Seychelles and Kenya (Fagoonee, 1996; McClanahan, 2002; Richmond, 2002). Activities such as trawling and seining involve the dragging of nets over mangrove floors, damaging the root systems of mangroves. The use of mangroves for fishing poles has also contributed to the decline of mangrove systems in the WIO countries (Ellison and Farnsworth, 1996) and dynamite fishing damages and destroys mangrove trees. These fishing methods also threaten the species richness and biodiversity within mangrove ecosystems as a variety of non-targeted species are affected.

Coastal degradation and erosion

Human encroachment has had major impacts on shallow coastal and estuarine systems. Degradation in the form of land clearance, forest removal, mining and urban developments near fragile ecosystems are key issues of concern within the WIO region (UNEP/GPA and WIOMSA, 2004a, 2004b; Duke et al., 2005; Schaffelke et al., 2005). The removal of mangrove forests for development, aquaculture, salt production and timber production has cascading effects on the estuarine functioning (Duke et al., 2005). Mangroves are used as traditional harvest grounds and local communities use mangroves as a source of wood for heating and building houses. Timber is also widely used to produce charcoal, tannins and resins for dying and leather making, furniture, bridges, poles for fish cages and traps, medicines, alcohol, boats as well as for export, particularly in Kenya. As a result, mangrove forests have been severely depleted in the Mida and Lamu, resulting in an export ban in 1975 (UNEP/GPA and WIOMSA, 2004b). In addition, salt production and agriculture in Kenya has resulted in the removal of over 5000 ha of mangrove forest for salt pan construction, especially in Ngomeni and Karawa. The large volume of salt produced in these regions results in the underground seepage of highly saline water that destroys neighbouring mangrove forests (Abuodha and Kairo, 2001).

Tanzanian mangroves in the Rufiji Delta region have been removed to accommodate rice fields, and it is estimated that 1700 ha of mangrove forest has already been destroyed. In Madagascar, these habitats have been extensively cleared for the construction of shrimp farms (UNEP/GPA and WIOMSA, 2004a). Besides the loss of habitat, mangrove destruction also alters tidal flow and sediment loading in estuaries and shallow coastal waters (Alongi, 2002).

Sediment delivery into coastal areas has increased in many WIO region countries due to catchment degradation, and this too has impacts on the integrity of mangrove systems. In Lamu (Kenya), approximately 100 ha of mangrove forest have been destroyed by sediment that was deposited in estuaries (Abuodha and Kairo, 2001). The Tana and Sabaki Rivers in Kenya deposit large volumes of sediment in estuarine and marine environments, negatively affecting mangrove habitats (Mmochi and Francis, 2003).

Land reclamation is another cause of habitat destruction. The WIO islands have had a boom in the resort and tourism industry, which has led to a demand for land (UNEP/GPA and WIOMSA, 2004a). Large areas of mangrove swamps have been converted into hotels, restaurants and shops in Grand Bay in Mauritius (UNEP/GPA and WIOMSA, 2004a).

Sewage and domestic waste water discharge

For most countries in the WIO region there is an urgent need for adequate sewage and waste water infrastructure as these wastes impact heavily on the environment. Mangrove swamps are commonly used for sewage and industrial discharge as the trees filter out nutrients and most of the pollutants are absorbed by mangrove soils, algae and microbes (Wong et al., 1997). However, such increases in pollution eventually render mangroves systems' absorptive capacities and processes inefficient.

Parts of Tanzania and Madagascar do not have sewage disposal facilities and wastes are discharged into estuarine and shallow waters (Richmond, 2002). In the major city of Mombasa (Kenya) there is no sewage or domestic waste water treatment facility, resulting in unquantifiable loads of raw sewage and waste water being released into estuarine areas (Mmochi and Francis, 2003). In Mozambique, the capital city Maputo is the only city with a sewage infrastructure. The rest of the country uses pit latrines and septic tanks which contaminate groundwater systems that drain into mangrove ecosystems and cause localized eutrophication (Mmochi and Francis, 2003).

The main pollutants derived from sewage and domestic waste water discharges are nitrogen and phosphorus. Studies have found that although mangroves can efficiently trap phosphorus for processing by bacterial communities, they are not as effective in nitrogen removal (Duarte, 2002). Mangroves display positive growth responses to nutrient concentrations derived from sewage (Schaffelke et al., 2005). However, at the same time, excess nutrients promote the over-growth of algae which smother and destroy the aerial roots of mangroves. This results in a decreased surface area for respiration and nutrient uptake (Duke et al., 2005, Schaffelke et al., 2005). Also, excessive organic loading in mangrove systems has caused disease outbreaks, retardation of growth, mangrove mortality and a decline in mangrove biodiversity (Duke et al., 2005, Schaffelke et al., 2005).

Industrial and agricultural discharge

Most of the economies of the WIO countries depend on agriculture and food processing industries such as breweries, distilleries and sugar factories. Other significant industries include textiles, tanning and paint manufacture. These industries dispose large amounts of toxic contaminants into estuaries and shallow coastal regions (Richmond, 2002). Mangroves act as pollution sinks (Wong et al., 1997; Yim and Tam, 1999) and numerous countries utilize these ecosystems as secondary waste treatment facilities. However, unusually high heavy metal loads in these environments can become sources of pollutants to plants and soils (Yim and Tam, 1999). With the increasing disturbance to mangrove ecosystems, mangrove soils reach their maximum absorptive capacity in terms of binding toxic metals and hence become a source of contaminants themselves. As heavy metals are not bio-degradable they are accumulated in plant tissue, affecting mangrove growth.

Evidence shows that excessive concentrations of heavy metals have adverse effects on mangrove leaf numbers, stem basal diameter and biomass production (Yim and Tam, 1999). Heavy metals also alter chlorophyll formation in leaves and hinder the uptake of essential mineral nutrients, as well as inhibiting root production. In addition to this, heavy metals negatively affect the microbial communities present in mangrove soils (Wong et al., 1997; Yim and Tam, 1999) i.e. decomposition rates become impaired thus limiting the nutrient processing capacity.

The expanding brewing industry in Tanzania has caused severe pollution to ecosystems in the Msimbazi River. Various other industries contribute to the untreated waste loads entering estuaries and shallow coastal environments (Mmochi and Francis, 2003). In Seychelles, industries such as canning and brewing also discharge considerable amounts of waste into the estuarine waters of the island (Mmochi and Francis, 2003), causing negative impacts on mangrove ecosystems .The major contributor of industrial waste in Mauritius is the sugar industry which releases industrial waste products directly into rivers and canals that empty into shallow coastal habitats and affect mangrove systems (Mmochi and Francis, 2003).

Agriculture is also major contributor to pollution of coastal environments. Agrochemicals such as herbicides and pesticides from waste water, leached groundwater and surface water runoff are notorious for causing mangrove defoliation and mangrove dieback (Duke et al., 2005, Schaffelke et al., 2005). Mangroves situated near agricultural areas are therefore particularly vulnerable to agrochemical exposure. Mangrove forests in Mombasa and Lamu (Kenya) provide an example, where approximately 80 tons of pesticides and fertilizers are used annually in the vicinity of these forests (Mmochi and Francis, 2003). Rice production in Tanzania requires intensive use of fertilizers and pesticides. Consequently the Rufiji Delta and Mafia Island complex receive large contaminant loads into their aquatic systems (Mmochi and Francis, 2003). Similarly 90% of Mozambique's agricultural activities are conducted along river systems which results in leached contaminants affecting mangrove systems downstream. Sugar cane farming in Mauritius uses large amounts of fertilizer and pesticides (Mmochi and Francis, 2003) which have also contributed to mangrove decline on the island.

Petroleum and oil pollution

Petroleum hydrocarbons are introduced to shallow coastal waters through urban sources such as land runoff, municipal and industrial wastes, as well as by port activities and bilge water discharges (Clark, 2002). Extensive mangrove forests in Maputo and Mombasa have been destroyed by oil spills (Munga, 1993; Richmond, 2002). Spillage from the British tanker, Cavalier, caused considerable damage and destruction of mangrove forests in Mombasa in 1972. Since then, the same coastline was subjected to five other severe spills. Such spillage has resulted in mangrove dieback, especially in Mida Creek where the effects of oil spills were still evident ten years after the last oil incident (Abuodha and Kairo, 2001). The main effects of oiling on mangrove ecosystems are complete smothering of estuarine vegetation and organisms (Abuodha and Kairo, 2001). As petroleum compounds persist over long-term periods in mangrove soils, toxic derivatives of oil are continuously re-released into the environment, thereby causing sub-lethal effects to mangroves (Duke et al., 1997). Oiling causes massive mangrove defoliation, chlorophyll-deficient mutations as well as seedling and tree mortality. The recovery of mangrove ecosystems from impacts of these hydrocarbons can take several years (Abuodha and Kairo, 2001).

3.2.3 Coral reefs

Coral reefs are shallow subtidal ecosystems found in tropical and subtropical oceans (McClanahan, 2002). They are formed by the calcification activities of coralline algae and scleractinian corals, which create a calcareous skeleton using chemical reactions (Richmond, 2002). These living structures thrive in shallow and nutrient limited waters up to depths of 20 to 30 meters (McClanahan, 2002).

Coral reefs serve dual roles as key producers of biomass in these environments and their skeletons provide structural habitat for a diverse range of algae, soft corals, sponges, invertebrates, fish and turtles. Besides providing a unique habitat for biota, coral reefs protect the shoreline from strong wave action, provide construction materials and support local subsistence and tourism.

The eastern coast of Africa has a string of coral reefs that covers over 1500 km of the WIO region coastline. There are four main types of coral reefs. The most common type found in the WIO is the fringing reef which is generally associated with shallow lagoons. Patch reefs, atolls and barrier reefs also occur (Table 3.3).

TABLE 3.3: Area of coral reefs in the WIO region (sources: Richmond, 2002; UNEP/GPA and WIOMSA, 2004a, 2004b; Obura, 2005)

COUNTRY	AREA OF CORAL REEF COVERAGE	LOCALITIES OF HIGHEST OCCURRENCES
Comoros	430 km^2	Fringing and patch reefs around the island
Kenya	630 km^2	Northern and southern coasts of the country
Madagascar	2230 km^2	Fringing and patch reefs around the island and the barrier reef, Grande Recife
Mauritius	870 km^2	Mahebourg barrier reef of Mauritius and patch reefs around the island
Mozambique	1860 km^2	Quirimbas, Bazaruto, Inhaca, Inhambane
Seychelles	1690 km^2	Fringing and patch reefs around the island
South Africa	< 50 km^2	Fringing and patch reefs in Sodwana, St Lucia and Aliwal Shoal and Leadsman Shoal
Tanzania	3580 km^2	Fringing reefs in Tanga, Pemba, Unguja, Mafia and patch reefs in the Zanzibar channel

Corals of the genera *Acropora* were the most abundant and diverse genus found in the WIO region. However since the 1998 bleaching event the geographic range of *Acropora* has become limited to southern Tanzania and northern Mozambique. *Millepora*, a once dominant genus in shallow coral communities throughout the WIO region, has also experienced a decline in these waters and is now represented in some regions by dead skeletons only. Previously dominant genera are now being replaced by those that are less vulnerable to bleaching, such as *Porites* (Obura, 2005). Other genera commonly found throughout the WIO region include *Astreopora*, *Alveopora*, *Cyphastrea*, *Echinopora*, *Favia*, *Favites*, *Galaxea*, *Goniastrea*, *Goniopora*, *Hydnophora*, *Leptoria*, *Montipora*, *Oxypora*, *Pavona*, *Platygyra* and *Pocillopora* (Fagoonee, 1990; Obura, 2005).

Global pressures threatening coral reefs

Coral reefs are extremely vulnerable to alterations in environmental conditions. These ecosystems have persisted over millions of years and survived great reductions of sea levels during glacial periods, meteor strikes and fluctuations in solar activity. However, such events incur recovery periods of thousands of years and many species have become extinct over time due to these drastic changes (Wilkinson, 1999; McClanahan, 2002). Current climate change scenarios have the propensity to contribute to coral reef destruction through sudden changes of sea levels. A drastic drop in sea level can result in coral exposure during very low tides (Wilkinson, 1999) and although an increase in sea level will provide an opportunity for reef expansion, deeper coral reefs be lost with rapid sea level increases (McClanahan, 2002).

Severe storms are known to influence coral reef structure. Major floods result in an excessive flow of freshwater bearing high loads of sediment into shallow coastal areas, and cause reef stress and ecological damage. The effect of global warming has the potential to cause major changes in weather patterns (Wilkinson, 1999). The El Niño event causes massive coral bleaching and mortality to reefs around the world (Wilkinson, 1999; McClanahan, 2002). Although the 1982 - 1983 bleaching event was considered rare, it was followed by another devastating event in 1997 - 1998, which resulted in some species extinctions (McClanahan, 2002). Coral mortality levels in Kenyan and Tanzanian waters varied between 50 - 90%, but the most extensive bleaching occurred in Mozambique with up to 99% mortality occurring on some patch reefs. Global patterns show that these events have increased in frequency and severity (Wilkinson, 1999). The increase of green house gases also alters the balance of carbonate and bicarbonate in the water column, which affects calcification processes in reef growth and repair. Therefore as CO2 levels increase, coral coverage will decline (Wilkinson, 1999). Similarly, high levels of UV radiation have sub-lethal effects on coral reefs and cause a change in coral height as reefs will shift to deeper waters to compensate for the increase in radiation (Wilkinson, 1999).

Anthropogenic stress to coral reefs includes sedimentation, pollution and over-exploitation of fish resources. Excessive suspended sediment in the water column causes increases in turbidity and abrasion. Organic contaminants derived from sewage, industrial and storm water effluents are significant environmental pollutants in coastal regions. Increased nutrient loads have the potential to cause severe eutrophication.

General issues threatening coral reefs in the WIO region

Destructive fishing practices

Destructive fishing methods commonly practiced in the WIO region are a major contributor to coral reef degradation and destruction. Dynamite fishing is the most destructive of these fishing practices and is especially common in Tanzania, Mauritius, Seychelles and Kenya (Fagoonee, 1996; McClanahan, 2002; Richmond, 2002). Dynamite fishing has been practiced in Tanzania since the 1960's, and has now reached an alarming levels. In the Songo Songo Archipelago, 30 blasts were recorded every three hours in one area by Wagner (2004) and 100 blasts were recorded during a six hour period at Mpovi reef. This fishing method is a highly effective, but incredibly damaging to coral reef ecosystems. Each blast of dynamite instantly kills all fish and most other living organisms within a 15 to 20 m radius (Wagner, 2004). Not only are the corals in the immediate vicinity of the blasts destroyed, but reef ecosystems located at a distance from the blasts are also affected by shock waves (Richmond, 2002).

Traditional poisons obtained from local trees are another straightforward and common way of fishing in eastern Africa. Poisonous extracts are obtained from trees barks and roots and are known to cause coral bleaching and death to other invertebrates that come into contact with the toxic substances. Cyanide and pesticides are used to capture fish for aquariums and cause harmful effects to the surrounding environment (Fagoonee, 1996; Richmond, 2002).

Several types of nets can damage the coral reef ecosystem. Bottom-dragging nets used in shallow trawls are common in Mozambique, Tanzania and Kenya and can destroy coral reef habitats. Sponges and coral communities are either removed or crushed in the process of trawling, and lost nets continue to cause destruction as they cover coral and continue to trap marine organisms.

In addition to the physical damage caused to coral reefs, trawling and explosive fishing causes suspension of sediment particles in the water column and the subsequent smothering and death of corals and benthic organisms (Richmond, 2002). Mechanical damage to coral reefs is also caused by coral trampling, boating and anchoring activities (Richmond, 2002).

In addition to the damages incurred by destructive fishing practices, the over-exploitation of coral reef ecosystems disrupts the overall functioning of the reef. Over-fishing of reef ecosystems disturbs the delicate balance in predator and prey interactions in the ecosystem. Excessive removal of predator fish promotes the increase of invertebrate population such as sea urchins which feed and erode reef substratum (McClanahan, 2002). Also, the removal of herbivorous fish causes an increase in algal growth which smothers reefs. Thus the exploitation of food resources from coral reefs has a great influence on the health status of the ecotone.

Coastal degradation and erosion

Excessive sedimentation smothers and scours coral reefs, and results in a decrease of light available for benthic macrophytes and photosynthetic coral reefs (Schaffelke et al., 2005). Corals have the ability to remove sediment particles on their surfaces by polyp distension, tentacular movements, cilliary action and mucus production (Pastorok and Bilyard, 1985; Wilkinson, 1999). However such actions require an expenditure of energy and heavy sedimentation causes complete burial of coral and subsequently, death. Suspended solids also reduce coral growth, recruitment, diversity and abundance (Wilkinson, 1999).

Activities such as coastal reclamation are commonly carried out in the island states where land is at a premium (UNEP/GPA and WIOMSA, 2004a, b). In Seychelles, land reclamation has been taking place since the 1970's, resulting in the fragmentation and destruction of coral reefs (UNEP/GPA and WIOMSA, 2004a, 2004b). The increase of port development and jetty construction throughout the WIO region cause excessive loads of sediment to be deposited in shallow waters, as well as the re-suspension of silt. In Kenya, the development of tourist resorts has resulted in severe coastal erosion in Mombasa, and in the Seychelles erosion is common on the Islands of Praslin and La Digue (Odada, 1996). Coral reefs in these regions have been negatively impacted. Coastal erosion is particularly problematic in Dar-es-Salaam and the islands of Zanzibar and Pemba, where coral reefs have been completely destroyed (Odada, 1996; UNEP/GPA and WIOMSA, 2004a, 2004b).

Sewage and domestic waste water discharge

The growth of populations in WIO countries has caused cities to become over-crowded and, in many cases, basic infrastructure cannot cope with the increased volume of sewage and domestic wastes (Richmond, 2002; UNEP/GPA and WIOMSA, 2004). Many countries dispose untreated sewage and waste water directly in shallow coastal environments. While nutrients are essential for promoting primary coral reef productivity, the excessive presence of sewage derived nutrients drastically increases the productivity and biomass of phytoplankton and opportunistic algae. The resulting conditions are similar to those experienced in sea grass beds in that the increase in algal and phytoplankton biomass increases light attenuation, which severely affects coral growth and survival. Additionally, algae tend to overgrow and smother corals and an increase in such productivity promotes the growth of other opportunist organisms such as sponges and tunicates, which out-compete corals for habitat space (Pastorok and Bilyard, 1985).

High concentrations of certain nutrients such as phosphorus actually inhibit coral calcification processes (Duke et al., 2005, Schaffelke et al., 2005). Eutrophication, algal blooms and smothering of corals found in shallow lagoons in Mauritius are common, particularly in Port Louis where coral mortality is prevalent (Ramessur, 2002). Certain parts of Tanzania do not have sewage treatment systems, leaving such wastes to be directly disposed of in the sea (Mmochi and Francis, 2003). Coral reefs in close proximity to sewage and domestic waste outfalls can suffer from the effects of eutrophication, bleaching or mortality (McClanahan, 2002).

Industrial and agricultural discharge

Rapid expansion of coastal developments has caused an increase of industrial waste discharge into shallow coastal waters (Richmond, 2002; UNEP/GPA and WIOMSA, 2004). Maputo has increased its industrial node in recent years, producing unquantified amounts of waste that are mostly discharged in the ocean, causing coral bleaching and mortality (Mmochi and Francis, 2003). The highly productive food processing, metal and textile industry in Kenya directly discharge untreated wastes into the Kilindini Harbour and Port Reitz, negatively affecting the health and productivity of sensitive ecosystems such as coral reefs (Mmochi and Francis, 2003).

Corals contain symbiotic zooxanthellae which are photosynthetic algae. The symbiotic relationship is one in which the coral provides zooxanthellae with a sheltered environment, nutrients (CO2 and nitrogenous and phosphorus by-products of coral cellular respiration) and in return the algae provides O2 and photosynthetic by-products to the coral. This unique relationship is maintained by chemical communication between the coral and algae, and this renders certain coral species are extremely sensitive to heavy metal contamination (Peters et al., 1997). Reef invertebrates and fish are vulnerable to metals and accumulate these contaminants within soft body tissues and display distinct physiological and cytological responses to varying levels of pollutant exposure (Rainbow, 1995; Ravera, 2001). In addition, heavy metals derived from industrial effluent are easily absorbed by the tissue of coral skeletons thereby altering various chemically mediated processes such as reproduction and recruitment. Consequently, such pollutant exposure causes severe modifications to reef productivity and mortality rates (Peters et al., 1997).

PCBs and pesticides are also extremely toxic to corals which have been shown to display decreases in photosynthesis of the symbiotic algae, changes in coral metabolism and growth retardation when exposed to such contaminants (Pastorok and Bilyard, 1985). Agrochemicals increase the nutrient loading in shallow waters, resulting in localized eutrophication, which impacts on coral health as outlined above. Numerous studies have reported high occurrences of diseases, blemishes and dead patches of coral reefs situated in close proximity to urban outfalls (McClanahan, 2002).

Petroleum and oil pollution

Petrochemicals are another potential pollution threat to coral reef ecosystems and are most commonly derived from run-off from land, waste water effluent and ballast water discharges from ships. The increase of port activities and shipping traffic has resulted in an increase of oil spills in shallow coastal waters. In the marine environment, this pollution floats above coral reefs (Peters et al., 1997) and even if petroleum does not come into contact will the reef, the pollutant contains toxic substances that are water soluble and are taken up by corals. Studies have shown that corals exposed to oil undergo a variety of negative impacts that include coral tissue death, bleaching, and impairment of biological processes such as photosynthesis, reproduction and growth (McClanahan, 2002). In addition, dispersants used to clean-up oil leaks contain toxic chemicals that exacerbate the effects of the oil spill and can prolong coral recovery by years (Peters et al., 1997).

The threat of oil spills are great in the WIO region which serves as a major oil tanker route stretching along the east African coastline and ferrying an estimated 420 million tons of oil each year. Some of the major spills over recent years were from the Katina P. in Mozambique (1992) and Castillo De Belver in South Africa (1983). So far Mauritius has only been affected by minor spillages of oil from tanks (Fagoonee, 1990). Petrochemical impacts on this island, as well as other countries that depend heavily on income from tourism are of major concern as the recovery of coral reef ecosystems from petroleum pollution may take years, severely impacting on the economy.

3.3 Effects of Pollutants on Marine Species

Contaminants can be introduced naturally to marine and estuarine environments by events such as volcanic activity, forest fires, wind blown dust and erosion of ore bearing rock (Clark, 2002). Metals such as zinc, copper and cobalt, as well as nutrients are essential for biological functioning and survival of biota. Nonetheless, the vast majority of contaminants present in coastal ecosystems are introduced by anthropogenic activities that include sewage discharge, industrial and domestic waste disposal, oil spills and dumping of solid wastes at sea. An excessive amount of these contaminants in marine habitats can be toxic to biota and severely interfere with the biological functioning of aquatic ecosystems.

Marine plants such as phytoplankton, seaweed and sea grasses absorb nutrients and toxic chemicals directly from the water column and from interstitial water of sediments. Macroalgae have large surface areas that can efficiently accumulate excessive pollutants, and trap toxins within their polysaccharide walls (Ravera, 2001). Polychaetes (marine worms) can easily 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, scavenging and carnivory. 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 crustaceans such as amphipods that feed on contaminated detritus and detached algae.

Suspension feeders such as mussels, oysters and barnacles obtain contaminants from the water column in addition to ingesting contaminated suspended particles. Bivalves such as clams are deposit feeders and ingest pollutant 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). Most organic pollutants such as PCBs and PAHs are accumulated in fatty tissue of marine organisms (Bryan, 1971). Predatory organisms may accumulate toxic substances from their food sources ultimately leading to very high concentrations in apex predators.

Exposure to pollution can cause a variety of effects in marine and estuarine 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 decline in growth and recruitment rates of marine organisms are significantly correlated with contaminant exposure (Bryan, 1971).

Metals are also 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; Eilsler, 1979). 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; Eilsler, 1979). Petroleum has been found to have similar effects as other organic pollutants on molluscs, crustaceans and fishes (Eilsler, 1979).

3.4 Thresholds of Ecotones for Pollutants

3.4.1 Selecting thresholds – complexity and Limitations

Environmental thresholds for any biogeochemical parameter may be defined as tolerance levels beyond which the community occupying a habitat may be changed as a result of loss or change in populations of one or more species though competition where more tolerant species are favoured. The development of thresholds for various parameters at the habitat level is bedevilled by the complexity inherent in each habitat. The various components (i.e. species at different trophic levels and/or those displaying complex interdependencies) of a particular community will have a varied response to change in particular physiochemical parameter or toxin. In defining thresholds at the habitat level it would then seem obvious at first that the most sensitive species in that community should be used to determine the threshold for any particular parameter. Thus the process of determining such thresholds involves review of available data on species occupying a particular ecotone. Such data may be in the form of in-situ monitoring of various parameters and resultant species response, or toxicity assays. A common limitation of such data is that usually the species selected for study are those that have commercial and/or aesthetic value or are generally well known or "popular" (e.g. dolphins). These species may not necessarily represent the organisms that are the most sensitive to the selected parameter within the ecotone.

In addition to the above, the development of thresholds from reported toxicity data is complicated by the fact that a specific end-point is measured, and most often, this is in the form of acute responses which determines levels of lethality at different levels of the particular stressor under controlled conditions and fixed exposure periods. Toxicity is thus most commonly reported at an LC_{50} which is level at which 50% of the test organisms are killed at a predetermined exposure period. From this it is difficult to determine a safe level for a particular parameter at which no deaths result. Even if such tests do report a no-observed-effect-level (NOEC), this "safe level" may not represent a no-effect level for sub-acute effects that are not measured in the test (e.g. physiological stress that may effect growth, fecundity etc.) that in the longer term lead to community changes through reduced recruitment. In addition under field conditions organisms are exposed to a range of physiochemical conditions (as opposed to controlled conditions in laboratory tests) which may have synergistic and/or antagonistic effects that would differ from the laboratory-measured response levels for any particular parameter. Another factor that would affect response to a physiochemical stressor is exposure period which under field conditions may be very varied in comparison to set exposure periods for laboratory tests. Toxicity tests also generally involve utilizing a certain life stage of the selected test organism and life stages can vary widely in terms of tolerance to different levels of the stressor being studied with larvae and juveniles, or seedlings in the case of plants, often being much more sensitive than the adults for that species. Nonetheless toxicity tests do provide valuable information which assist in determining possible safe levels and thresholds.

The final factor affecting the selection of thresholds is the fact that within the WIO region a single widespread species may be exposed to very different physiochemical environments within local regions e.g. different temperatures, water and soil chemistry influenced by differing geology etc. Such species would have over a long period evolved particular genetic lineages that may vary in their tolerance to certain parameters such as heavy metals, nutrient levels etc. As such, thresholds for any stressor even within a single species can vary according to conditions prevailing in their particular local environment.

3.4.2 Guidelines for selection of threshold Levels

Given the above account of complexity within ecotones and the limitations presented by existing toxicity data, a set a rules/guidelines have been devised to facilitate the development of tentative threshold levels for the selected parameters for each of ecotones present in the WIO region. Such threshold levels may have to be revised for particular local areas as communities may be exposed to differing physiochemical environments i.e. background conditions. Also given that the WIO region covers tropical, subtropical and temperate regions tolerance ranges must cover the natural variation for certain parameters (e.g. temperature, in local regions).

- For each parameter use data (laboratory tests or in-situ measurements) for the most sensitive species present in the ecotone

- For any particular species use the most sensitive life stage if data is available
- For any particular species use sub-acute measurements in preference to acute test responses if available
- If LC_{50} data is used then the threshold for a particular chemical in the environment should be at approximately 0.1 X LC_{50} concentration. If LC_5 data is available then the threshold should be no more than 0.5 X LC_5 concentration
- Where experience or literature indicates that certain biota (species, genera, families etc) are generally sensitive to a particular parameter, but there are no data for the particular species present in the WIOLAB region, then data from other regions may be used as a guide
- In the absence of hard data use experience, expert opinion or precautionary levels but identify these clearly.

A summary of the data that used for this assessment is listed in Appendix IV.

3.4.3 Derived threshold levels for the WIO region

The derived constituent threshold levels for ecotones in the WIO region, as described in Chapter 3.4.2 above) are presented in Table 3.4. (NB: having completed the exercise of allocating threshold values according to the rules indicated above it is clear that some of the thresholds developed may be too conservative and there is perhaps a need to review some of the rules in particular the one that states that thresholds should be set at 10% of the experimental LC_{50} values found in the literature).

TABLE 3.4: Derived constituent threshold levels for ecotones in the coastal zone of the WIO region

CONSTITUENT	ECOTONE		
	Seagrasses	Mangroves	Coral reefs
Physico-chemical variables			
Temerpature (°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
Nutrients			
Dissolved inorganic nitrogen-N (NH_4-N+ NO_3-N + NO_2-N) (µg/ℓ)	<500	<1000	<15
Dissolved inorganic phosphate-P (µg/ℓ)	<50	<100	<5
Toxic Substances			
Ammonia-N (µg/ℓ)	<30 as NH_3 -N (800 as total Ammonia-N)	<50 as NH_3-N (<1000 as total Ammonia-N)	<25 as NH_3-N (<600 as total Ammonia-N)
Chlorine (µg/ℓ)	0.2	<1	<0.2
Hydrogen Sulphide (µg/ℓ)	<0.02	<0.02	<0.02
Arsenic (µg/ℓ)	15	20	15
Cadmium (µg/ℓ)	5	5	5
Copper (µg/ℓ)	<1	5	1
Lead (µg/ℓ)	1	1	1
Mercury (µg/ℓ)	0.3	0.3	0.3
Nickel (µg/ℓ)	10	10	10
Silver (µg/ℓ)	1	1	1
Zinc (µg/ℓ)	17	17	17
Petroleum (Water Soluble Fraction) (mg/ℓ)	Fuel or bunker oil 0.2 Crude oil 1.5	Fuel or bunker oil 0.2 Crude oil 2	Fuel or bunker oil 0.2 Crude oil
DDT (µg/ℓ)	0.05	0.05	0.05
Lindane (µg/l)	0.08	0.08	0.08
Dieldrin (µg/ℓ)	0.85	0.85	0.85
Aldrin (µg/ℓ)	3.15	3.15	3.15
Endosulfan (µg/ℓ)	0.003	0.003	0.003

4. STRATEGY FOR DEVELOPMENT OF ENVIRONMETAL QUALITY OBJECTIVES AND TARGETS FOR THE COASTAL ZONE OF THE WIO REGION

4.1 Protection of Coastal Aquatic Ecosystems

An Environmental Quality Objective (EQO) is a broad, narrative statement describing the desired quality levels (or goals) for a particular environment, in this case the coastal zone. For the Protection of Aquatic Ecosystems the following generic EQO is proposed:

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

From a management perspective, this broad objective needs to be translated into measurable targets. The following sections propose a strategy for the establishment of EQTs for the protection of coastal aquatic ecosystems in the WIO Region, including a set of generic EQTs.

4.1.1 Water

Objectionable matter

Recommended EQTs related to objectionable matter are usually narrative and typically require that areas be free from (Table 2):

- Objectionable floating matter or oily films
- Non-natural matter that will settle to form objectionable deposits on the seabed
- Submerged objects and other subsurface hazards that arise from non-natural origins and which would be a danger to recreational users
- Objectionable smells or odours.

Following international trends, it is therefore recommended that a similar approach be adopted for the WIO Region, i.e. providing descriptive (or narrative) targets for matters related to objectionable matter. Currently, South Africa is the only country within the region that has official EQTs recommended for objectionable matter (refer to Appendix I). As these are very much aligned with those recommended internationally, it is proposed that the South African guidelines be adopted as the generic EQTs for the WIO Region.

Physico-chemical variables

Large variability exists in the physico-chemical characteristics of coastal waters within the WIO Region with different coastal ecosystems or ecotones being well adapted to the ambient conditions within their particular area. It is therefore considered inappropriate to recommend generic environmental quality guideline values for physico-chemical variables across the WIO region, but rather to recommend an approach that could be applied to derive site-specific EQTs.

For the WIO Region, it is proposed that the Biological and ecological effects data and/or Reference system data approaches be applied to derive EQTs for physico-chemical variables (refer to Chapter 2.1.1). However, it is expected for only limited biological and ecological effect data, describing the response of coastal ecotones within WIO Region to changes in physico-chemical variables, to be available.

A Reference system approach may therefore be more appropriate, particularly in the short- to medium term. In this regard, the method put forward by ANZECC (2000), is considered most practical and useful. This method uses an appropriate percentile (e.g. 20th and/or 80th percentile) of the physico-chemical data collected from a specific site prior to modification (or an appropriate Reference site) to derive recommended EQTs.

In instances where no reference data are available and where seasonal and event influences are poorly defined, single target values could be derived from any other available data, as an interim measure, based on professional judgement (e.g. using the derived constituent threshold levels as presented in Table 3.4).

NOTE:

The approach and methodology followed in South Africa and Mauritius in the development of EQTs for physico-chemical variables are not clear (RSA DWAF, 1995, Mauritius, 2006a). Therefore, although the approach proposed here does not exclude the countries for maintaining those EQTs for their coastal areas, a more transparent approach is proposed for the larger WIO region.

Nutrients

Similar to physico-chemical characteristics, large variability in ambient nutrient concentrations is expected within the coastal zone of the WIO region with different coastal ecotones being well adapted to the characteristics within their particular domain. Again, it would therefore be inappropriate to recommend generic generic environmental quality guideline values for nutrients in the region. An approach to derive site-specific EQTs is considered more appropriate.

Another important consideration related to nutrient processes, is that impact or disturbance caused by nutrients in coastal ecosystems generally occurs through transformation in the environment and that there may, therefore, not be a direct relationship between the ambient nutrient concentration and the biological response measured at any time.

As a result, the Predictive modelling approach is increasingly becoming the preferred method for deriving EQTs for nutrient on a site-specific scale, although alternative approaches, such as the Biological and ecological effects data and Reference system data approaches are not discarded (ANZECC, 2000; CEC, 2000; US-EPA, 2001). The Predictive modeling approach is therefore also recommended as the preferred approach for the WIO region.

However, where this Predictive modeling approach may be difficult to implement (e.g. modeling technologies are not available), it is recommended that the Reference system data approach be applied as an alternative – using appropriate local reference system(s). To be able to derive target values for nutrients, it is necessary to also set targets for parameters that could be impacted on, for example, chlorophyll a (indicator of algal blooms), turbidity (a result of algal blooms) and dissolved oxygen (affected by organic nutrient inputs and subsequent degradation of algal biomass). Therefore both the 80th percentile of the reference system distribution for the causative (e.g. inorganic nitrogen and phosphate) and response (e.g. chlorophyll a, turbidity and dissolved oxygen) variables is derived as EQTs (where possible, these should be obtained for that part of the seasonal or flow period when the probability of aquatic plant growth is most likely).

Where few reference data are available and seasonal and event influences poorly defined, single target values could be derived from available data (e.g. information from related areas linking ambient, natural nutrient levels with period of algal blooms), as an interim measure, based on professional judgement (e.g. using the derived constituent threshold levels as presented in Table 3.4).

NOTE:

The South African water quality guidelines provide only a broad narrative statement with regard to nutrients and could easily be accommodated in the above-mentioned approach (RSA DWAF, 1995). The Mauritian guidelines provide numerical target values for nutrients, but the approach and methodology used in deriving those targets are not transparent. Therefore, although the approach proposed here does not exclude the countries for maintaining these site-specific EQTs for their coastal areas, a more transparent approach is proposed for the larger WIO region.

Toxic substances

Internationally, it is common to derive single value EQTs for toxic substances on national (Canada) and/or regional scales (e.g. Australia and New Zealand), unlike for physico-chemical variables and nutrients requiring a more site –specific approach. Although there may well be large variability in the responses of coastal ecosystems (and different trophic levels) to toxic substances, these considered to generally be less variable than for physico-chemical variables and nutrients. Hence, the common approach assumes that if a large enough data set, meeting specific requirements (refer to Chapter 2.1.1), is interrogated generic, single value EQTs can be derived for toxic substances with some confidence.

The most recent critical review of EQTs for toxic substances, linked to the protection of coastal ecosystems, was done by Australia and New Zealand (ANZECC, 2000). The review considered procedures and target values form a large number of countries and organizations (including those discussed in this document – refer to Chapter 2.1.1).

In setting EQTs for toxic substances, the Ecological and biological effects data approach is mainly used (ANZECC, 2000, CCME, 1999; CEC, 1983, 1984a, 1984b, 1986, 1988, 1990; Russo, 2002). Although, ideally, site-specific ecological and biological effects data should be interrogated, sufficient data are generally not available with the result that most countries interrogate large toxicological databases - of which the US-EPA's AQUIRE (now part of ECOTOX) seems to be the most popular (US-EPA, 2007; ANZECC, 2000; Russo, 2002). Australia and New Zealand also used AQUIRE for deriving water quality guidelines for toxic substances, but supplemented that with additional data from studies conducted in the southern hemisphere (AQUIRE contains mainly data from northern hemisphere regions).

As it is unlikely that there will be sufficient (and appropriate) toxicological data available from within the WIO Region to derive EQTs for toxic substances, it is recommended that the Australian and New Zealand target values (ANZECC, 2000) be adopted for the WIO Region until such time as these could be refined using regional data (Appendix I). The motivation here is three-fold, namely that the ANCEZZ (2000) target values are:

- Based on the most recent international review
- Derived from both southern and northern hemisphere data sets (WIO region stretches across both hemispheres
- Most conservative as these were derived from NOEC data, rather than LOEC data (e.g. as is the case in Canada).

NOTE:

Although the EQTs recommended for South Africa (RSA DWF, 1995b) and Mauritius (Mauritius, 2006a) are generally within the same order as most of the ANZECC target values, the approach and methodology used in the derivation of these target values are not transparent. Therefore although the approach proposed here does not exclude these countries for maintaining their site-specific EQTs for their coastal areas, a more transparent approach is proposed for the larger WIO region.

Although the derived threshold concentration levels for toxic substances - obtained from limited data sets specifically relevant to the WIO region (referring to Table 3.4) - can also be considered, these values may not be as robust as those derived by ANCEZZ (2000) which used a much larger data base.

4.1.2 Sediment

Based on the international review, conducted as part of this study, EQTs for sediments are generally only specified for the protection of aquatic ecosystems, and in particular for toxic substances. Currently there are no official EQTs for sediments for countries in the WIO Region, specifically aimed at the protection of coastal aquatic ecosystems (refer to Chapter 1.2).

Ideally, EQTs for sediments should be developed from detailed dose-response data that describe the acute and chronic toxicity of individual substances in sediments to sensitive life stages of sensitive aquatic organisms. However, for most countries such detailed data sets are usually not available and are also very costly to collate.

As a result the EQTs for sediments adopted by a number of countries (ANZECC, 2000; CCME, 1995) are primarily derived from a set of sediment quality target values developed by the National Oceanic and Atmospheric Administration (NOAA) in the United States in the 1990s, as part of the National Status and Trends Program and that was initially intended to provide a means of interpreting sediment monitoring data (Long and Morgan, 1990; revised by Long et al. 1995, NOAA, 1999). In the late 1990s, MacDonald and co-workers expanded on the NOAA approach when they developed a set of saltwater sediment quality taret values for the State of Florida (USA), Department of Environmental Protection (MacDonald et al., 1996). They expanded the saltwater database that was originally used by Long and co-workers with additional data on saltwater.

Whilst it is unlikely that there will be sufficient (and appropriate) toxicological data available from the WIO Region to refine EQTs for sediments, it is recommended that the NOAA targets (TEL/PEL), as per MacDonald et al. (1996), be adopted as interim EQTs for toxic substances in sediments until such time as these can be refined for the region (refer to Appendix II). MacDonald et al. (1996) expanded the original database used by Long et al. (1995) with additional data on salt water and also revised the database by carefully screening data., therefore the recommendation to adopt the NOAA targets as per MacDonald et al. (1996).

It is further recommended that, the Canadian protocol (as illustrated in Figure 7) be adopted for future refinement of EQTs for sediments in the WIO Region (CCME, 1995). This protocol incorporates the National Trends and Status Program Approach as per NOAA (1999). Although this approach may have limitations (as discussed in Chapter 2.1.2), it appears to be accepted worldwide as the preferred option (CCME, 1995; NOAA, 1999; ANZECC, 2000). 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 of 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).

4.2 Recreational use

For Recreational use of coastal ecosystems, the following general EQO is proposed:

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

For the WIO region, it is proposed that this general EQO be translated into EQTs linked to aesthetic quality, as well as microbiological indicators and toxic substances, where applicable (reflecting risks to human health).

EQTs relevant to aesthetic quality are in essence similar to that related to the presence of objectionable matter (referring to the Protection of coastal ecosystems – Chapter 4.1.1). It is proposed that similar EQTs apply to recreational areas.

As for microbiological indicators, it is recommended that both *E. coli* and Enterococci be used as indicator organisms. The reasoning is that, although Enterococci is considered to be most suitable for marine waters, instances have been documented where *E. coli* (faecal coliforms) may be more suitable, e.g. where faecal pollution originates for a waste stabilisation pond (WSP). Also, in some countries (e.g. South Africa), *E. coli* (faecal coliforms) has been used as indicator organisms for several years and it will therefore be crucial to run a dual system, for continuation.

As per the WHO approach (WHO, 2003), it is also proposed that, instead of using 'single' target values that classify recreational waters (beach) as either 'safe' or 'unsafe', a range of target values be derived corresponding to different levels of risk. As it is envisaged that there will not be sufficient epidemiological data from the WIO Region to customise such values, it is recommended that the risk-based target values of the WHO (2003) be adopted. In this regard, research undertaken by the WHO indicated that *E. coli* to Enterococci ratios ranging from 2 to 3 reflect equal risk (CEC, 2002).

With reference to toxic substances, it is proposed that suitable Drinking water quality guidelines (e.g. WHO, 2004) be consulted to make preliminary risk assessments in recreational areas where toxic substances could be present at levels posing a risk to human health (following the example of the WHO, 2003). 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. Note that this approach may, however, not be appropriate to substances of which the effects are related to direct contact with water, e.g. skin irritations.

4.3 Marine Aquaculture

For Marine aquaculture activities (including harvesting or collecting of organisms for human consumption), the following general EQO is proposed:

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

For the WIO region, it is proposed that this general EQO be translated into target values linked to:

- Protection of the health of aquatic organisms used in the culture and harvesting of seafood
- Protection of the health of human consumers
- Tainting of seafood products.

With reference to the protection of aquatic organisms used in the culture and harvesting of seafood, it is proposed that the EQTs for the protection of coastal ecosystems be applied, rather than developing a separate series of EQTs. This simplified approach seems to be the international trend, particularly where these activities rely on natural stocks. This approach is also current practice in South Africa (RSA DWAF, 1995b).

With reference to the protection of human consumers, it is proposed that the allowable limits of toxic substances and human pathogens controlled through legislation, as is the norm internationally. Where such standards are currently not in place, it is recommended that the relevant Government Departments be approached to initiate such legislation. Chapter 2.4.1 refers to examples of existing international legislation on such matters which could be consulted.

In terms of shellfish (filter-feeder) growing areas, it is proposed that the EQTs for bacteria (faecal coliform) put forward by the US-EPA (and adopted by most other countries, including Mauritius) also be adopted for the WIO Region (US-EPA, 1986a), namely:

Median faecal coliform concentration should not exceed 14 Most Probable Number (MPN) per 100 ml with not more than 10% of the samples exceeding 43 MPN per 100 ml for a 5-tube, 3-dilution method.

However, the application of this EQT must be supported by a sanitary survey (refer to Chapter 6.2.3), as well as acceptable quality of shellfish meat, to be specified in legislation (see above). This concept is further elaborated on in Chapter 6.

NOTE:

Shellfish exported to the European Union must comply with the standards laid down in the Shellfish Directive (CEC, 1991).

In the USA, shellfish imports must meet both Federal and State requirements to gain free access to US markets. In addition, fresh and fresh frozen molluscan shellfish products must meet the specific temperature, microbiological, and identification standards contained in the NSSP. The NSSP standards have been adopted into state law and are enforced by both federal and state officials. The NSSP standards apply equally to both domestic and imported fresh and frozen shellfish (FDA, 2003).

Estimated threshold concentrations for tainting substances, as listed for Australia, New Zealand, South Africa and the US-EPA (RSA DWAF 1995b; ANCEZZ, 2000; US-EPA, 2002a), can also be used to provide guidance for deriving such EQTs for the WIO region.

4.4 Industrial Use

It is proposed that industrial water use be recognised as a (beneficial) use of coastal waters in the WIO region. In waters used for Industrial purposes, the following general EQO is proposed:

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

However, as a result of the large variation in environmental quality requirements that are mainly driven by specific processes and technologies applied by industries, EQTs should be derived site-specifically, based on the specific requirements of industries in the area.

5. RECOMMENDED ENVIRONMENTAL QUALITY OBJECTIVES AND TARGETS FOR THE COASTAL ZONE OF THE WIO REGION

The ultimate goal in the management of coastal ecosystems is *to keep the resource suitable for all designated uses – both existing and future uses* (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning). One of the aspects to be managed, to ensure fitness-for-use is water and sediment quality. For the WIO region it is proposed that the following broad categories be recognised in terms of designated uses:

- Protection of coastal aquatic ecosystems
- Recreational use
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial use.

Translating the ultimate goal into category-specific objectives, the following generic EQOs are proposed for the WIO Region (recognizing that these EQOs may have to be adapted site-specifically, based on local ecological, social and economic conditions):

Protection of coastal aquatic ecosystems	*The physical, chemical and biological conditions defining the structure of, and processes within, a particular coastal ecosystem are maintained*
Recreational use	*Environmental quality is suitable for recreational use from an aesthetic, safety and hygienic point of view*
Marine aquaculture	*Environmental quality sustains acceptable product quality and prevents any health risks to consumers*
Industrial use	*Environmental quality does not result in mechanical interferences, sustains acceptable product quality and prevents any health risks to consumers*

From a management perspective, this broad objective needs to be translated into measurable target values (or EQTs). The following sections propose generic EQTs for the protection of coastal aquatic ecosystems in the WIO region. A summary of constituent types for which generic EQTs are provided, linked to each of the designated use categories, is provided in Figure 5.1.

Figure 5.1: Summary of constituent types for which EQTs are provided, linked to each of the designated use categories

Constituent Type		Designated Use			
		Protection of Aquatic Ecosystem	Recreation	Marine Aquaculture	Industrial Use
Water	Objectionable matter/ Aesthetics	✓	✓	Similar to Protection of Aquatic Ecosystem	To be based on site-specific requirements of industrial uses
	Physico-chemical Variables	✓	Refer to Drinking Water Guidelines		
	Nutrients	✓			
	Toxic substances	✓			
	Microbiological Indicators		✓	✓	
	Tainting Substances			✓	
Sediment	Toxic substances	✓		Similar to Protection of Aquatic Ecosystem	

As per the proposed strategy for the development of EQO/Ts for the coastal zone of the WIO region (refer to Chapter 4), the following sections list the EQTs proposed for the Protection of coastal aquatic ecosystems as well as other designated uses (i.e. recreation, marine aquaculture and industrial use).

5.1 Protection of Coastal Aquatic Ecosystems

5.1.1 Water

EQTs for the protection of coastal aquatic ecosystems are recommended for the following constituent types:

- Objectionable matter (e.g. resulting in entanglement of marine organisms)
- Physico-chemical variables
- Nutrients
- Toxic substances.

Recommended EQTs for these constituent types are presented in Tables 5.1 to 5.4

Where few site-specific reference data are available and seasonal and event influences poorly defined, in particular for the physico-chemical variables and nutrients, single value EQTs could be derived from available data based on professional judgement, as an interim measure. To assist in establishing such interim EQTs, proposed thresholds levels for different constituent types of the ecotones within the WIO Region, are provided in Chapter 3.4 (in particular Table 3.4). The more detailed data tables on threshold levels, as presented in Appendix VI, may also be useful.

Objectionable matter

TABLE 5.1: Recommended EQTs for Objectionable matter (aesthetics) for coastal waters in the WIO region (adopted from RSA, DWAF, 1995)

CONSTITUENT	RECOMMENDED EQT
Objectionable Matter/Aesthetics	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.

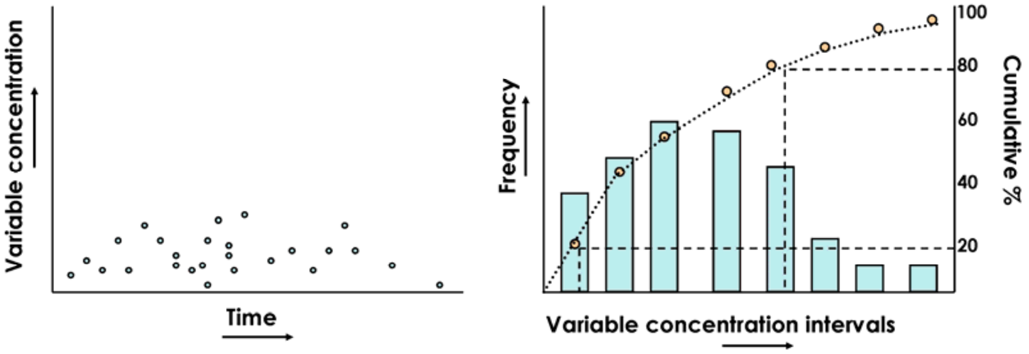
Physico-chemical variables

TABLE 5.2: Recommended EQTs for physico-chemical variables in coastal waters in the WIO region (adopted from ANZECC, 2000)

CONSTITUENT	RECOMMENDED EQT
Temperature	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the range defined by the 20%ile and 80%ile of the seasonal distribution for the reference system. Test data: Median concentration for the period
Salinity	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20%ile or 80%ile of the reference system(s) distribution, depending upon whether low salinity or high salinity effects are being considered. Test data: Median concentration for the period

CONSTITUENT	RECOMMENDED EQT
pH	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value range should be determined as the range defined by the 20%ile and 80%ile of the seasonal distribution for the reference system. pH changes of more than 0.5 pH units from the seasonal maximum or minimum defined by the reference systems should be fully investigated. Test data: Median concentration for the period
Turbidity Suspended solids	Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline values should be determined as the 80%ile of the reference system(s) distribution. Additionally, the natural euphotic depth (Z_{eu}) should not be permitted to change by more than 10%. Test data: Median concentration for period
Dissolved oxygen	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20%ile of the reference system(s) distribution. Where possible, the guideline value should be obtained 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 by using the lowest diurnal DO concentrations

The concept of using 20th or 80th percentiles of the reference system(s) distribution is schematically illustrated below:



Monthly data collected over a two-year period are considered to be sufficient to indicate ecosystem variability and can be used to derive EQTs for constituents that do not show large seasonal or event-scale effects. However, in ecosystems where concentrations of physico-chemical variables and the ecological and biological responses are influenced by 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 EQTs need to be derived for corresponding key periods.

Where the above-mentioned data are not available, the derived constituent threshold levels for physico-chemical variables can be used as recommended interim EQT (referring to Table 3.4):

CONSTITUENT	RECOMMENDED INTERIM EQT		
	Seagrasses	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

Nutrients

TABLE 5.3: Recommended EQTs related to nutrients in coastal waters in the WIO region (adopted from ANZECC , 2000)

CONSTITUENT	RECOMMENDED EQT
Chlorophyll a	Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline value should be determined as the 80%ile of the reference system(s) distribution.
Dissolved oxygen	Refer to Table 5.2
Turbidity	Refer to Table 5.2
Nutrients	Nutrient concentrations in the water column should not result in chlorophyll a, turbidity and/or dissolved oxygen levels that are outside the recommended water quality guideline range (see above). This range should be established by using either suitable statistical or mathematical modelling techniques. Alternatively, where a modelling approach is difficult to implement, nutrient concentrations can be derived using the reference system data approach: Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline value should be determined as the 80%ile of the reference system(s) distribution.

Where the above-mentioned data are not available the derived threshold levels for nutrients can be used as recommended interim EQT (referring to Table 3.4):

CONSTITUENT	RECOMMENDED INTERIM EQT		
	Seagrasses	Mangroves	Coral reefs
Dissolved Inorganic Nitrogen-N (µg/ℓ) (NH_4-N + NO_3-N+ NO_2 –N)	500	1000	15
Dissolved inorganic phosphate-P (µg/ℓ)	50	100	5

Toxic Substances

TABLE 5.4: Recommended EQTs for toxic substances in coastal waters in the WIO Region (adopted from ANZECC, 2000) (threshold levels sourced from measured data specifically relevant to the WIO region are provided in brackets - refer to Table 3.4)

CONSTITUENT	RECOMMENDED EQT (µg/ℓ)
Total Ammonia-N	910 (600 - coral reefs)
Total Residual Chlorine-Cl	3 (0.2)
Cyanide (CN^-)	4
Fluoride(F^-)	5 000*
Sulfides (S^-)	1 (0.02)
Phenol	400
Polychlorinated Biphenyls (PCBs)	0.03**
Trace metals (as Total metal):	
Arsenic	As(III) - 2.3; As(V) - 4.5 (15)
Cadmium	5.5 (5)
Chromium	Cr (III) - 10; Cr (VI) - 4.4
Cobalt	1
Copper	1.3 (1)
Lead	4.4 (1)
Mercury	0.4 (0.3)
Nickel	70 (10)
Silver	1.4 (1)
Sn (as Tributyltin)	0.006

CONSTITUENT	RECOMMENDED EQT (µg/ℓ)
Vanadium	100
Zinc	15 (17)
Aromatic Hydrocarbons (C6-C9 simple hydrocarbons - volatile):	
Benzene (C6)	500
Toluene (C7)	180
Ethylbenzene (C8)	5
Xylene (C8)	Ortho - 350; Para - 75; Meta - 200
Naphthalene (C9)	70
Poly-Aromatic Hydrocarbons (< C15 - acute toxicity with short half-life in water)	
Anthracene (C14)	0.4
Phenanthrene (C14)	4
Poly-Aromatic Hydrocarbons (> C15, chronic toxicity, with longer half-life in water)	
Fluoranthene (C15)	1.7
Benzo(a)pyrene (C20)	0.4
Pesticides:	
Aldrin	(3.15)
DDT	0.001 (0.05)
Dieldrin	0.002 (0.85)
Endosulfan	(0.003)
Endrin	0.002
Lindane	(0.08)

* *No values are recommended in ANZECC (2000) – interim value derived from South African guidelines (RSA DWAF, 1995)*
** *No values are recommended in ANZECC (2000) – interim values derived from the US-EPA criteria (2002a)*

5.1.2 Sediment

Recommended EQTs for sediment linked to the protection of coastal aquatic ecosystems are provided in Table 5.5

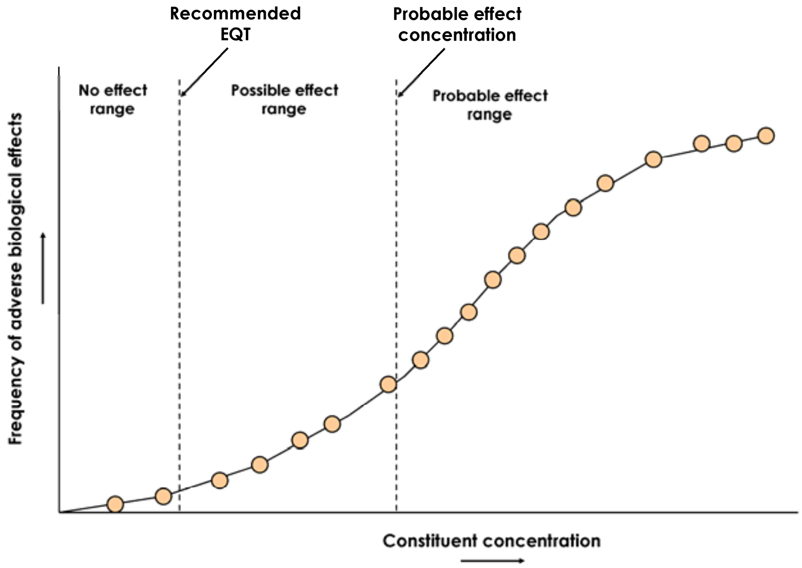
TABLE 5.5: Recommended EQTs for sediments for the Protection of aquatic ecosystems in the coastal zone of the WIO Region (adopted from MacDonald et al, 1996)

CONSTITUENT	RECOMMENDED EQT	PROBABLE EFFECT CONCENTRATION
TRACE METALS (mg/kg dry weight)		
Antimony	-	-
Arsenic	7.24	41.6
Cadmium	0.68	4.21
Chromium	52.3	160
Copper	18.7	108
Lead	30.2	112
Mercury	0.13	0.7
Nickel	15.9	42.8
Silver	0.73	1.77
Tin as Tributyltin-Sn*	0.005	0.07
Zinc	124	271
TOXIC ORGANIC COMPOUNDS (µg/kg dry weight normalized to 1% organic carbon)		
Total PAHs	1684	16770
Low Molecular PAHs	312	1442
Acenaphthene	6.71	88.9
Acenaphthalene	44	640

CONSTITUENT	RECOMMENDED EQT	PROBABLE EFFECT CONCENTRATION
Anthracene	46.9	245
Fluorene	21.2	144
2-methyl naphthalene	-	-
Naphthalene	34.6	391
Phenanthrene	86.7	544
High Molecular Weight PAHs	655	6676
Benzo(a)anthracene	74.8	693
Benzo(a) pyrene	88.8	763
Dibenzo(a,h)anthracene	6.22	135
Chrysene	108	846
Fluoranthene	113	1494
Pyrene	153	1398
Toxaphene	-	-
Total DDT	3.89	51.7
p p DDE	2.2	27
Chlordane	2.26	4.79
Dieldrin	0.72	4.3
Total PCBs	21.6	189

* *Guidelines for tributyltin were estimated on the basis of equilibrium partitioning, based on data summarised from the US-EPA (ANCEZZ, 2000)*

By deriving two threshold values (i.e. an EQT and a probable effect concentration), three ranges of concentration are defined, namely, those that are rarely, occasionally and frequently associated with adverse biological effects as illustrated below:



5.2 Recreational Use

EQTs for the Recreational use are proposed for following constituent types:

- Aesthetics
- Microbiological indicators, as related to protection of human health
- Toxic substances, as related to protection of human health.

Aesthetics

The EQTs related to the aesthetic quality of coastal area, would be similar to that described for Objectionable matter (refer to Table 5.1).

Microbiological indicators

Instead of using 'single' target values to classify recreational areas (beaches) either 'safe' or 'unsafe', a range of target values is proposed corresponding to different risk levels (Table 5.6). It is proposed that Enterococci (faecal streptococci) be used as indicator organism most suitable for marine water. However, instances have been documented where *E. coli* was still considered more suitable, e.g. where faecal pollution originated from waste stabilisation ponds (WSP). Research undertaken by the WHO indicated that *E. coli* to Enterococci ratios between 2 and 3 (2.5 was used for the estimated *E. coli* counts proposed in Table 5.6) (CEC, 2002).

TABLE 5.6: Risk-based EQTs recommended for application in coastal waters used for (contact) recreation in WIO Region (adopted from WHO, 2003)

RISK CATEGORY	RECOMMENDED EQT	
	95th PERCENTILE OF ENTEROCOCCI per 100 ml (estimated *E. coli* equivalents)	ESTIMATED RISK PER EXPOSURE
A	<40 (<100)	<1% gastrointestinal (GI) illness risk <0.3% acute febrile respiratory (AFRI) risk
B	40 – 200 (100 - 500)	1–5% GI illness risk; 0.3–1.9% AFRI risk
C	201 – 500 (501-1250)	5–10% GI illness risk; 1.9–3.9% AFRI risk
D	> 500 (>1250)	>10% GI illness risk; >3.9% AFRI risk

Acknowledging the potential for microbial indicator survival and regrowth in tropical coastal systems, it may be necessary to include an additional indicator organism, *Clostridium perfringens*, in tropical areas where there are uncertainties whether impacts are linked to human faecal contamination. The recommended EQTfor *C. perfringens* is a geometric mean of equal or less than 5 counts/100 ml.

Toxic Substances

With reference to toxic substances, it is proposed that appropriate Drinking water quality guidelines (e.g. WHO, 2004) be consulted to make preliminary risk assessments in areas where these substances are expected to be present at levels that pose a risk to human health (following the example of the WHO, 2003).

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. Note that this approach may, however, not be appropriate to substances of which the effects are related to direct contact with water, e.g. skin irritations.

5.3 Marine Aquaculture

EQTs related to marine aquaculture activities are proposed for following:

- Protection of the health of aquatic organisms cultured and harvested for seafood
- Protection of the health of human consumers
- Tainting substances affecting the quality of seafood products.

Protection of Aquatic Organism Health

With reference to the protection of aquatic organisms cultured and harvested for seafood, it is proposed that the recommended EQTs for the Protection of coastal aquatic ecosystems be applied (refer to Tables 5.2 to 5.5). This simplified approach is also applied internationally, particularly where activities rely on natural stocks.

Protection of Health of Human Consumers

With reference to the protection of human consumers, it is proposed that the allowable limits of toxic substances and human pathogens be controlled through legislation, as is the norm internationally. Where such standards are currently not in place, it is recommended that the relevant Government Departments be approached to initiate such legislation. Examples of existing international legislation on such matters which could be consulted include:

- Australia and New Zealand Food Standards Code (ANZFA, May 2007)
- United States Food and Drug Administration's website on Seafood Information and Resources (US-FDA, 2009), as well as the National Shellfish Sanitation Program (US-FDA, 2007)
- The US-EPA (2002a) also provides guidelines for toxic substances in waters in which organisms are collected for human consumption (summarised in Appendix C). These target values were primarily derived using the Methodology for deriving ambient water quality criteria for the protection of human health (US-EPA, 2000b)
- Canadian Food Inspection Agency, which specifies action levels for different seafood products (Canadian Food Inspection Agency, 2004)
- European Union, as set out in the Shellfish Hygiene Directive (Table 10) (CEC, 1991)
- South Africa, where the legal limits for chemical and human pathogens in seafood are specified under the Foodstuffs, Cosmetics and Disinfectants Act (No. 54 of 1972) and are provided in the Regulation - Marine food (Department of Health, 1973) and the Regulations related to metals and foodstuffs (Department of Health, 1994)

In terms of shellfish growing areas, it is proposed that EQTs, as described in Table 5.7, be applied, in conjuction with a sanitary survey (refer to Chapter 6.2.3) and acceptable quality of shellfish meat (as per the above).

TABLE 5.7: Recommended EQTs for microbiological indicators in coastal areas where shellfish are collected or cultured for direct human consumption in the WIO region (adopted from US-EPA, 1986a)

INDICATOR	RECOMMENDED EQT
Faecal coliform	Median concentrations should not exceed 14 Most Probable Number (MPN) per 100 ml with not more than 10% of the samples exceeding 43 MPN per 100 ml for a 5-tube, 3-dilution method.

Tainting Substances

Estimated threshold concentrations for tainting substances for consideration in the WIO Region are listed in Table 5.8.

TABLE 5.8: Recommended EQTs for tainting substances in coastal waters used for marine aquaculture in the WIO Region (adopted from RSA, DWAF, 1995; ANCEZZ, 2000 and US-EPA, 2002a)

TAINTING SUBSTANCE	THRESHOLD CONCENTRATIONS ABOVE WHICH TAINTING IS LIKELY TO OCCUR (mg/ℓ)
Acenaphthene	0.02
Acetophenone	0.5
Acrylonitrile	18
Copper	1
m-cresol	0.2
o-cresol	0.4
p-cresol	0.12
Cresylic acids (meta, para)	0.2
Chlorobenzene	-
n-butylmercaptan	0.06
o-sec. butylphenol	0.3
p-tert. butylphenol	0.03
2-chlorophenol	0.001
3-chlorophenol	0.001
3-chlorophenol	0.001
o-chlorophenol	0.001
p-chlorophenol	0.01
2,3-dinitrophenol	0.08
2,4,6-trinitrophenol	0.002
2,3 dichlorophenol	0.00004
2,4-dichlorophenol	0.001
2,5-dichlorophenol	0.023
2,6-dichlorophenol	0.035
3,4-dichlorophenol	0.0003
2-methyl-4-chlorophenol	0.75
2-methyl-6-cholorophenol	0.003
3-methyl-4-chlorophenol	0.02 – 3
o-phenylphenol	1
Pentachlorophenol	0.03
Phenol	1
2,3,4,6-tetrachlorophenol	0.001
2,4,5-trichlorophenol	0.001
2,3,5-trichlorophenol	0.001
2,4,6-trichlorophenol	0.003
2,4-dimethylphenol	0.4
Dimethylamine	7
Diphenyloxide	0.05
B,B-dichlorodiethyl ether	0.09
o-dichlorobenzene	< 0.25
p-dichlorobenzene	0.25
Ethylbenzene	0.25
Momochlorobenzene	0.02

TAINTING SUBSTANCE	THRESHOLD CONCENTRATIONS ABOVE WHICH TAINTING IS LIKELY TO OCCUR (mg/ℓ)
Ethanethiol	0.24
Ethylacrylate	0.6
Formaldehyde	95
Gasoline/Petrol	0.005
Guaicol	0.082
Kerosene	0.1
Kerosene plus kaolin	1
Hexachlorocyclopentadiene	0.001
Isopropylbenzene	0.25
Naphtha	0.1
Naphthalene	1
Naphthol	0.5
2-Naphthol	0.3
Nitrobenzene	0.03
a-methylstyrene	0.25
Oil, emulsifiable	15
Pyridine	5
Pyrocatechol	0.8
Pyrogallol	0.5
Quinoline	0.5
p-quinone	0.5
Styrene	0.25
Toluene	0.25
Outboard motor fuel as exhaust	0.5
Zinc	5

5.4 Industrial Use

It is proposed that the following activities be recognised as industrial uses of coastal waters, which may have specific requirements in term of water and sediment quality:

- Seafood processing industries
- Salt production
- Desalination
- Aquariums and oceanariums
- Harbours and ports
- Cooling water intake
- Ballast water intake
- Coastal mining
- Make-up water for offshore marine outfalls
- Exploration drilling
- Scaling and scrubbing.

However, as a result of the large variation in quality requirements of these activities, mainly driven by specific processes and technologies, it is further proposed that EQTs be derived site-specifically, based on specific requirements of industries in the area.

6. PROPOSED IMPLEMENTATION PRACTICE

6.1 Ecosystem-based Management Framework

Traditionally, management of natural resources and the environment, including the coastal zone, was organised around specific uses or sectors, such as fisheries, agriculture, water supply and demand, wastewater and housing development, each with their own governing structures (UNEP, 2006).

NOTE:

***Governance** concerns the values, policies, laws and institutions by which issues are addressed and it defines the fundamental goals, the institutional processes and the structures that are the basis for planning and decision-making. **Management**, in contrast, is the process by which human and material resources are harnessed to achieve a known goal within a known institutional structure. Thus, governance sets the stage within which management occurs (UNEP, 2006).*

Time has shown that this sectoral approach not only results in conflict among different uses, but also in ineffective and inappropriate utilisation of valuable, and often limited, human and financial resources. This led to the realisation that natural resources and the environment can be managed much more effectively, if the 'ecosystem' becomes central and management occurs through cooperative governance between different sectors – referred to as ecosystem-based management.

In essence, ecosystem-based management recognizes that plant, animal and human communities are interdependent and interact with their physical environment to form distinct ecological units called ecosystems (UNEP, 2006). At the large scale, lies the Earth's ecosystem, and although it is very important that governance and management strategies also be formulated at the larger (international) scale, decentralization to regional, national and local levels as, in many instances, implementation occurs at the 'distinct ecological unit' (local or regional) level.

The challenge in ecosystem-based management is to ensure sustainable development, which can be defined as:

> ".. *development which fulfils the needs of the present generation without jeopardizing the possibilities of future generations to fulfill their needs.*"

In this context the ultimate goal in coastal ecosystem management would be to keep the resource suitable for all designated uses – both existing and future uses (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning). To achieve this goal, it is important to protect the biodiversity and functioning of coastal aquatic ecosystems (i.e. ecology) so as to support important (beneficial) uses of the marine environment (i.e. social and economic values).

In many instances sustainable use of coastal ecosystems rely on the systems remaining functional. In turn, the integrity of coastal ecosystems depends on a number of factors, including:

- Stream flows (referring to river and groundwater inflows)
- Physical habitat (referring to water circulation processes, sediment type and climatic conditions)
- Water and sediment quality (referring to the biogeochemical status)
- Availability of suitable migrations or recruitment routes
- Food web integrity and availability.

In order to effectively manage coastal systems so as to remain suitable for designated use, measurable targets should be set for the different parameters defining the integrity of these systems. In terms of water and sediment quality, generic EQO/Ts – as proposed here - are developed to provide guidance to local managers and governing authorities in setting site-specific EQO/Ts, focusing on specific issues of relevance and potential concern in their area. Thus, generic EQO/Ts should be considered as a first phase approach in setting local

EQO/Ts and depending on site-specific conditions (ecological, social and/or economic) these may have to be refined and or adapted.

The development and implementation of EQO/Ts should not occur in an *ad hoc* manner, but rather form part of a proper management strategy or framework. Such a framework has been proposed by Taljaard et al (2006) and is illustrated in Figure 6.1. A brief overview on each of the components follows.

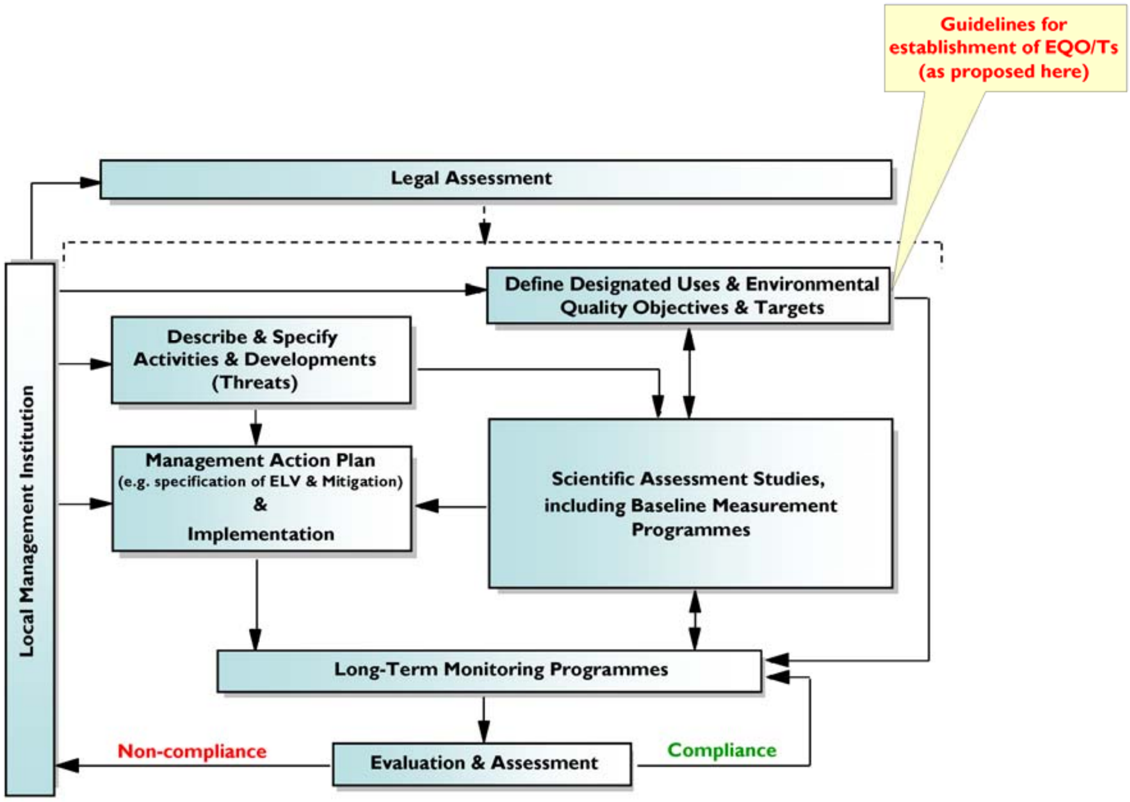


Figure 6.1: Proposed management framework within which to implement EQO/Ts in the coastal zone of the WIO Region (adapted from Taljaard et al, 2006)

Local Management Institution

A key driving factor in the successful operation of any coastal management programme is the establishment of the appropriate cross-sectoral **management institution**, including the identifation of the roles and responsibilities of all members. Not only do these local management institutions provide an ideal platform for stakeholder consultation on, for example, designated uses and local EQO/Ts, but they also fulfil the important role of 'local watchdogs' or 'custodians'. Although such institutions usually do not have executive powers, they have shown themselves to be very successful mechanisms through which to empower (and pressurize) responsible authorities to execute their legal responsibilities.

It is also essential that local management institutions include all relevant stakeholders in order to facilitate a participatory approach to decision-making. The inclusion of responsible local, provincial and national government authorities is also important, as these are usually the routes through which the institutions gain executive powers. Local management institutions should therefore include representatives from, for example:

- National and provincial government departments
- Nature conservation authorities
- Local authorities
- Industries

- Tourism boards and recreation clubs
- Local residents, e.g. through ratepayers' association
- Non-government organizations.

The key to the success of local management institutions is a sound scientific information base through which stakeholders (both government and private) are informed and empowered to partake in the decision-making process.

UNEP (2006) argues that the institutional and societal conditions necessary for an ecosystem-based (coastal) management framework to be successful requires:

- Unambiguous goals (objectives) against which to measure the effectiveness of a programme (see *Environmental quality objectives*)
- Active support from a core of well-informed and supportive *constituencies* composed of stakeholders in both the private sector and government agencies
- Governmental *commitment* to the policies of a programme and allocation of financial resources required for long-term implementation
- Sufficient initial *capacity* is present within the institutions responsible for the programme to implement its policies and plan of action.

A management institution, being actively involved in coastal management at local level, is also ideally positioned to test the effectiveness and applicability of legislation and policies, which are normally developed at national or regional levels. It is therefore also important that these institutions be utilized by higher tiers of government as a mechanism for improving legislative frameworks related to coastal management, supporting the principle of Adaptive Management.

Legal Assessment

A coastal management programme needs to be designed and implemented within the statutory framework governing coastal related issues in a particular country, taking into account international treaties and obligations. The statutory framework is likely to differ from one country to another, and the purpose of this legal assessment is to establish existing policies and management strategies that need to be considered. Often the legal frameworks within countries are still very much sectorally-based and this assessment, therefore, also aims at extracting and consolidating that that which is relevant to the coastal zone.

Environmental Quality Objectives and Targets

Environmental quality objectives must be set to provide a basis from which to assess and evaluate management strategies and actions, supporting the Management by Objectives (MBO) Approach (Wibeck, et al. 2006; Edvardsson, 2004). This may be achieved through a four-step approach:

- Define and delineate the geographical boundaries of the study area
- Define and delineate important and sensitive coastal aquatic ecosystems and designated uses within the area
- Define site-specific EQO for important and sensitive coastal aquatic ecosystems and each of the designated uses
- Determine site-specific environmental quality target values for *coastal sediment and water quality,* among others.

It is in the latter steps that the generic EOO/Ts - as proposed here – is used to derive site-specific objectives and target values (Figure 6.1).

NOTE:

The approach for establishing EOQ/Ts - as proposed here - is very much in line with the concept of ocean zoning. Ocean zoning is a planning tool that comes straight out of the land use planning methodologies that are used at the municipal, county, state, regional, and national levels (as on land, it allows a strategic allocation of uses based on a determination of an area's suitability for those uses, and reduction of user conflicts by separating incompatible activities. There are generally two components to an ocean zoning plan: 1) a map that depicts the zones and 2) a set of regulations or standards applicable to each type of zone created. More on ocean zoning can be obtained from Agardy (2007).

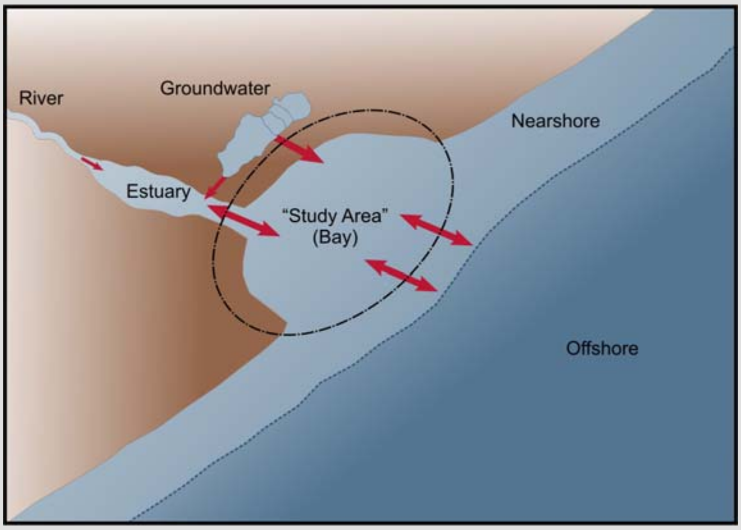
The selection of the geographical boundary of a specific coastal system is important. It needs to consider interdependencies between the coastal fauna and flora and human communities, as well as their interaction with the physical coastal environment. Aspects that need to be considered include:

- Anticipated spatial influence of human activities and developments, both in the near and far field, including land-derived wastewater discharges
- Proximity of depositional areas where pollutants can accumulate – these can be at distant locations for specific sources, particularly where the source discharges into a very dynamic environment but subsequently is transported to an area of lower turbulence
- Possible synergistic effects in which the negative impacts resulting from a particular activity could be aggravated through another activities or even through interaction with natural processes.

NOTE:

Recognising that many of the challenges posed by intensifying human activity and ecosystem change cannot necessarily be solved by managing river basins (or catchments), coast zones and larger marine ecosystems (LMEs) in isolation (UNEP, 2006), it may be necessary, from a practical perspective, to limit the size of the 'local management unit'.

In terms of the impact of land-based activities on the marine environment, it is usually coastal zones adjacent to large urban areas (also referred to as 'hot spots') or coastal areas that received runoff from large catchments that are in the 'line of firing'. It is therefore considered appropriated to use these 'hot spots' as departure point for defining the geographical boundaries of local coastal ecosystem, insofar as it pertains to management of land-based activities, but still recognising interaction with adjacent environments (e.g. river basins and the LME) as illustrated below (taken from Taljaard, 2006b):



In this context, the local coastal management unit can be seen as a sub-section of the larger integrated river basin and/or LME management unit.

Similar to the European Union's approach, it is proposed that, for the WIO region, in contrast to other designated use areas where protection is required only in specific areas where such uses occur (e.g. recreation beaches), protection of coastal aquatic ecosystems should be striven for in all waters (CEC, 2003), the exception to this being perhaps in approved sacrificial zones (e.g. in proximity to wastewater discharges and certain areas within ports) – the rationale being that the coastal ecosystems should be protected to a high level in its entirety, where possible. Agreement on the designated uses and site-specific EOO/Ts within a particular coastal zone should be obtained in consultation with local stakeholders through, for example, the local management institutions.

Agreement on the designated uses and EQO/Ts for a specific area should be determined in consultation with local stakeholders through, for example, the local management institutions. Social and economic factors need to be evaluated to determine if the EQO/Ts can realistically be attained. For example, it may be that wastewater emission targets, based on EQTs, are not achievable in the short term, due to social and economic factors. A longer-term plan, therefore, needs to be adopted where EQO/Ts are periodically re-evaluated and refine to ensure that the desired quality is ultimately attained.

NOTE:

As a rule of thumb, it is recommended that the following simple application rules apply:

1. ***Compliance with EQO/Ts for the Protection of marine aquatic ecosystems (refer to Chapters 5.1 and 6.2.1) should be aimed at in all coastal areas, except in approved sacrificial zones, e.g. near wastewater discharges and certain areas within ports.***
2. ***In addition to (1), the aesthetic EQO/Ts, as well as the classification system ranking waters in terms of human health risks for Recreational use, should be applied in relevant areas (Refer to Chapters 5.2 and 6.2.2). With reference to toxic substances, it is recommended that suitable Drinking water quality guidelines be consulted to make preliminary risk assessments, where these substances are expected to be present at levels that could pose a risk to human health (following the example of the WHO, 2003).***
3. ***In addition to (1), the classification system recommended for Marine aquaculture should be applied in areas where shellfish are collected or cultured for human consumption so as to manage human health risks (refer to Chapters 5.3 and 6.2.3). The assumption is that the health of the organisms is catered for under the Protection of marine aquatic ecosystems (referring to 1).***
4. ***In addition to (1), site-specific EQO/Ts, based on the requirements of local industries (refer to Chapter 5.4), should be applied, where and if applicable.***

Activities and Developments (Threats)

Effective coastal management in a particular area requires, amongst other things, quantitative data on activities or developments that directly (or indirectly) affect water and sediment quality (e.g. land-derived wastewater discharges). Although human perturbations of coastal water and sediment quality are usually perceived to be the result of waste disposal (either land-based or disposal at sea), it is important to realize that developments that modify circulation dynamics in the coastal areas, such as harbour and marina structures, can also modify quality characteristics (e.g. by creating depositional or stagnant areas).

Scientific Assessment Studies

Scientific assessment studies are required to assess whether the coastal system is able to support important ecosystems and designated beneficial uses (as defined in terms of the EQO/Ts) in a sustainable manner, in addition to being subject to modifications associated with human activities and developments in the area.

These assessments need to take into account environmental process complexities and natural variability, which require data, understanding and information on physical, biogeochemical and biological characteristics and process scales. Depending on the availability of scientific data and information on the area, scientific assessments may also include **baseline field measurement programmes**.

NOTE:

It is important to note the differences between baseline measurement programmes (usually part of Scientific Assessment Studies) and monitoring programmes (implemented as part of Long-term Monitoring Programmes):

- ***Baseline measurement programmes (or surveys) usually refer to shorter-term or once-off, intensive investigations on a wide range of parameters to obtain a better understanding of ecosystem functioning***
- ***Long-term monitoring programmes refer to ongoing data collection programmes that are done to evaluate continuously the effectiveness of management strategies/actions designed to maintain a desired environmental state so that responses to potentially negative impacts, including cumulative effects, can be implemented in good time (using selected indicators).***

Numerical (predictive) modelling techniques have proven to be powerful tools as part of coastal management programmes (provided that these are properly calibrated and validated) in that:

- Models provide a workable platform for incorporating the complexity of spatial and temporal variability in the marine environment
- Model assumptions and inputs provide a means of synthesizing existing understanding of the key processes and, in doing so, provide a means of stimulating stakeholder discussion on their relevance to achieving environmental quality objectives
- Modelling assists in defining the most critical spatial and time scales of potential negative impacts on the receiving system
- Model outputs provide quantitative results which can be used, together with field data, to check the quality of assumptions and insights.

Management Actions

The outcomes of the scientific assessment studies, amongst others, are typically presented to the responsible management authorities and institutions for final decision making to provide management actions regarding, for example:

- Critical limits for developments and activities (e.g. setting wastewater emission targets [WET], based on EQO-approach)
- Modifications to the structural design of the development where relevant
- Mitigating actions to be implemented during the construction and/or operation of coastal developments and activities.

Based on the outcome of the scientific assessment studies it may be necessary to negotiate 'trade-offs' in terms of recommended environmental quality targets versus allowing activities and developments with large socio-economic benefits to proceed, provided that all reasonable attempts have been taken to mitigate or minimise environmental impacts. In order to facilitate a participatory approach in decision-making, governing authorities need to take decisions on such matters in consultation with local stakeholders, e.g. through local management institutions.

Long-term Monitoring

Long-term monitoring form an integral part of a coastal management programme and refers to ongoing data collection programmes which are designed and implemented so as to continuously evaluate the:

- Effectiveness of management actions in achieving compliance with EQO/Ts, critical limits (e.g. WET) and the implementation of mitigating actions

- Trends and status of changes in the environment in terms of the health of important ecosystem components and designated beneficial uses in order to respond, where appropriate, in good time to potentially negative impacts, including cumulative effects
- Whether the predicted environmental responses, identified during the scientific assessment process, match the actual responses
- Whether the initial assumptions remain valid such as for example the geographical boundary conditions.

It is also important to remember that any long-term monitoring programme is a dynamic, iterative process that needs to be adjusted continuously to incorporate new knowledge, thereby supporting the principle of adaptive management.

Evaluation and Assessment

This component within a coastal management programme provides an explicit mechanism whereby the outcomes of the programme are assessed and evaluated and where upon management needs to response. Evaluation and Assessment can take on different formats and can occur on different time scale, for example:

- Monthly to quarterly meeting of the local management institution to evaluate short-term progress and highlight concerns
- Annual progress reports and public meetings to communicate outcomes of the management programme to the wider community
- Five-yearly State of the Coast Reports using, for example a Driver-Pressure-State-Impact-Response (DPSIR) method.

6.2 Proposed Implementation Process for Environmental Quality Objecticves and Targets

Within the Management Framework proposed above, EQO/Ts for coastal areas need to be determined in consultation with relevant stakeholders. Once these have been established, site specific, measurable target values need to be derived based on the generic EQO/Ts provided as part of this document. The following sections proposed a process by which these could be derived for each of the identified use categories.

6.2.1 Protection of Coastal Aquatic Ecosystems

Following international best practice, it is recommended that generic EQO/Ts for the protection of coastal aquatic ecosystems in the WIO region be applied as benchmarks, following a risk assessment or phased approach as illustrated in Figure 6.2.

NOTE:

The EOTs for the protection of coastal aquatic ecosystem are primarily derived fom toxicological data and bioassay studies. It is therefore based on the general tolerance of biota to different constituent concentrations (refer to Chapter 2) and not necessarily take <u>natural backround concentrations</u> of such constituents into consideration. It is therefore important that these EQTs be validated site-specifically by applying a risk assessment approach as set out in Figure 6.2

Where scientific assessments studies or monitoring results reveal that recommended EQO/Ts are exceeded, this should trigger the incorporation of additional information or further investigation to determine whether or not a real risk to the ecosystem exists, and, where necessary, to adjust the EQO/Ts for site-specific conditions.

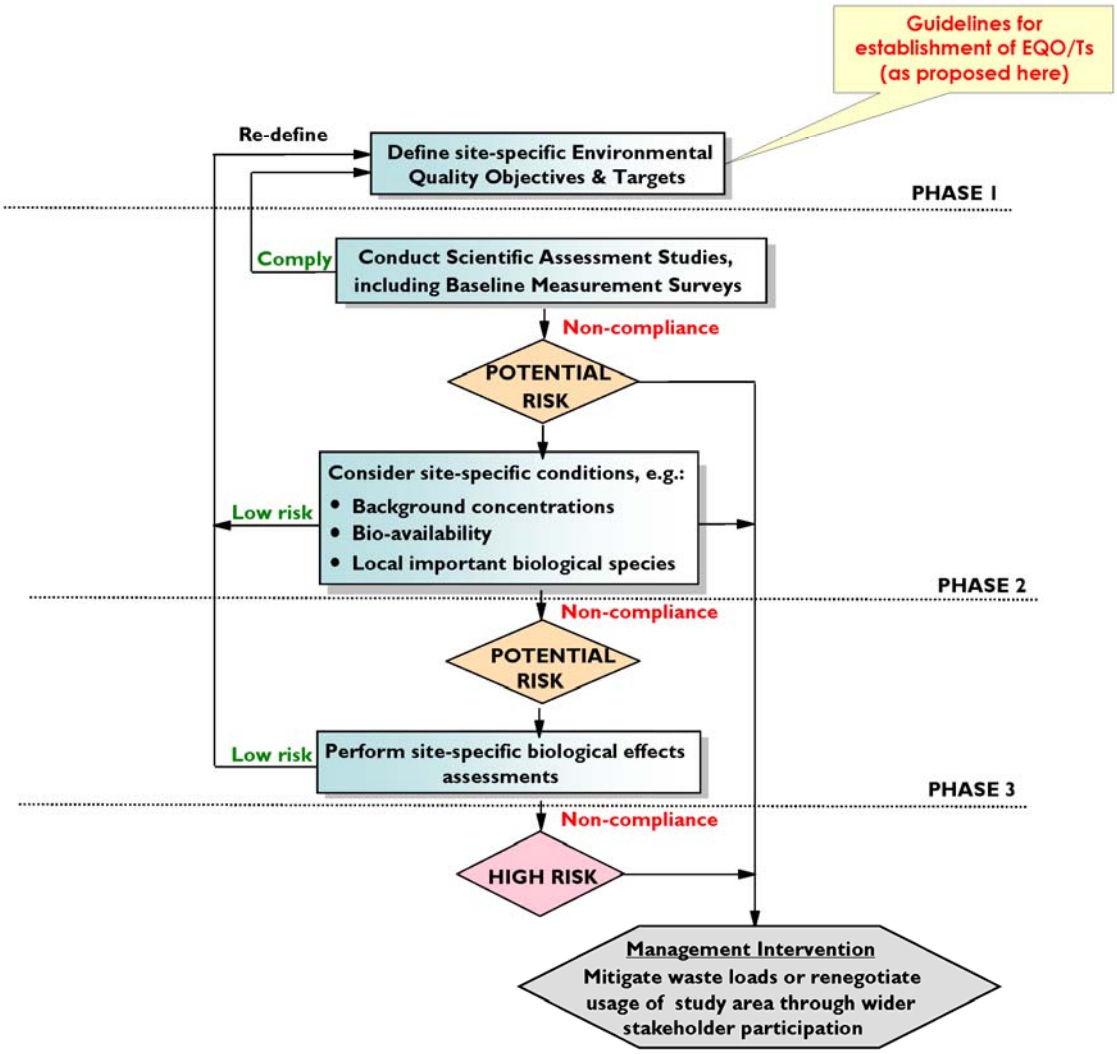


Figure 6.2: **Schematic illustration of the proposed process for deriving site-specific EQO/Ts for coastal waters and sediment linked to the Protection of aquatic coastal ecosystems in the WIO region**

EQTs should be compared with the median of the measured or simulated data set. Where an EQT was based on professional judgement, the rationale for the selection of such a value should be provided and a process should be put in place whereby the adopted value is reviewed and supported or modified in light of emerging information, following the principle of adaptive management.

Similar to the implementation practice recommended for EQO/Ts for coastal waters, it is recommended that EQO/Ts for sediments for the WIO region be applied as benchmarks, following a risk assessment or phased approach: When scientific assessment studies or monitoring indicate that the recommended quality guideline values are exceeded, this should trigger the incorporation of additional information or further investigation to determine whether or not a real risk to the ecosystem exists, and, where necessary, to adjust the EQO/Ts for site-specific conditions. The recommended approach is schematically illustrated in Figure 6.2.

EQO/Ts are valuable tools for assisting in managing complex systems (such as an aquatic marine ecosystem) in a phased approach. As part of the initial phase, guidelines provide a means of 'screening' for potential adverse biological effects related to sediment quality.

6.2.2 Recreational Use

It is recommended that the WIO region adopt a beach classification system, rather than the traditional approach of classifying recreational waters as either safe or unsafe (based on a percentage compliance with a faecal indicator organism). With reference to water quality, the classification should be based on both a sanitary survey, as well routine microbiological surveys. The classification rating should be re-evaluated on an annual basis.

An example of a sanitary survey checklist is provided in the document of the New Zealand Minister of Environment (NZME, 2003) (www.mfe.govt.nz/publications/water/microbiological-quality-jun03/).

In this regard, it is recommended that the classification system of the WHO (2003) and New Zealand (NZME, 2003) be adopted, as it is currently the most widely used worldwide (Table 6.1).

NOTE

In the microbial water quality assessment, the sampling programme should be representative of the range of conditions in the recreational water environment while it is being used and a sufficient number of samples should be collected. The precision of the estimate of the 95th percentile is higher when sample numbers are increased. For example, the number of results available can be increased significantly by pooling data from multiple years, unless there is reason to believe that local (pollution) conditions have changed. For practical purposes, data on at least 100 samples from a 5-year period and a rolling 5-year data set can be used for water quality assessment purposes.

TABLE 6.1: Recommended classification system for recreational areas in coastal waters in the WIO region (adopted from WHO, 2003 and NZME, 2003)

		MICROBIOLOGICAL QUALITY ASSESSMENT CATEGORY (95TH PERCENTILE ENTEROCOCCI/100 ml – refer to Table 5.7)				
		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]	Action required
	Low	Very Good	Good	Fair	Follow-up[1]	
	Moderate	Good[2]	Good	Fair	Poor	
	High	Good[2]	Fair[2]	Poor	Very poor	
	Very high	Follow-up[2]	Fair[2]	Poor	Very poor	
	Exceptional circumstances[3]	Action required				

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 and a grading would not apply until the episode has abated.*

NOTE:

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, namely the 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. Based upon percentile evaluation of the $\log_{10}$ normal probability density function of microbiological data acquired from a particular bathing water, the percentile value is derived as follows (CEC, 2006b):

- ***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 percentile point of the data probability density function is derived from the following equation: upper 95 percentile = antilog (μ + 1,65 σ)
The upper 90 percentile point of the data probability density function is derived from the following equation: upper 90 percentile = antilog (μ + 1,282 σ)

The non-parametric approach does not assume any particular distribution and uses data ranking. 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 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, … , n, rank the n data from lowest to highest where ranked data is Y_i: i = 1, 2, …, n*
- *Compute the percentile fraction (i.e., proportion) as p = P/100 (P is e.g. 95percentile)*
- *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 Pth 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, in the equations in item 3 above].

In addition to a classification system, it is also recommended that a day-to-day management system be adopted. In this regard, the New Zealand approach is considered to be most useful (NZME, 2003) (Figure 6.3).

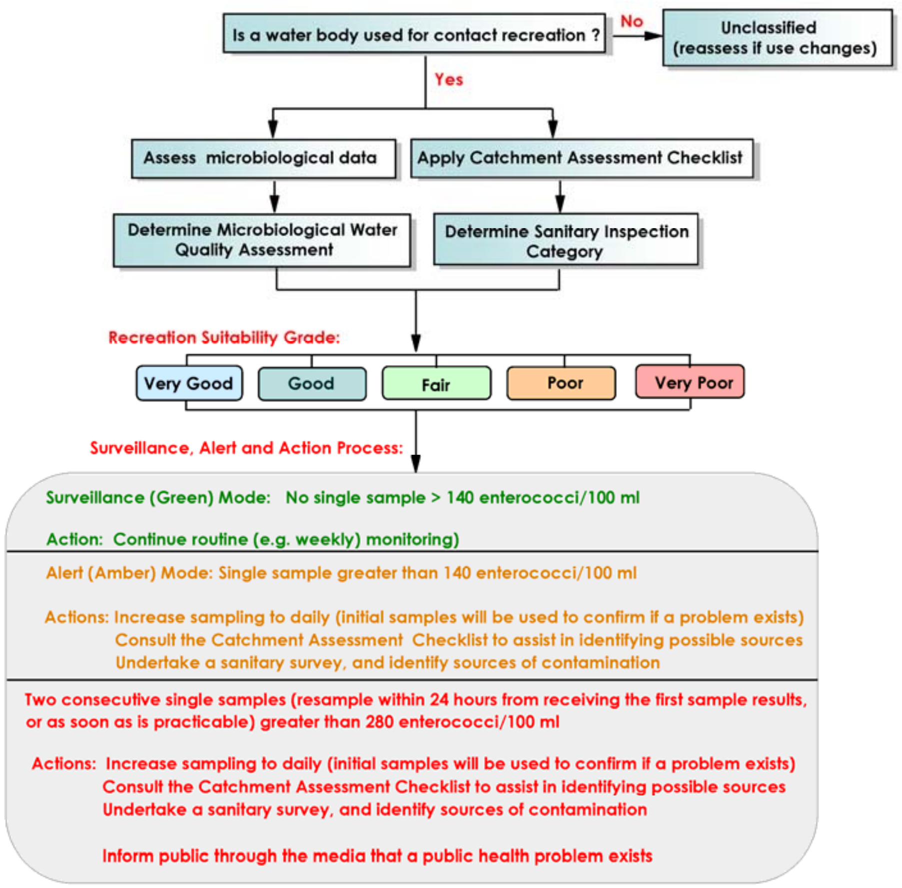


Figure 6.3: Grading, surveillance, alert and action process recommended for the management of recreational areas in the coastal zone of the WIO region (adopted from NZME, 2003)

NOTE:

The single samples target values proposed for the operational management system, is adopted from New Zealand (NZME, 2003) and was taken from previous uncontrolled epidemiological studies (e.g. Cabelli, 1983b). Recognising numerous limitation the single sample target values were obtained by assuming that intestinal enterococci distributions would be lognormal, that the standard deviation of the logarithms of intestinal enterococci concentration is 0.7 (a reasonable average from available data) and that intestinal enterococci concentration limit is at a median of 35 counts per100 ml (corresponding to a swimming-associated risk of 19 per 1000 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, respectively. Acknowledging the uncertainty in estimating the standard deviation of the logarithms it was considered appropriate to round these values to 140 and 280 enterococci per 100 ml, respectively.

Where beaches are earmarked as (international) tourist destinations, authorities are encouraged to subscribe to the Blue Flag Initiative, not only to provide safe beaches, but also as marketing tool (FEE, 2004).

6.2.3 Marine Aquaculture

It is recommended that a classification system for shellfish growing areas be adopted for the WIO region. **Major export markets may eventually dictate** the approach that will have to be followed by countries in the region. To address this issue it is recommended that a regional task team (e.g. through the WIO Mariculture Forum - http://www.wiomariculture.org/forum/?page_id=2) be convened to decide on the final approach for the classification of shellfish growing areas in the WIO region.

NOTE

South Africa's Department of Environmental Affairs is in the process of putting regulatory structures in place to implement a shellfish sanitation program that is likely to meet the demands of the European Union and other countries to which South Africa exports. More details on this can be obtained from Louw et al (2005) that investigated the establishment of shellfish sanitation program for the larger BCLME Region.

As an interim measure for the WIO region, unless dictated otherwise, it is recommended that the National Shellfish Sanitation Program (NSSP) approach, applied by the United States Food and Drug Administration, be followed for the classification of shellfish growing areas in the WIO region (US-FDA, 2007). This approach is considered to be the most practical in terms of implementation, as it classifies areas on the basis of the condition of the waters in the growing area, rather than, for example, the European Union's approach, which classifies areas on the basis of levels of contaminants in shellfish flesh. The NSSP's approach is also the most widely used internationally (refer to Chapter 2.4). The NSSP approach also 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 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 for Sanitary Surveys that consist of:

- Identification and evaluation of all potential and actual pollution sources (Shoreline Survey) — this survey describes the studies required 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 survey refers to the measurement of faecal indicator levels in the growing areas.

Resurveys are conducted regularly to determine if sanitary conditions have undergone significant change.

The proposed classification system for shellfish growing areas in the WIO region is provided in Tables 6.2 and 6.3.

TABLE 6.2: Recommended (interim) classification system of shellfish growing areas in the WIO region (adopted from US-FDA, 2007)

CLASS	DESCRIPTION
Approved	Approved areas need to be free from pollution and shellfish from such areas are suitable for direct human consumption of raw shellfish.
Conditionally approved/restricted	Where areas are subjected to limited, intermittent pollution caused by discharges from wastewater treatment facilities, seasonal populations, non-point source pollution, or boating activity they can be classified as conditionally approved or conditionally restricted. However, it must be shown that the shellfish harvesting area will be open for the purposes of harvesting shellfish for a reasonable period of time and the factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' for harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Restricted areas are subject to a limited degree of pollution. However, the level of faecal pollution, human pathogens and toxic or deleterious substances is such that shellfish can be made fit for human consumption by either relaying or depuration.
Prohibited	An area is classified as 'Prohibited' for shellfish harvesting if no comprehensive survey has been conducted or where a survey finds that the area is: • adjacent to a sewage treatment plant outfall or other point source outfall with public health significance • contaminated by (an) unpredictable pollution source(s) • contaminated with faecal waste so that the shellfish may be vectors for disease micro-organisms • affected by algae which contain biotoxin(s) sufficient to cause a public health risk • contaminated with poisonous or deleterious substances whereby the quality of shellfish may be affected. NOTE: Where an event such as a flood, storm or marine biotoxin outbreak occurs in either 'Approved' or 'Restricted' areas, these can also be classified as temporarily 'Prohibited' areas.

TABLE 6.3: Summary of requirements associated with each class in the recommended (interim) classification system of shellfish growing areas in the WIO region (adopted from US-FDA, 2007)

CLASS	REQUIREMENTS*
Approved	A sanitation survey must be completed according to specification to be reviewed annually. The area shall not be contaminated with faecal coliform (as listed) and shall not contain pathogens or hazardous concentrations of toxic substances or marine biotoxins (an approved shellfish growing area may be temporarily made a prohibited area, e.g. when a flood, storm or marine biotoxin event occurs). Evidence of potential pollution sources, such as sewage lift station overflows, direct sewage discharges, septic tank seepage, etc., is sufficient to exclude the growing waters from the approved category. Faecal coliform median (or geometric mean MPN or MF (mTEC) of the water sample results shall not exceed 14 per 100 ml and the estimated 90th percentile shall not exceed an MPN or MF (mTEC) of: (a) 43 MPN per 100 ml for a five tube decimal dilution test; (b) 49 MPN per 100 ml for a three-tube decimal dilution test; or (c) 31 CFU per 100 ml for a MF (mTEC) test. Total coliform geometric mean of the water sample results for each sampling station shall not exceed 70 MPN per 100 ml and the estimated 90th percentile shall not exceed an MPN of: (a) 230 MPN per 100 ml for a 5-tube, decimal dilution test; (b) 330 MPN per 100 ml for a 3-tube, decimal dilution test.
Conditionally approved/restricted	Factors determining this period are known, predictable and are not so complex as to preclude a reasonable management approach. A management plan must be developed for every conditionally approved/restricted area. When 'open' for shellfish harvesting for direct human consumption, the water quality in the area must comply with the limits as specified for 'Approved' area. When 'closed' for direct consumption but 'open' for harvesting for relaying or depuration, the requirements of 'Restricted' area must be met. At times when the area is 'closed' for all harvesting, then the requirements of 'Prohibited Areas' apply.
Restricted	Faecal coliform median or geometric mean MPN of the water sample results shall not exceed 88 per 100 ml and the estimated 90th percentile shall not exceed a MPN of: (a) 260 MPN per 100 ml for a five tube decimal dilution test; or (b) 300 MPN per 100 ml for a three-tube decimal dilution test. Total coliform geometric mean MPN of the water sample results for each station shall not exceed 700 per 100 ml and not more than 10% of the samples shall exceed an MPN of: (a) 2300 MPN per 100 ml for a 5-tube, decimal dilution test; or (b) 3300 MPN per 100 ml for a 3-tube, decimal dilution test; or (c) 1386 MPN per 100 ml for a 12-tube, single dilution test.
Prohibited area	No requirements specified

*: *The implementation and interpretation of the microbiological limits are subject to some understanding of statistical shortcomings which are discussed in further detail in US-FDA, 2007)*

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APPENDIX I

SUMMARY OF INTERNATIONAL MARINE WATER QUALITY GUIDELINES (TARGETS) FOR PROTECTION OF MARINE (COASTAL) AQUATIC ECOSYSTEMS

Physico-chemical variables and Nutrients:

VARIABLE	MAURITIUS (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-EPA, 2002a)	CANADA (CCME, 2002)	EUROPEAN COMMUNITY (CEC, 2000)
Salinity	-	33 – 36	Low-risk trigger concentrations for salinity should be determined as the 20%ile or 80%ile of the 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	-	Human activities should not cause the salinity (expressed as parts per thousand) of marine and estuarine waters to fluctuate by more than 10% of the natural level expected at that time and depth.	-
Temperature	Ambient	The maximum acceptable variation in ambient temperature is +/-1 °C	Where an appropriate reference system(s) is available, and there are sufficient resources to collect the necessary information for the reference system, the trigger range should be determined as the range defined by the 20%ile and 80%ile of the 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.	Human activities should not cause changes in ambient temperature of marine and estuarine waters to exceed ±1°C at any time, location, or depth. The natural temperature cycle characteristic of the site should not be altered in amplitude or frequency by human activities. The maximum rate of any human-induced temperature change should not exceed 0.5°C per hour (interim guideline)	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.
pH	7.5 – 8.5	7.3-8.2	Where an appropriate reference system(s) is available, and there are sufficient resources to collect the necessary information for the reference system, the trigger range should be determined as the range defined by the 20%ile and 80%ile of the seasonal distribution for the reference system. pH changes of more than 0.5 pH units from the seasonal maximum or minimum defined by the reference systems should be fully investigated. Test data: Median (or mean) concentration for the period	6.5 - 8.5	The pH of marine and estuarine waters should fall within the range of 7.0 - 8.7 units unless it can be demonstrated that such a pH is a result of natural processes. Within this range, pH should not vary by more than 0.2 pH units from the 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, and any change should tend towards the recommended range	6 – 8.5 (recommended Wolff *et al.*, 1988)
Dissolved oxygen	> 5 mg/ℓ	For the west coast, the dissolved oxygen should not fall below 10 % of the established natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 mg/ℓ (99 % of the time) and below 6 mg/ℓ (95 % of the time)	Where an appropriate reference system(s) is available, and there are sufficient resources to collect the necessary information for the reference system, the trigger value for DO should be determined as the 20%ile of the reference system(s) distribution. Where possible, the trigger value should be obtained during low flow and high temperature periods when DO concentrations are likely to be at their lowest. Test data: Median DO	2.3 mg/ℓ (CMC); 4.8 mg/ℓ (CCC) Refer to US-EPA (2000a) for further details on criteria	The recommended minimum concentration of DO in marine and estuarine waters is 8.0mg/ℓ.* Depression of DO below the recommended value should only occur as a result of natural processes. When the natural DO level is less than the recommended interim guideline, the natural concentration should become the interim guideline at that site. When ambient DO concentrations are >8.0 mg/ℓ, human activities should not cause DO levels to	Oxygenation conditions do 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 (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-EPA, 2002a)	CANADA (CCME, 2002)	EUROPEAN COMMUNITY (CEC, 2000)
			concentration for the period, calculated using the lowest diurnal DO concentrations		decrease by more than 10% of the natural concentration expected in the receiving environment at that time.	
Chemical oxygen demand	2 mg/ℓ	-	-	-	-	-
Turbidity/Water Clarity		Should not reduce the depth of the euphotic zone by more than 10 % of ambient levels measured at a suitable control site (turbidity) Should not be more than 35 *Hazen units* above ambient concentrations (colour)	Where an appropriate reference system(s) is available and there are sufficient resources to collect the necessary information for the reference system, the trigger value for turbidity or light penetration should be determined as the 80%ile of the reference system(s) distribution. Additionally, the natural euphotic depth (Z_{eu}) 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.
Suspended solids	5 mg/ℓ	Should not be increased by more than 10 % of ambient concentrations		-	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)	-
Dissolved inorganic nutrients	Coral communities: NO_3-N: 200 µg/ℓ PO4-P: 40 µg/ℓ Other natural areas: NO_3-N: 300 µg/ℓ PO4-P: 50 µg/ℓ	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen*	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.	Phosphorus: 0,1 µg/ℓ (elemental) Refer to US-EPA (2001) for further 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 (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-EPA, 2002a)	CANADA (CCME, 2002)	EUROPEAN COMMUNITY (CEC, 2000)
			Test data: Median (or mean) concentrations measured during growth periods			
Chlorophyll a	-		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 further 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.

Toxic substances:

VARIABLE	MAURITIUS (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-EPA, 2002a)	CANADA (CCME, 2002)	EUROPEAN COMMUNITY (CEC, 2000)
Total Ammonia-N (µg/ℓ)	-	600 (20 as NH_3-N)	910 (M)	Target values are pH and Temperature dependent - refer to US-EPA (1989) for further details on criteria Total ammonia-N at pH 8.2 and 15°C: 6700 (CMC); 1000 (CCC)	-	21 (un-ionised) (recommended Seager *et al.*, 1988)
Total Residual Chlorine-Cl (µg/ℓ)	-	-	3 (L)	13 (CMC); 7.5 (CCC)	0.5	-
Cyanide (CN^-) (µg/ℓ)	10	12	4 (M)	1	-	-
Fluoride(F^-) (µg/ℓ)	-	5 000	-	-	120 (freshwater)	-
Sulfides (S^-) (µg/ℓ)	-	-	1 (L)	2	-	10 (un-dissociated) (recommended Mance *et al.*, 1988a)
Phenol (µg/ℓ)	50	-	400 (M)	-	-	
Chloroform (µg/ℓ)	-					12
Carbon tetrachloride (µg/ℓ)	-					12
Oil and Grease (mg/ ℓ						
TRACE METALS (µg/ℓ):						
Arsenic	50	12 (T)	As(III): 2.3T (T, L) As(V): 4.5 (T, L)	69 (D, CMC); 36 (D, CCC)	12.5 (T)	25D (recommended Mance *et al.*, 1984c)
Cadmium	20	4 (T)	5.5T (H)	40 (D, CMC); 8.8 (D, CCC)	0.12 (T)	0.5 (D) (estuaries) 0.25 (D) (coastal waters)
Chromium	50	8 (T)	Cr (III): 10 (T, M) Cr (VI): 4.4 (T, H)	- 1100 (D, CMC); 50 (D, CCC)	56 (T) 1.5 (T)	15 (D) (recommended Mance *et al.*, 1984a)
Cobalt	-	-	1 (T, H)	-	-	-
Copper	50	5 (T)	1.3 (T, H)	4.8 (D, CMC); 3.1 (D, CCC)	-	5 (D) (recommended Mance *et al.*, 1984b)
Lead	50	12 (T)	4.4 (T, H)	210 (D, CMC); 8.1 (D, CCC)	-	25 (D) (recommended Brown *et al.*,1984)
Mercury	0.5	0.3 (T)	0.4 (T, H)	1.8 (D, CMC); 0.94 (D, CCC)	-	0.5 (D) (estuaries) 0.3 (D) (coastal waters)
Nickel	-	25 (T)	70 (T, H)	74 (D, CMC); 8.2 (D, CCC)	-	30 (D) (recommended Mance and Yates, 1984a)
Selenium	-	-	-	290 (D, CMC); 71 (D, CCC)	-	-
Silver	-	5 (T)	1.4 (T, H)	1.9 (D, CMC)	-	-
Sn (as Tributyltin)	-	-	0.006 (H)	0.42 (CMC); 0.0074 (CCC) revised US-EPA (2003a)	0.001	0.001 (recommended Zabel *et al.*, 1988)
Vanadium	-	-	100 (T, H)	-	-	100 (T) (recommended Mance *et al.*, 1988b)

VARIABLE	MAURITIUS (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-EPA, 2002a)	CANADA (CCME, 2002)	EUROPEAN COMMUNITY (CEC, 2000)
Zinc	-	25 (T)	15 (T, H)	90 (D, CMC); 81 (D, CCC)	-	40 (D) (recommended Mance and Yates, 1984b)
VOLATILE ORGANIC CARBON COMPOUNDS (μg/ℓ):						
Benzene	-	-	500 (M)	-	110	-
Toluene	-	-	180 (L)	-	215	-
Ethylbenzene	-	-	5 (L)	-	25	-
Xylene		-	Ortho: 350 (L): Para: 75 (L) Meta: 200 (L)	-	-	-
POLY-AROMATIC HYDROCARBONS (μg/ℓ):						
Naphthalene	-	-	70 (M)	-	1.4	-
Anthracene	-	-	0.4 (L)	-	-	-
Phenanthrene	-	-	4 (L)	-	-	-
Fluoranthene	-	-	1.7 (L)	-	-	-
Benzo(a) pyrene	-	-	0.4 (L)	-	-	-
PESTICIDES (μg/ℓ):						
Aldicarb	-	-	-	-	0.15	-
Aldrin	-	-	-	1.3 (CMC)	0.32	0.01
Carbaryl	-	-	-	-	-	-
Chlordane	-	-	-	0.09 (CMC); 0.004 (CCC)	-	-
Chlorothalonil	-				0.36	-
Chlorpyros	-				0.002	-
DDT	-	-	-	0.13 (CMC); 0.001 (CCC)	-	0.01 (estuaries) 0.025 (coastal waters)
Dieldrin	-	-	-	0.71 (CMC); 0.0019 (CCC)	-	0.01
Endosulfan	-	-	-	0.034 (CMC); 0.0087 (CCC)	-	0.01
Endrin	-	-	-	0.037 (CMC); 0.0023 (CCC)	-	0.005
Heptachlor	-	-	-	0.053 (CMC); 0.0036 (CCC)	-	-
Isodrin	-	-		-	-	0.005
Lindane (Hexachlorocyclohexane)	-	-	-	0.16 (CMC)	-	0.02
Methoxychlor	-	-		-	-	-
Toxaphene	-	-	-	0.21 (CMC); 0.0002 (CCC)	-	-
OTHER CHLORINATED COMPOUNDS (μg/ℓ):						
Monochlorobenzene	-	-	-	-	25	-
Poly Chlorinated Biphenyls (PCBS)	-	-	-	0.03 (CCC)	-	-
1,2-.dichlorobenzene	-	-	-	-	42	-
1,2,4-Trichlorobenzene	-	-	-	-	5.4	-
Hexachlorobenzene	-	-	-	-	-	0.03
Pentachlorophenol	-	-	-	-	-	2
Hexachlorobutadiene	-	-	-	-	-	0.1
1,2 dichloroethane	-	-	-	-	-	10
Trichloroethylene	-	-	-	-	-	10
Perchloroethylene	-	-	-	-	-	10
Trichlorobenzene	-	-	-	-	-	0.4

NOTE:: T = Total; D = Dissolved; H = High reliability; M = Moderate reliability; L= Low reliability; CCC = Criteria Maximum concentration; CMC = Criteria Continuous Concentration

APPENDIX II

SUMMARY OF INTERNATIONAL SEDIMENT QUALITY GUIDELINES (TARGETS) FOR THE PROTECTION OF MARINE (COASTAL) AQUATIC ECOSYSTEMS

VARIABLE	SOUTH AFRICA * (unpublished)		AUSTRALIA/NEW ZEALAND (ANZECC, 2000)		NOAA (Long *et al.*, 1995)		STATE OF FLORIDA (MacDonald, 1996)		US-EPA	CANADA (CCME, 2002)	
	Special Care	**Prohibited**	**Low (Trigger value)**	**High**	**ERL**	**ERM**	**TEL**	**PEL**		**ISQG**	**PEL**
Cyanide	**-**	**0.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TRACE METALS (mg/kg dry weight)											
Antimony	-	-	2	25	-	-	-	-		-	-
Arsenic	30 - 150	> 150	5	70	8.2	70	7.24	41.6		7.24	41.6
Cadmium	1.5 - 10	> 10	1.5	10	1.2	9.6	0.68	4.21		0.7	4.2
Chromium	50 - 500	> 500	80	370	81	370	52.3	160		52.3	160
Copper	50 - 500	> 500	65	270	34	270	18.7	108		18.7	108
Lead	100 - 500	> 500	50	220	46.7	218	30.2	112		30.2	112
Mercury	0.5 - 5	> 5	0.15	1	0.15	0.71	0.13	0.7		0.13	0.7
Nickel	50 - 500	> 500	21	52	20.9	51.6	15.9	42.8		-	-
Silver	-	-	1	3.7	1	3.7	0.73	1.77		-	-
Tin as Tributyltin-Sn	-	-	0.005	0.070	-	-	-	-		-	-
Zinc	150 -750	> 750	200	410	150	410	124	271		124	271
Combined levels of Cd and Hg	1.0 - 5	>5	-	-	-	-	-	-		-	-
Combined levels of As, Cr, Cu, Pb, Ni and Zn	50 - 500	>500	-	-	-	-	-	-		-	-
TOXIC ORGANIC COMPOUNDS (µg/kg dry weight normalized to 1% organic carbon)											
Organohalogens	0.05 – 0.1	> 0.1	-	-	-	-	-	-		-	-
Oils	1000 - 1500	> 1500	-	-	-	-	-	-		-	-
Total PAHs	-	-	4000	45000	4022	44792	1684	16770	Refer to US-EPA (2003e) for details	-	-
Low Molecular PAHs	-	-	552	3160	552	3160	312	1442		-	-
Acenaphthene	-	-	16	500	16	500	6.71	88.9		6.71	88.9
Acenaphthalene	-	-	44	640	44	640	-	-		5.87	128
Anthracene	-	-	85	1100	85.3	1100	46.9	245		46.9	245
Fluorene	-	-	19	540	19	540	21.2	144		21.2	144
2-methyl naphthalene	-	-	-	-	-	-	-	-		20.2	201
Naphthalene	-	-	160	2100	160	2100	34.6	391		34.6	391
Phenanthrene	-	-	240	1500	240	1500	86.7	544		86.7	544

* The *South African Water Quality Guidelines for coastal marine waters* do not provide guidelines for setting quality objectives for sediments. Such objectives are typically determined from site-specific field measurements and numerical modelling output. Other guidelines include those of the Department of Environmental Affairs and Tourism, which provide suggested levels of ANNEX I and ANNEX II substances under the London Convention (unpublished documentation from the Department of Environmental Affairs and Tourism, Cape Town). These guidelines are particularly aimed at areas that require dredging (e.g. ports).

VARIABLE	SOUTH AFRICA * (unpublished)		AUSTRALIA/NEW ZEALAND (ANZECC, 2000)		NOAA (Long *et al.*, 1995)		STATE OF FLORIDA (MacDonald, 1996)		US-EPA	CANADA (CCME, 2002)	
	Special Care	Prohibited	Low (Trigger value)	High	ERL	ERM	TEL	PEL		ISQG	PEL
TOXIC ORGANIC COMPOUNDS (µg/kg dry weight normalized to 1% organic carbon) *continued…*											
High Molecular Weight PAHs	-	-	1700	9600	1700	9600	655	6676			
Benzo(a)anthracene	-	-	261	1600	261	1600	74.8	693		74.8	693
Benzo(a) pyrene	-	-	430	1600	430	1600	88.8	763		88.8	763
Dibenzo(a,h)anthracene	-	-	63	260	63.4	260	6.22	135		6.22	135
Chrysene	-	-	384	2800	384	2800	108	846		108	848
Fluoranthene	-	-	600	5100	600	5100	113	1494		113	1494
Pyrene	-	-	665	2600	665	2600	153	1398		153	1398
Toxaphene										0.1	
Total DDT	-	-	1.6	46	1.58	46.1	3.89	51.7		1.19	4.77
p p DDE	-	-	2.2	27	2.2	27	-	-		2.07	374
o.p + p,p DDD	-	-	2	20	-	-	-	-		1.22	7.81
Aroclor										63.3	709
Chlordane	-	-	0.5	6	-	-	2.26	4.79		2.26	4.79
Dieldrin	-	-	0.02	8	-	-	0.72	4.3	28 µg/g organic carbon, provided that organic carbon > 0.2%	0.71	4.3
Endrin	-	-	0.02	8	-	-	-	-	0.99 µg/g organic carbon, provided that organic carbon > 0.2%	2.67	62.4
Heptachlor										0.6	2.74
Lindane	-	-	0.32	1	-	-	-	-		0.32	0.99
Total PCBs	-	-	23	-	-	-	21.6	189		21.5	189

APPENDIX III

SUMMARY OF INTERNATIONAL MARINE WATER QUALITY GUIDELINES (TARGETS) FOR MARINE AQUACULTURE

Protection of Organism Health - Physico-chemical variables and nutrients:

VARIABLE	MAURITIUS (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	EUROPEAN COMMUNITY (CEC, 2006c)
Salinity	-	As for the Protection of Aquatic Ecosystems (refer to Appendix I	33 - 37	≤ 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 2.0°C change over 1 hour	Discharges affecting shellfish waters must not cause the temperature of the waters to exceed by more than 2°C the temperature of waters not so affected (G) (75% of sample to comply based on quarterly sampling over 12 months)
pH	7.5 - 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	2 mg/ℓ by alkaline potassium permanganate method		-	
Gas super-saturation	-		< 100%	-
Turbidity/Water clarity	-		30-40 Pt-Co units	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	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	-

Protection of Organism Health –Toxic substances:

VARIABLE	SOUTH AFRICA (RSA DWAF, 1995b)	MAURITIUS (Republic of Mauritius, 2006a)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	EUROPEAN COMMUNITY (CEC, 2006c)
Total Ammonia-N (µg/ℓ)	As for the Protection of Aquatic Ecosystems (refer to Appendix I	-	100 (un-ionised)	
Total Residual Chlorine-Cl (µg/ℓ)		-	3	
Cyanide (CN^-) (µg/ℓ)		10	5	
Sulfides (S^-) (µg/ℓ)		-	2	
Phenol (µg/ℓ)		50	-	
Methane (µg/ℓ)		-	65 000	
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	
Benzene		-	-	
Toluene		-	-	
Ethylbenzene		-	-	
Xylene		-	-	
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		-	-	
Aldrin		-	-	
Chlordane		-	0.004	
DDT		-	-	
Dieldrin		-	-	
Endosulfan		-	0.001	
Endrin		-	-	
Heptachlor		-	-	
Lindane		-	0.004	
Paraquat		-	0.01	
Toxaphene		-	-	
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)

Tainting of organism flesh - Estimated threshold concentration (mg/l) of substances:

VARIABLE	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (2002a)	EUROPEAN COMMUNITY (CEC, 2006c)
Acenaphthene	-	0.02	0.02	Concentration lower that that liable to impair the taste of shellfish (I)
Acetophenone	0.5	0.5	-	
Acrylonitrile	18	18	-	
Copper	-	1	1	
m-cresol	0.2	0.2	-	
o-cresol	0.4	0.4	-	
p-cresol	0.12	0.1	-	
Cresylic acids (meta, para)	0.2	0.2	-	
Chlorobenzene	-	0.02	-	
n-butylmercaptan	0.06	0.06	-	
o-sec. butylphenol	0.3	0.3	-	
p-tert. butylphenol	0.03	0.03	-	
2-chlorophenol			0.0001	
3-chlorophenol			0.0001	
3-chlorophenol			0.0001	
o-chlorophenol	0.001	0.0001-0.015	-	
p-chlorophenol	0.01	0.0001	-	
2,3-dinitrophenol	-	0.08	-	
2,4,6-trinitrophenol	-	0.002	-	
2,3 dichlorophenol	0.84		0.00004	
2,4-dichlorophenol	0.001	0.0001-0.014	0.0003	
2,5-dichlorophenol	0.023	0.02	0.0005	
2,6-dichlorophenol	0.035	0.03	0.0002	
3,4-dichlorophenol	-	0.0003	0.0003	
2-methyl-4-chlorophenol	0.75	2.0	1.8	
2-methyl-6-cholorophenol	0.003	0.003	0.02	
3-methyl-4-chlorophenol	-	0.02-3	3	
o-phenylphenol	1	1	-	
Pentachlorophenol	-	0.03	0.03	
Phenol	1	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	0.003	0.002	0.002	
2,4-dimethylphenol	-	0.4	0.4	
Dimethylamine	7	7	-	
Diphenyloxide	0.05	0.05	-	
B,B-dichlorodiethyl ether	0.09	0.09-1	-	
o-dichlorobenzene	-	<0.25	-	
p-dichlorobenzene	0.25		-	
Ethylbenzene	0.25	0.25	-	
Momochlorobenzene			0.02	
Ethanethiol	0.24	0.2	-	
Ethylacrylate	0.6	0.6	-	
Formaldehyde	95	95	-	
Gasoline/Petrol	0.005	0.005	-	
Guaicol	0.082	0.08	-	
Kerosene	0.1	0.1	-	

VARIABLE	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (2002a)	EUROPEAN COMMUNITY (CEC, 2006c)
Kerosene plus kaolin	1	1	-	
Hexachlorocyclopentadiene	-	0.001	0.001	
Isopropylbenzene	0.25	<0.25	-	
Naphtha	0.1	0.1	-	
Naphthalene	1	1	-	
Naphthol	0.5	0.5	-	
2-Naphthol	0.3	0.3	-	
Nitrobenzene		0.03	0.03	
a-methylstyrene	0.25	0.25	-	
Oil, emulsifiable	15	>15	-	
Pyridine	5	5-28	-	
Pyrocatechol	0.8	0.8-5	-	
Pyrogallol	0.5	20-30	-	
Quinoline	0.5	0.5-1	-	
p-quinone	0.5	0.5	-	
Styrene	0.25	0.25	-	
Toluene	0.25	0.25	-	
Outboard motor fuel as exhaust	0.5	7.2	-	
Zinc	-	5	5	

Protection of Human Health through consumption – Microbiological contaminants (shellfish growing areas):

VARIABLE	MAURITIUS (Republic of Mauritius, 2006a)	SOUTH AFRICA (RSA DWAF, 1995b)	AUSTRALIA/NEW ZEALAND (ANZECC, 2000)	US-EPA (US-FDA, 2007)	CANADA (CFIA, DFO and EC, 2004)	EUROPEAN COMMUNITY (CEC, 2006c)
Total coliform	Aquaculture: 1000 CFU/100 ml Shellfish: 70 MPN per 100 ml	-	-	-	-	-
Faecal coliform	Aquaculture: 200 CFU/100 ml Shellfish: 14 MPN per 100 ml	Maximum acceptable count per 100 ml: 20 in 80 per cent of the samples 60 in 95 per cent of the samples	Median faecal coliform concentration should not exceed 14 Most Probable Number (MPN) per 100 ml with not more than 10% of the samples exceeding 43 MPN per 100 ml for a 5-tube dilution method			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 in 75% of the samples based on quarterly sampling over 12 months.
E. coli	-		-	-	-	-

Protection of Human Health through consumption – Toxic substances:

VARIABLE (as µg/ℓ)	US-EPA (2002a)
Total Ammonia-N	-
Total Residual Chlorine-Cl	-
Cyanide (CN^-)	140 (revised US-EPA 2003)
Fluoride(F^-)	
Sulfides (S^-)	
Phenol	1 700 000
Methane	-
Arsenic	0.14
Nickel	4.6
Zinc	26 000
Benzene	51
Toluene	15 000 revised US-EPA, 2003b
Ethylbenzene	2100, revised US-EPA, 2003b
Anthracene	40 000
Phenanthrene	-
Fluoranthene	140
Benzo(a) pyrene	0.018
Aldrin	0.00005
Chlordane	0.00081
DDT	0.00022
Dieldrin	0.000054
Endosulfan	89
Endrin	0.06, revised US-EPA, 2003b
Heptachlor	0.000079
Lindane	1.8, revised US-EPA, 2003b
Paraquat	-
Toxaphene	0.00028
Poly chlorinated biphenyls (PCBs)	0.000064

APPENDIX IV

DATA TABLES USED IN DERIVATION OF PROPOSED CONSTITUENT THRESHOLD LEVELS FOR DIFFERENT ECOTONES IN THE COASTAL ZONE OF THE WIO REGION

Physico-chemical Parameters:

Ecotone	Range	TEMPERATURE (°C) Species Effects	References
Seagrassses		Sea grass	
	<9	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl McRoy, 1971
	> 30	*Zostera marina* displays decrease in photosynthesis rates	Biebl McRoy, 1971
	>34	*Zostera marina* tissue death within 12 hrs	Biebl McRoy, 1971
	38	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl McRoy, 1971
		Shrimp Penaeus sp. (Adult)	
	11 – 39	Optimum temperature range for the shrimp *P. indicus*	McClurg, 1974.
	24 – 34	Optimum temperature range for the shrimp *P. monodon*	Kungvankij et al. 1986a; 1986b
Mangroves		Shrimp larvae	
	26 – 31	Optimum ☐emperature range for shimp larvae, but sudden changes should not exceed 2oC	Kungvankij. Et al. 1986
	27.9	Optimum range for maturation of broodstock of Penaeidea prawns	Shrimp Farming Short Course, 1990
	26-30	Optimum larval tempereature range	Lee and Wickens, 1992
Coral Reefs		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
		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

Ecotone	Range	SALINITY Species Effects	References
		Green algae species	
	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 strss	Wieche and Davenport, 1987
		Sea grass	
	15 - 35	maximum growth of *Zostera capensis*	Adams and Bate, 1994
	40	*Zostera capensis* Setchell displays tissue alteration	Iyer and Barnabas, 2003
	60	*Zostera capensis* Setchell leaf blade cells damaged	Iyer and Barnabas, 2003
	>20	inhibition of seed germination and seedling survival of *Zostera marina.*	Kamermans et al., 1999
	>32	Decrease in shoot and leaf production in mature Z*ostera 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
Sea grasses	0 and 70	100% mortality in *Thalassia testudinum* seedling survival	Kahn and Durako, 2006
		Penaeid shrimp (Adult)	
	1 - 75	*P. indicus* can tolerate such a wide salinity range if acclimation time is atleast 48hrs	McClurg, 1974.
	15 - 30	Tolerant salinity range, above and below which *P. monodon* displays physiological stress	Kungvankij et al. 1986a; 1986b
	18	Salinity limit for *P. semisulcatus,* above which respiration decreased and mortality occurs	Clark, 1992.
	25 - 40	Tolerant salinity range, above and below which *P. indicus* displays physiological stress	Kungvankij et al. 1986a; 1986b
	27 - 32	Tolerant salinity range, above and below which *P. japonicus* displays physiological stress	Kungvankij et al. 1986a; 1986b
		Estuarine Fish	
	5 - 25	Tolerant range for fish larvae from the family Mugilidae	Paulraj and Kiron, 1988
	>30	Larval mortality	Paulraj and Kiron, 1988
Mangroves		Phytoplankton	
	<15	Significant growth changs in *Skletonema costatum*	Su et al., 1990
	>30	Significant growth changs in *Skletonema costatum*	Su et al., 1990
		Shrimp Penaeus Monodon larvae	
	30 - 32	*P. monodon* larval tolerant range	Kungvankij et al. 1986a; 1986b
	33.5	Maturation of *P. monodon* broodstock (larvae)	Lee and Wickens, 1992.
		Mud crab *Scylla serrata*	Hill, 1974
	<5	Zoeae mortality within 4 months	Hill, 1974
	<10	Female crabs do not enter water to release their eggs	Hill, 1974
	<10	larvea inactive	Hill, 1974
	<17,5	Significant larval mortality	Hill, 1974
	15-25	oxygen uptake of adult crabs decreased significantly at 22, 27, and 32"C	Hill, 1974
	15-30	N-excretion increased in adult crabs	Jiann-Chu Chena and Peng-Gek Chia, 1996
	23 - 25	46 % sulvival of first-stage zoeae	Hill, 1974
	25-30	Optimum larval salinity range	Jiann-Chu Chena and Peng-Gek Chia, 1996

		SALINITY	
Ecotone	**Range**	**Species Effects**	**References**
	21 -24	faster growth rate of postlarvae	Hill, 1974
	>25	100% zoeae mortality and significant growth rate reduction of postlarvae	
		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 Villers and Allanson, 1989
Coral Reefs	Not > 10% above annual mean and never above 41	Optimum range for coral productivity	Edwards, 1987

		DISSOLVED OXYGEN (mg/l)	
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Penaeid shrimp (Adult)	
	0.5 - 1.2	Lethal range from Penaeid adults	Allan and Maguire, 1991; Coastal Aquaculture, 1988
	3.7	Level necessary for normal biological functioning in *P. monodon*	Coastal Aquaculture, 1988
	>4	Tolerable range for adults of Penaeid family	Evans, 1993.
Mangroves		Penaeid shrimp	
	0.74	Lethal concentration for *P. chinensis* juveniles	Chen and Nan, 1992.
	0.9	LC50 (over 96hrs)concentration for *P. monodon* juveniles	Allan and Maguire, 1991
	2.2	Critical concentration for *P. monodon* juveniles	Coastal Aquaculture, 1988
Coral Reefs		Coral	
	4.0 - 4.5	Optimum range for coral productivity	Edwards, 1987
		Abalone	
	<4	Mortality of abalone adults	Hahn, 1989
	>110	Adults display abnormal behaviour	Hahn, 1989
	>150	Prolonged espousre results in death	Hahn, 1989
		Rock Lobster	
	0.4	Critical limit for *Palinurus* sp.	Harvey and Przybylak, 1985; Wessels, 1993
	2	Significant mortality in *Palinurus sp.*	Harvey and Przybylak, 1985; Wessels, 1993

Nutrients:

NITRITE-N			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Penaeid shrimp (Adult)	
	100 - 250 µg/l	Safe level of nitrite for Penaeid adults	Coastal Aquaculture, 1988; Lee and Wickens, 1992
		Penaeid shrimp	
	100 – 300 µg/l	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course, 1990
	0.11 mg/l	Safe level for *P. monodon* larvae	Chen and Chin, 1988
	1.36 mg/l	Safe level for *P. monodon* post-larvae	Chen and Chin, 1988
	2.3 mg/l	Safe concentration for *P. chinensis* juveniles	Chen et al., 1990a
	3.8 mg/l	Safe concentration for *P. monodon* juveniles	Chen and Lei, 1990
	10.6 mg/l	Safe concentration for *P. monodon* adolescents	Chen et al., 1990a
	171 mg/l	LC50 value (over 96hrs) for *P. monodon* adolescents	Chen et al., 1990a
Coral Reefs		Rock Lobster	
	5 mg/l	Favourable concentration for *Palinurus sp.*	Wessels, 1993

NITRATE-N			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Penaeid shrimp (Adult)	
	100 - 200 mg/l	Favourable range for Penaeid adults	Lee and Wickens, 1992
Mangroves		Penaeid shrimp	
	10 - 40 µg/l	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course, 1990
	1 mg/l	High mortality rate of *P. monodon* larvae within 40hrs	Muir et al., 1991

TOTAL DISSOLVED NITROGEN-N (NH_4 + NO_3 + NO_2)			
Ecotone	**Range**	**Species Effects**	**References**
Coral Reefs	1.0 mM	maximum limit for coral productivity	Lapointe et al., 1997

REACTIVE PHOSPHATE-P			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Algae	
	6.7 - 45.3 µg/l	Concentration for normal growth in *Ulva lactuca*, sublethal concentration and effects unkown.	Ho, 1988
Coral Reefs	0.1 mM	maximum limit for coral productivity	Lapointe et al., 1997

Toxic Substances:

Ecotone	Range	AMMONIA-N Species Effects	References
		Molluscs	
	100 µg/l	Favoured level for molluscian growth, above which severe physiological functioning is altered	Barnabe, 1989.
		Fish	
	>100 µg/l	Growth inhibition of finfish	Morimura, 1993; Tarazona et al., 1991
		Penaeid shrimp (Adult)	
	<20 µg/l	Torable range for Penaeid adults in the presence of nitrite	Lee and Wickens, 1992.
Sea grasses	80 µg/l	Safe level for *P. monodon* adults	Chen et al., 1990a
	90 – 110 µg/l	Safe level for Penaeid adults	Lega et al., 1992
	110 µg/l	Maximum level for Penaeid adults over 40 days	Chen and Lin, 1992.
	450 µg/l	Growth rate of Penaeid shrimps drastically declined by 50%	Kungvankij et al. 1986a
	12.9 mg/l	LC_{50} value (24hrs) for *Palaemontes pugio*	Burton and Fisher, 1990
		Amphipoda	
	49 mg/l	LC_{50} value (96 hrs) for *Ampelisca abdita*	Kohn et al., 1994
		Shrimp	
	6.1 - 8.1 mg/l	LC_{50} value (over 96hrs) for *Penaeius japonicus* zoeae	Lin et al., 1993
	10 ug/l	Safe level for *P. monodon* nauplii larvae	Chin and Chen, 1987.
	20 - 40 µg/l	Concentration required for maturation of brroodstock in Penaied larvae	Shrimp Farming Short Course, 1990
	32 µg/l	Maximum limit for ammonia to *P. monodon* post-larvae	Chen and Tu 1991
	52.7 mg/l	LC_{50} value (over 96hrs) for *Penaeius japonicus* juveniles	Lin et al., 1993
	60 - 183 µg/l	*P. monodon* post-larvae displayed a 5o% declione in growth and body condition	Chen et al., 1990b
	100 µg/l	Safe level for *P. monodon* juveniles	Chen and Lei 1990
Mangroves	>210 µg/l	P. monodon dispalys a 5% reduction of growth rates over 3 weeks	Evans, 1993
	350 µg/l	Maximum limit of ammonia to *P. japonicus* juveniles	Chen and Kou, 1992
	1040 µg/l	LC_{50} value over 96hrs for *P. monodon* post-larvae	Chin and Chen, 1987
	1.2 - 2.57 mg/l	LC_{50} value (48hrs) for *Palaemontes pugio* juveniles	Burton and Fisher, 1990
		Crustacean - mud crab	
	4.05 mg/l	LC_{50} value (over 24hrs) for *Scylla serrata* zoeae	Neil et al., 2005
	6.54 mg/l	100% mortality of *S. serrata* larvae	Neil et al., 2005
Coral Reefs		Molluscs	
	500 µg/l	Growth inhibition in abalone	Hahn, 1989

AMMONIA-N			
Ecotone	**Range**	**Species Effects**	**References**
		Rock Lobster	
	320 – 512 µg/l	Safe ammonia level for *Homarus americanus* adult	Younglai et al., 1991
	720 – 3250 µg/l	LC_{50} value (over 96hrs) for *Homarus americanus* larvae	Younglai et al., 1991
	3500 µg/l	Tolerable level for *Palinurus sp.*	Wessels, 1993

CHLORINE (µg/l)			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Penaeid shrimp (Adult)	
	37	LC_{50} (over 48 hrs) for *Palaemonetes pugio*	Roberts and Gleeeson, 1978
		Molluscs	
	<300	Valve closure for 6 hrs in *Donax serra*	Hill, 1977
	>600	Immediate valve closure for 8 days in *Donax serra*	Hill, 1977
	600 - 1200	>90% mortality of *Donax serra* after 14 days of exposure	Hill, 1977
Mangroves		Phytoplankton	
	>400	Growth inhibition in *Skletonema costatum*	Carpenter et al., 1972
	1500 - 2300	Lethal range for *Skletonema costatum*	Carpenter et al., 1972
	20 000	Lethal range for *Chlamydomonas spp.*	Carpenter et al., 1972
Coral Reefs		Coral	
	200	Maximum limit for coral productivity	Tomascik, 1992
		Rock Lobster	
	410 - 2900	LC_{50} (over 48 hrs) for *Homarus americanus* larvae	Capuzzo, 1979

HYDROGEN SULPHIDE (µg/l)			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Penaeid shrimp (Adult)	
	<0.002	Favoured level for Penaeid adults	Lee and Wickens, 1992.
	0.033	Safe level for *P. monodon*	Coastal Aquaculture, 1988
	4	Severe mortality in Penaeid adults	Coastal Aquaculture, 1988; Lee and Wickens,1992; Clark and Griffiths, 1990
Mangroves		Penaeid shrimp	
	0.117	LC_{50} value (over 96hrs) for *Penaeus indicus* juveniles at pH 6 - 6.3	Gopakumar and Kuttyamma, 1996
	0.189	LC_{50} value (over 96hrs) for *Penaeus indicus* juveniles at pH 7 - 7.3	Gopakumar and Kuttyamma, 1996
	4 ppm	100% mortality in *P. japonicus*	Gopakumar and Kuttyamma, 1996
Coral Reefs		Molluscs	
	50	Growth inhibition in abalone	Hahn, 1989
	500	Mortalities in abalone	Hahn, 1989

Ecotone	Range	ARSENIC (As) (µg/l) Species Effects	References
Sea grasses		Marcoalgae	
	19 – 20	Reduced growth in algae	Eisler, 1988
	75	Phytoplankton biomass reduced	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 (ver 96 hours) for mullet species (*Chelon labrosus)*	Eisler, 1988
	60 000	LC_{50} value (ver 192 hours) for *Macoma balthica*	Eisler, 1988
Mangroves		Phytoplankton	
	130	Growth inhibition in *Skletonema costatum*	Eisler, 1988
		Molluscs	
	2000	Reduction of oxygen consumption in mud snail *Nassarius absoleus*	Eisler, 1988

Ecotone	Range	CADMIUM (Cd) Species Effects	References
Sea grasses		Copepod	
	1.37mg/l	LC_{50} value (over 24hrs) for *Acartia simplex*	Arnott and Ahsanullah, 1979
		Amphipod	
	1,320 µg/l	LC_{50} value (96 hrs) for *Ampelisca abdita*	Kohn et al., 1994
		Molluscs	
	0.17 - 0.25 mg/l	LC_{50} value (over 96hrs) for *Donax faba*	Ong and Din, 2001
	>1 ppm	Inhibition of enzyme activty in *Donax trunculus*	Mizrahi and Achituv, 1989
	0.53 mg/l	LC_{50} value for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Pesch and Stewart, 1980
		Adult shrimp	
	1,850 mg/l	LC_{50} value (over 168 hrs) for *Palaemon sp.*	Ahsanullah, 1976
	0.2 - 0.4 mg/L	LC_{50} value for *Palaemon pugio*	Pesch and Stewart, 1980
	0.42 - 0.76 mg/l	LC_{50} (over 48hrs) for *Palaemon pugio*	Burton and Fisher, 1990
Mangrove		Diatom	
	0.06 mg/l	Growth inhibition in Chaetoceros species	Ismail et al., 2001
		Shrimp	
	200 µg/l	Severe growth and survival of *Penaeus japonicus* larvae	Brown and Mclachlan, 1990

Ecotone	Range	CADMIUM (Cd) Species Effects	References
	490 µg/l	LC_{50} value (14 days) for *Callianassa australiensis*	Ahsanullah and Arnott, 1978
	0.8 mg/l	LC_{50} value (48hrs) for *Palaemontes vulgaris* juveniles	Burton and Fisher, 1990
	1.3 mg/l	LC_{50} value (48hrs) for *Palaemontes pugio* juveniles	Burton and Fisher, 1990
	3.1 mg/l	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
		Fish	
	27.3ppm	LC_{50} value for milkfish (species not reported)	Bonifacio and Montaño, 1998
		Molluscs	
	1.01ppm	LC value for estuarine clams (species not reported)	Bonifacio and Montaño, 1998
Coral Reef		Coral	
	5 mg/l	Reduction of fertilization in *Acropora tenuis*	Reichelt-Brushett and Harrison, 2005
		Echinoderms	
	95 µg/l	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison, 2005
	>100 µg/l	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison, 2005

Ecotone	Range	COPPER (Cu) Species Effects	References
Sea grasses		Macroalgae	
	>10 µg/l	Reduced growth rates of *Sargassum* seaweed	Joshi et al., 1982
	35.9mg/l	LC_{50} value (48hrs) for adult *Palaemontes pugio*	Burton and Fisher, 1990
		Copepod	
	0.2mg/l	L $_{50}$ value (over 24hrs) for *Acartia simplex*	Arnott and Ahsanullah, 1979
		Phytoplankton	
		Inhibits 50% growth after 96 hours in *Chaetoceros calcitrans*	Ismail et al., 2001
	>0.05 – 0.08 mg/l	Growth inhibited over 10 – 14 days in *Phaeodactylum tricornutum*	Braek and Jensen, 1976
	0.25 mg/l		
		Molluscs	
	0.2 – 0.93 mg/l	LC_{50} values (over 96hrs) for juvenile and adult *Donax faba*	Tong et al., 1999a
	0.029 mg/l	LC_{50} value (ober 96hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al., 1988
	0.051 mg/l	LC_{50} value (ober 96hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson et al., 1988
	0.75 – 1.24 mg/l	LC_{50} value (ober 96hrs) for *Donax faba*	Ong and Din, 2001

		Diatom	
	0.07mg/l	Growth inhibition in *Chaetoceros sp.*	Ismail et al., 2001
		Shrimp	
	50 µg/l	Lethal level for Penaeid post-larvae	Shrimp Farming Short Course, 1990
	190 µg/l	LC_{50} value (over 14 dyas) for *Callianassa austrliensis*	Ahsanullah et al., 1981
	2.1 mg/l	LC_{50} value (48hrs) for *Palaemontes pugio* juveniles	Burton and Fisher, 1990
	2.5 mg/l	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
Mangroves	580 µg/l	LC_{50} value (96hrs) for *Penaeus monodon*	Tong et al., 1999a
		Crustacean – Mud crab	
	80ug/L	LC_{50} value (over 48hrs) for *Scylla serrata* embyro	Tong et al., 1999a
	346.7 ppm HgCl2	LC_{50} value (over 96hrs) for *Scylla serrata*	Nagabhushanam et al., 1986
		Fish	
	8ug/l	LC_{50} value (over 96hrs) for milkfish (*Chanos chanos*)	Tong et al., 1999a
	2.55 – 2.65 µg/l	LC_{50} value (over 96hrs) for mullet juveniles (*Liza vaigiensis*)	Tong et al., 1999a
		Coral	
	14.5 – 18.5 µg/l	Reduction of fertilization rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison, 2005
	15.2 µg/l	Reduction of fertilization rate by 50% in A*cropora longicyathus.*	Reichelt-Brushett and Harrison, 2005
	17.4 µg/l	Reduction of fertilization rate by 50% in *Acropora millepora.*	Reichelt-Brushett and Harrison, 2005
	17.4 µg/l	Reduction of fertilization rate by 50% in *Acropora corporamillepora*	Reichelt-Brushett and Harrison, 2005
	24.9 µg/l	Reduction of fertilization rate by 50% in *Goniastrea retiformis*	Reichelt-Brushett and Harrison, 2005
	39.7 ug/l	Reduction of fertilization rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison, 2005
	48 µg/l	LC_{50} value (over 96hrs) of adult *Montipora verrucosa*	Reichelt-Brushett and Harrison, 2005
		Abalone	
	40 µg/l	100% mortality (within 48 hrs) of *Haliotis discus* larvae	Coastal Aquaculture, 1988
Coral Reefs	50 µg/l	LC_{50} value (over 96hrs) for *H. cracherodii* adults	Hahn, 1989
	65 µg/l	LC_{50} value (over 96hrs) for *H. rufescens* adults	Hahn, 1989
	80 µg/l	Mortalities in abalone larvae	Hahn, 1989
		Rock Lobster	
	95.5 µg/l l	LC_{50} value (over 24hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran, 2004
	158.5 µg/l	LC_{50} value (over 96hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran, 2004
		Echinoderms	
	7 µg/l	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison, 2005
	14 µg/l	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison, 2005

Ecotone	Range	LEAD (Pb) Species Effects	References
Sea grasses		Amphipod	
	0.547 µg/l	LC_{50} value (over 96hrs) for amphipods from the genus *Ampelisca*	Eisler, 1988.
		Molluscs	
	8.6 µg/l	LC_{50} value (ober 96hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al., 1988
	5.4 µg/l	LC_{50} value (ober 96hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson et al., 1988
		Phytoplankton	
	>5000 µg/l	LC_{50} value (over 96hrs) for *Phaeodactylum tricornutum*	Eisler, 1988.
Mangroves		Phytoplankton	
	17 -31 µg/l	LC_{50} value (over 96hrs) for *Acartia tonsa*	Tong et al., 1999b
	5.1 µg/l	Growth reduced by 50% (over 12 days) in *Skletonema costatum*	Eisler, 1988
	10 µg/l	100% growth retardation in *Skletonema costatum*	Eisler, 1988
		Penaeid shrimp	
	7.2 mg/l	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
Coral Reefs		Coral	
	1453 µg/l	Reduction of fertilization rate by 50% in *Acropora longicyathus.*	Reichelt-Brushett and Harrison, 2005
	1801 µg/l	Reduction of fertilization rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison, 2005
	2467 µg/l	Reduction of fertilization rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison, 2005
		Rock Lobster	
	50 µg/l	Alteration of enzyme activity and biochemical functions in *Homarus americanus*	Eisler, 1988

Ecotone	Range	MERCURY (Hg) Species Effects	References
Sea grasses		Phytoplankton	
	50 µg/l	Growth retardation in *Dunaliella minuta*	Gotsis, 1982.
		Penaeid shrimp	
	>6 µg/l	No significant reduction in growth in *P. indicus*	McClurg, 1984
		Molluscs	
	>1 ppm	Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv, 1989
		Adult Penaeid shrimp	
	0.016 mg/l	Threshold level for *Penaeus monodon*	Das and Sahu; 2002

MERCURY (Hg)			
Ecotone	**Range**	**Species Effects**	**References**
	0.024 mg/l	Threshold level for *Penaeus indicus*	Das and Sahu; 2002
	0.036 mg/l	LC_{50} value (over 96hrs) for *Penaeus monodon*	Das and Sahu; 2002
	0.042 mg/l	LC_{50} value (over 96hrs for *Penaeus indicus*	Das and Sahu; 2002
Mangroves		Shrimp	
	<56 µg/l	Reudced survival of *Penaeus valgaris* post-larvae after 48hrs	Shealy and Sandifer, 1975
	56 µg/l	Critical limit for *Penaeus valgaris* post-larvae within 24hrs	Shealy and Sandifer, 1975
		Fish	
	0.38ppm	LC value for milkfish (species not reported)	Bonifacio and Montaño, 1998
		Crustacean	
	5.88 ppm $HgCl_2$	LC_{50} value (over 96hrs) for *Scylla serrata*	Nagabhushanam et al., 1986

NICKEL (Ni)			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Algae	
	100 - 1000 mg/l	Growth rates of *Chlorella vulgaris* effected	Sakaguchi et al., 1977
		Flatworms	
	16.8 mg/l	LC_{50} value (96 hrs) for *Dugesia tigrina*	See et al., 1974
		Amphipoda	
	40 mg/l	EC_{50} value (10 days) for *Ampelisca abdita*	Haley, M.V., and C.W. Kurnas, 1996
Coral Reefs	>100ug/l	Reduction of fertilization rate by 60% in *Goniastrea aspera*	Reichelt-Brushett and Harrison, 2005

MANGANESE (Mn)			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Phytoplankton	
	>18.6 mg/l	Inhibits 50% growth after 96 hours in *Chaetoceros calcitrans*	Ismail et al., 2001

		SILVER (Ag)	
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Macroalgae	
	50 µg/l	LC_{50} value for algae (species type not reported)	World Health Organization, 1982
		Fish	
	10 – 40 µg/l	LC_{50} value for fish (specific speices not reported)	World Health Organization, 1982
Mangroves		Fish	
	10 - 40 µg/l	LC_{50} value for fish (specific speices not reported)	World Health Organization, 1982
Coral Reefs		Fish	
	10 - 40 µg/l	LC_{50} value for fish (specific speices not reported)	World Health Organization, 1982

		ZINC (Zn)	
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Macroalgae	
	>80 µg/l	Reduced growth rates of *Sargassum* seaweed	Joshi et al., 1982
		Copepod	
	1.86 mg/l	LC_{50} value (over 24hrs) for *Acartia simplex*	Arnott and Ahsanullah, 1979
		Molluscs	
		LC_{50} value (ober 96hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al., 1988
	2.25 mg/l	LC_{50} value (ober 96hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson et al., 1988
	2.95 mg/l	LC_{50} value (ober 96hrs) for *Donax faba*	Ong and Din, 2001
	1.94 - 4.74 mg/l	50% Inhibition of enzyme activty in *Donax trunculus*	Mizrahi and Achituv, 1989
	>10 ppm		
		Adult shrimp	
		LC_{50} value (over 96hrs) for *Palaemon sp.*	Ahsanullah and Arnott, 1978
	1.230 mg/l	LC_{50} value (over 96hrs) for *Palaemon sp.*	Ahsanullah, 1976;
	13.1 mg/l	LC_{50} value (48hrs) for adult *Palaemon sp.*	Burton and Fisher, 1990
Mangroves		Penaeid shrimp	
	>250 µg/l	Growth reduction and decreased survival of *P. japonicus* larvae	Liao and hsieh, 1988.
	6.2 mg/l	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
	11.3 mg/l	LC_{50} value (48hrs) for *Palaemontes pugio* juveniles	Burton and Fisher, 1990
		Crustacean	

		ZINC (Zn)	
Ecotone	**Range**	**Species Effects**	**References**
	398.1 ppm $HgCl_2$	LC_{50} value (over 96hrs) for *Scylla serrata*	Nagabhushanam et al., 1986
		Abalone	
Coral Reefs	19 µg/l	No observed effects in *Haliotis rufescens* larvae 48hrs	Hunt and Anderson. 1989
	39 µg/l	No observed effects in Haliotis *rufescens* larvae over nine days	Hunt and Anderson 1989

		PETROLEUM (mg/l)(Water Soluble Fraction)	
Ecotone	**Range**	**Species Effects**	**References**
		Penaeid shrimp	
Sea grasses	>3	Crude oil. Significant growth inhibition *Penaeus monodon* adults within 6 weeks	Tong et al., 1999c
	13.8	Crude oil. LC_{50} value (over 96hrs) for *Penaeus monodon* adults	Tong et al., 1999c
		Penaeid shrimp	
	1.6	No. 2 fuel oil. LC_{50} value (over 96hrs) for *Penaeus pugio*	Tatem et al., 1978
	2.2	Bunker C oil. LC_{50} value (over 96hrs) for *Penaeus pugio*	Tatem et al., 1978
	10.7	South Louisiana oil. LC_{50} value (over 96hrs) for *Penaeus pugio*	Tatem et al., 1978
	20.3	Crude Oil. LC_{50} value (over 96hrs) for *Penaeus monodon* larvae	Tong et al., 1999c
Mangroves			
		Crustacean	
	>23.6	Crude Oil. LC50 value (over 96hrs) for *Scylla serrata*	Tong et al., 1999c
		Fish	
	22.8	Crude Oil. LC50 value (over 96hrs) for mullet juveniles (*Mugil* sp.)	Tong et al., 1999c
	0.5	Dispersed oil – maximum threshold for coral	Lane and Harrison, 2002
Coral Reefs	3.0	Bunker oil (oil slick) – maximum threshold for coral	Lane and Harrison, 2002
	8.0	Oil dispersant – maximum threshold for coral	Lane and Harrison, 2002

		ORGANOCHLORINES DDT	
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Algae	
	> 0.3 µg/l	Biological effects on *Chlorella sp.*	DeLorenzo et al., 2001
	3.6 - 36 µg/l	p,p'-DDT inhibits photosynthetic processes in Green algae *Selenastrum capricornutum*	DeLorenzo et al., 2001
	>10 µg/l	Photosynthesis inhibited in marine algae	DeLorenzo et al., 2001
	1 mg/l	Blue-gren algae *Anabaena sp.* display negative physiological effects	DeLorenzo et al., 2001
	1 mg/l	Population growth rates in Green algae *Chlorella sp.* declines	Lowe, 1965
		Sea grasses	

ORGANOCHLORINES DDT			
Ecotone	**Range**	**Species Effects**	**References**
	50 ppb	Photosynthesis and respiration in *Halophila ovalis* affected	Ramachandra et al., 1984
	50 ppb	Photosynthesis and respiration in *Halophila uninervis* affected	Ramachandra et al., 1984
		Copepods	
	>5 µg/l	Mortality (48 hrs) of *Cyclops sp.*	Naqvi and Ferguson, 1964
	10 - 13 µg/l	LC_{50} (1 day) for *Eucalanus sp*. (Calanoid copepod)	Rajendran and Venugopalan, 1988
	28 µg/l	LC_{50} (1 day) for *Acartia sp*. (Calanoid copepod)	Rajendran and Venugopalan, 1988
	1 mg/l	Mortality (24 hrs) of *Cyclops sp.*	Ludemann and Neumann, 1964
		Penaeid shrimp	
	0.10 µg/l	Growth inhibition in Penaeid aduts (30days)	Nimmo and Blackmann, 1972
		Diatom	
	50 µg/l	Growth of *Skletonema costatum* reduced (48 hrs)	Fisher, 1975
		Penaied juveniles	
Mangroves	0.6 µg/l	EC_{50} value (48 hrs) for Penaied juveniles	Lowe et al., 1970

Lindane			
Ecotone	**Range**	**Species Effects**	**References**
Sea grasses		Sea grasses	
	50 µg/l	Reduction of photosynthetic proceses in *Hadodule uninervis* (6 hrs)	Ramachandran et al., 1984
		Algae	
	50 µg/l	Accumulation in Green algae *Chlorella sp.* (24 hrs)	Geyer et al., 1984
	0.300 mg/l	Mortality of Green algae *Anabaena sp.* (72 hrs)	bringmann and Kuhn, 1978
	1 mg/l	Accumulation in Green algae *Anabaena sp.*	Mathur and Saxena, 1986
	60 mg/l	Mortality of Green algae *Anabaena sp*. (72 hrs)	Das and Singh, 1977
		Copepods	
	0.8 µg/l	EC_{50} value for *Acartia tonsa*	Chen, 1991
	6.2 µg/l	Growth inhibition in *Acartia tonsa*	Chen, 1991
	400 – 600 µg/l	Mortality of *Cyclops* copepods (48 hrs)	Naqvi and Ferguson, 1968
		Penaied Shrimp – Adults	
	1 mg/l	Mortality of *Penaeus sp.* (24 hrs)	Reddy and Rao, 1987

Ecotone	Range	Lindane Species Effects	References
Mangroves		Penaied Shrimp – Juveniles	
	0.5 – 10 µg/l	Reduction of growth in *P. monodon* (30 days)	Reddy and Rao, 1987
	1 µg/l	*P. monodon* display development inhibiton (24 hrs)	Reddy and Rao, 1987

Ecotone	Range	Dieldrin Species Effects	References
Sea grasses		Algae	
	>1 mg/l	Significant effects on respiration of Blue-gren algae	DeLorenzo et al., 2001
	15 mg/l	Mortlity of blue-green algae *Anabaene cylindrica* (7 days)	Vance and Drummond, 1969
		Diatom	
	1.7 µg/l	Acumulation in *Skletonema costatum* (2 hrs)	Sikka and Rice, 1974
		Amphipod	
	60 µg/l	LC_{50} value 24 hrs for *Ampelisca abdita*	Werner and Nagel, 1997

Ecotone	Range	Aldrin Species Effects	References
Sea grasses		Copepods	
	1 mg/l	Mortality of *Cyclops* copepods (24 hrs)	Ludemann and Neumann, 1962
		Penaied Shrimp – Adults	
	6.3 µg/l	Enzyme disruption in *P. indicus* (96 hrs)	Reddy and Rao, 1991

Ecotone	Range	Endosulfan Species Effects	References
Sea grasses		Sea grass	
	50 µg/l	Reduction of photosynthetic proceses in *Hadodule uninervis* (6 hrs)	Ramachandran et al., 1984
		Copepods	
	0.03 µg/l	LC_{50} value (96 hrs) for *Acartia tonsa*	Schimmel, 1981
	0.1 µg/l	LC_{50} value (48 hrs) for *Eucyclops sp.*	Naqvi and Hawkins, 1989
	0.6 µg/l	LC_{50} value (48 hrs) for *Diaptomus sp.*	Naqvi and Hawkins, 1989
	176 µg/l	LC_{50} value (24 hrs) for *Eucalanus sp.*	Rajendran and Venugopalan, 1988

Ecotone	Range	Endosulfan Species Effects	References
		Penaeus shrimp	
	0.13 µg/l	LC_{50} value (96 hrs) for *P. indicus* juvenile	Rao et al., 1988
	0.35 µg/l	LC_{50} value (72 hrs) for *P. indicus* juvenile	Rao et al., 1988
	0.46 µg/l	LC_{50} value (48 hrs) for *P. indicus* juvenile	Rao et al., 1988
	0.98 µg/l	LC_{50} value (24 hrs) for *P. indicus* juvenile	Rao et al., 1988
	4.64 µg/l	LC_{50} value (48 hrs) for *P. monodon* post-larvae	Joshi and Mukhopadhyay, 1990
	7.53 µg/l	LC_{50} value (24 hrs) for *P. monodon* post-larvae	Joshi and Mukhopadhyay, 1990
	12.2 µg/l	LC_{50} value (48 hrs) for *P. monodon* juveniles	Joshi and Mukhopadhyay, 1990
Mangroves	17.6 µg/l	LC_{50} value (24 hrs) for *P. monodon* juveniles	Joshi and Mukhopadhyay, 1990
	26.3 µg/l	LC_{50} value (96 hrs) for *P. monodon* intermoult stage	Rao et al., 1988
	37.3 µg/l	LC_{50} value (48 hrs) for *P. monodon* intermoult stage	Rao et al., 1988
		Mud crab	
	178 µg/l	LC_{50} value (96 hrs) for *Scylla serrata*	Rao et al., 1987
	257 µg/l	LC_{50} value (72 hrs) for *Scylla serrata*	Rao et al., 1987
	389 µg/l	LC_{50} value (48 hrs) for *Scylla serrata*	Rao et al., 1987
	478 µg/l	LC_{50} value (24 hrs) for *Scylla serrata*	Rao et al., 1987
		Coral	
Coral Reefs	10 µg/l	Visual bleaching observed in *Acropora millepora* after 6-12 hrs	Markey et al., 2007
	>30 µg/l	Fertilization of *Acropora millepora* gametes declined	Markey et al., 2007

APPENDIX V: PERSONS, INSTITUTIONS AND ORGANISATIONS THAT HAVE CONTRIBUTED TO THE PREPARATION OF THESE GUIDELINES

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South Africa	Council for Scientific and Industrial Research (CSIR)	35. National Ports Authority 36. Department of Water Affairs & Forestry 37. Department of Environmental Affairs & Tourism
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