Environmental Protection Department

Review and Development of Marine Water Quality Objectives

First Stage Public Engagement

Technical Note

Review of Local Conditions and Overseas Practices

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List of Abbreviations/Acronyms

%	percent
‰	part(s) per thousand
^{o}C	degree Celsius
AA	Annual Average
ADI	Acceptable Daily Intake
AF	Assessment Factor
AFCD	Agriculture, Fisheries and Conservation Department
AFRI	Acute Febrile Respiratory Illness
Ag	Silver
Al	Aluminum
ANZECC	Australian and New Zealand Environment and Conservation Council
APEC	Asia Pacific Economic Cooperation
ARMCANZ	Agriculture and Resource Management Council of Australian and New Zealand
As	Arsenic
ASEAN	Association of Southern Asian Nations
BAF	Bioaccumulation factor
BC	British Columbia
BCF	Bioconcentration factor
BMF	Biomagnification factor
BOD	Biological Oxygen Demand
BU	Beneficial Use
bw	body weight
C_b	Background concentration
CCC	Criterion Continuous Concentration
CCME	Canadian Council of Ministers of the Environment
CCPC	Centre for Coastal Pollution and Conservation
CCREM	Canadian Council of Resource and Environment Ministers
Cd	Cadmium
CEPT	Chemically Enhanced Primary Treatment
cfu	colony-forming unit(s)
CITYU	City University of Hong Kong
CMC	Criterion Maximum Concentration
Co	Cobalt
COD	Chemical oxygen demand
Cr	Chromium
Cu	Copper
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene

DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
dw	Dry weight
EC	European Commission
EC_{50}	Half maximal effective concentration
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
EQG	Environmental quality guideline
EQS	Environmental quality standard
ERL	Environmental risk limit
ERM	Environmental Resources Management
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAV	Final Acute Value
FCV	Final Chronic Value
FI	Fish Intake
FSANZ	Food Safety Authority of Australia and New Zealand
g	gram(s)
ha	hectare(s)
HATS	Harbour Area Treatment Scheme
HC_5	Concentration that protects 95% of the species in the species sensitivity distribution of NOEC or EC10 data
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
Hg	Mercury
HKSAR	Hong Kong Special Administrative Region
HU	Hazen Unit(s)
kg	kilogram(s)
km^2	Square kilometer(s)
K_{ow}	Octanol-water partition coefficient
L	liter(s)
LC_{50}	Lethal concentration to 50% of test species
LOEC	Lowest Observable Effect Concentration
LOEL	Lowest Observable Effects Level
m	meter(s)
MAC	Maximum Allowable Concentration
MAC_{eco}	Maximum Acceptable Concentration for ecosystems
MAC-EQS	Maximum Allowable Concentration in water for protection against short-term, direct and acute ecotoxic effects
MEP	Ministry of Environment
mg	milligram(s)
Mg	Magnesium

mL	milliliter(s)
MPC	Maximum permissible concentration
N	Nitrogen
NA	Negligible addition from the maximum permissible level
NC	Negligible Concentration
ng	nanogram(s)
NGO	Non-Governmental Organization
NH_3	Ammonia
NH_3-N	Ammonia nitrogen
NHMRC	National Health & Medical Research Council
Ni	Nickel
NO_2	Nitrite
NO_3	Nitrate
NOAEL	No Observed Adverse Effect Level
NOEC	No Observed Effect Concentration
NO_x	Nitrogen oxide (nitrate and nitrite compounds)
NTU	Nephelometric Turbidity unit(s)
O_2	Oxygen
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
PAH	Polyaromatic hydrocarbon
Pb	Lead
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyl
PCDDs	Polychlorinated dibenzo-*p*-dioxins
PCDFs	Polychlorinate dibenzofurans
Pg	picogram(s)
PNEC	Predicted Non-Effect Concentration
$PNEC_{oral}$	Predicted No Effect Concentration from oral intake
POPs	Persistent organic pollutants
PRD	Pearl River Delta
Pt	Platinum
QS	Quality Standard
RC	Reference Concentration
RfD	Reference Dose
RIVM	National Institute of Public Health and the Environment
s	second(s)
SCTEE	Scientific Committee on Toxicity, Ecotoxicology and the Environment
SF	Safety Factor
spb	secondary poisoning of biota
SRC	Serious Risk Concentration

SS	Suspended Solids
SSD	Species Sensitivity Distribution
SSDS	Strategic Sewage Disposal Scheme
SSSI	Site of Special Scientific Interest
STW	Sewage Treatment Work
TBT	Tributyltin
TDI	Tolerable Daily Intake
TDS	Total Dissolved Ssolids
TEQ	Toxicity Equivalent
TIN	Total Inorganic Nitrogen
TL	Threshold Level
TN	Total Nitrogen
TON	Threshold Odour Number
TP	Total Phosphorus
TRC	Tissue Residue Criterion
TRG	Tissue Residue Guideline
UK	United Kingdom
UKTAG	United Kingdom’s Technical Advisory Group
US	United States
USA	United States of America
USEPA	United States Environmental Protection Agency
V	Vanadium
VROM	Ministry of Housing, Spatial Planning and the Environment
WCZ	Water Control Zone
WHO	World Health Organization
WQC	Water Quality Criteria
WQG	Water Quality Guideline
WQO	Water Quality Objective
WQS	Water Quality Standard
ww	Wet weight
Zn	Zinc
µg	microgram(s)

1 Introduction

1.0.1 The consultancy study on the Review and Development of Marine Water Quality Objectives (WQOs) was initiated in October 2008, and we have completed an initial review about the existing WQOs, conditions of our marine environment, and overseas practices.

1.0.2 This WQO review is important in a number of aspects such as beneficial uses of marine waters, marine water quality management, marine conservation, coastal development, environmental impact assessment, and pollution control in Hong Kong. We would like to hear your views and concerns at this early stage, so as to identify a set of WQOs appropriate for Hong Kong in the decades to come.

1.0.3 The objective, need and initial issues of the WQO review have been outlined in the "First Stage Public Engagement Document". The purpose of this Technical Note is to provide more in-depth technical details about the initial review.

2 Characterization of marine waters in Hong Kong

2.0.1 Based on the fundamental differences in hydrographic conditions along the estuarine-oceanic transition gradient, water circulation, water depth, the bathymetric condition, potential pollution sources levels of contaminants, the major delineation of marine biota and the occurrence of various sensitive receivers, it is considered useful to divide the waters of Hong Kong into 7 water bodies (Figure 2.1). The following provides a narrative summary on the beneficial uses and sensitive receivers; physical, chemical and biological characteristics of these 7 water bodies.

2.1 Beneficial uses and sensitive receivers

2.1.1 Typical beneficial uses and sensitive receivers in our marine waters are summarized below and Table 2.1. Their distributions are shown in Figure 2.2:

(a) Sites of special scientific interest (SSSI),
(b) Sites/species of high conservation values (e.g., corals, seagrass, mangroves and marine mammals)
(c) Marine parks and marine reserve
(d) Nursery and spawning grounds
(e) Mariculture zones and oyster culture grounds
(f) Habitats of ecologically important species (e.g., keystone species)
(g) Bathing beaches and secondary contact recreation
(h) Seawater intakes for flushing and cooling
(i) Navigation
(j) Effluent disposal
(k) Spoil disposal, and marine fill borrowing

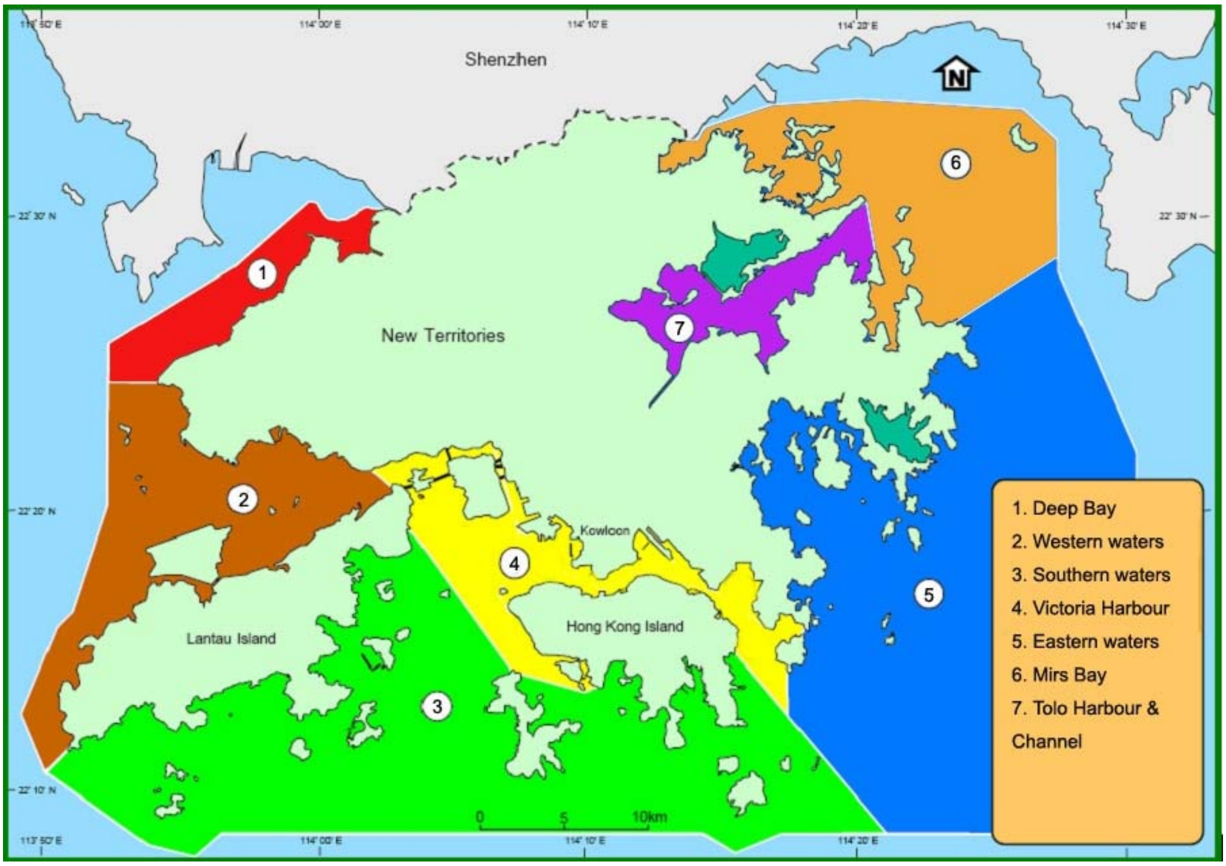

Figure 2.1 Seven water bodies for characterization of marine waters of Hong Kong

Figure 2.2 Different habitats for aquatic life and various beneficial uses in the marine waters of Hong Kong

Table 2.1 Summary on present beneficial uses and sensitive receivers in the 7 water bodies of Hong Kong

Characteristics	Water bodies (see Figure 2.1 and notes at the end of this table)						
	1	2	3	4	5	6	7
	Deep Bay	Western waters	Southern waters	*Victoria Harbour (& Junk Bay	Eastern waters	Mirs Bay	Tolo Harbour & Channel
Current beneficial uses							
Nature reserves and Site of special scientific interest	✓	✓	✓		✓	✓	✓
Maintenance of natural ecosystems and wildlife	✓	✓	✓	✓	✓	✓	✓
Production of fish, crustaceans and shellfish for human consumption	✓	✓	✓	✓	✓	✓	✓
Bathing, diving and primary contact recreation	✓	✓	✓	✓	✓	✓	✓
Boating, fishing and secondary contact recreation	✓	✓	✓	✓	✓	✓	✓
Aesthetic enjoyment	✓	✓	✓	✓	✓	✓	✓
Industrial and domestic water supply	✓	✓	✓	✓	✓		✓
Supply of flushing water		✓	✓	✓	✓		✓
Seawater intakes	Nil	Yes (3 proposed seawater pumping stations (SW P/Ss) and 1 existing SW P/S)	Nil	Yes (1 proposed SW P/S) and 16 existing SW P/Ss)	1 proposed SW P/S	Nil	2 existing SW P/Ss
Navigation and shipping		✓	✓	✓	✓	✓	✓
Typhoon shelters		✓	✓	✓	✓		✓
Reception and dilution of effluents	✓	✓	✓	✓	✓		✓

Characteristics	Water bodies (see Figure 2.1 and notes at the end of this table)						
	1	**2**	**3**	**4**	**5**	**6**	**7**
	Deep Bay	**Western waters**	**Southern waters**	***Victoria Harbour (& Junk Bay**	**Eastern waters**	**Mirs Bay**	**Tolo Harbour & Channel**
Sensitive Receivers							
Sites of special scientific interest	Tsim Bei Tsui Egretry, Tsim Bei Tsui, Inner Deep Bay, Pak Nai, Mai Po Marshes	Nil	Sham Wan, Shek O Headland, San Tau Beach, Tai Tam Harbour (inner bay)	Nil	Tai Long Bay, Pak Sha Wan Peninsula, Ninepin Group	A Chau, Lai Chi Wo Beach, Port Island, Yim Tso Ha Egretry	Kei Ling Ha, Ting Kok
Marine Parks/Reserve	Nil	1 (Sha Chau and Lung Kwu Chau Marine Park)	1 (Cape d'Aguilar Marine Reserve)	Nil	Nil	2 (Yan Chau Tong Marine Park, Tung Ping Chau Marine Park)	1 (Hoi Ha Wan Marine Park)
Marine mammals	Chinese white dolphin (++)	Chinese white dolphin (++++)	Chinese white dolphin (++) and black finless porpoise (++)	Chinese white dolphin (+)	Black finless porpoise (+)	Black finless porpoise (+)	Nil
Spawning and nursery grounds	Nil	Fishes	Fishes, shrimps, Mantis shrimps, Crabs	Nil	Fishes	Fishes	Nil
Mariculture	1 oyster farming area	Nil	4 fish culture zones	2 fish culture zones	7 fish culture zones	9 fish culture zones	4 fish culture zones
Corals	Nil	Nil	14 sites	Nil	12 sites	6 sites	5 sites
Mangroves	6 sites	6 sites	4 sites	Nil	8 sites	9 sites	10 sites
Seagrasses	6 sites	3 sites	Nil	Nil	2 sites	6 sites	Nil
Bathing beaches	Nil	6 gazetted beaches	21 gazetted beaches	8 gazetted beaches	6 gazetted beaches	Nil	Nil
Secondary recreational uses	Yes (+)	Yes (+)	Yes (++)	Yes (+)	Yes (+++)	Yes (+++)	Yes (+++++)

Notes:

(+) denotes the relative abundance of the respective sensitive receivers in each water body.

1. The delineation of water bodies is based on the hydgrographic and bathymetric conditions, potential pollution sources, levels of contaminants, location of marine biota and sensitive receivers. *Victoria Harbour covers the coastal waters of Tsing Yi, the harbour, Junk Bay and east of Tung Lung Chau. Eastern waters zone covers the southern part of Mirs Bay and Port Shelter. Mirs Bay confines to the Mirs Bay waters and extends as far as Shek Ngau Chau and Wong Mau Chau.

2. Environmental Protection Department. Justification of Ecological Value Assigned to Sites of Special Scientific Interest (SSSI) (http://www.epd.gov.hk/epd/textonly/english/environmentinhk/eia_planning/sea/terr_table74a.html)
3. Shin et al. (2004)
4. Leung (1999)
5. CITYU (1999)
6. Leung and Leung (2000)
7. Taylor (1994)
8. Leung and Morton (2000)
9. Blackmore and Rainbow (2000)
10. Leung (1992)
11. Shin (1985)
12. Taylor and Shin (1989)
13. Taylor (1992)
14. Binnie (1995a)
15. ERM (1998)

2.2 General hydrography, water quality and major biological communities

2.2.1 The general hydrography and water quality of various water bodies in Hong Kong are well understood. Overall in Hong Kong marine waters, the hydrographical conditions exhibit a gradual transition from a sheltered, estuarine environment in the west, to an exposed, oceanic environment in the east, with a transition zone in the middle receiving heavier pollution loading from the urbanized area fringing Victoria Harbour. Table 2.2 provides a summary and comparison on the major physical conditions and water quality (salinity, temperature, nutrients, current, bathymetry, suspended solids, bacteria), and pollution sources in different parts of Hong Kong waters (Data compiled from EPD's monitoring programme 2003-2007; http://epic.epd.gov.hk/ca/uid/marinehistorical). Except where specifically mentioned, median values are given to provide a general indication and comparison. A synopsis of key points, which are relevant to the present review study, is provided in the following sub-sections.

2.2.2 An analysis of nutrient levels in different parts of Hong Kong waters shows the following:

- Highest levels of total nitrogen (1.53 mg/L), total phosphorus (0.13 mg/L), unionized ammonia (0.017 mg/L), and total inorganic nitrogen (1.36 mg/L) are found in Deep Bay, followed in decreasing order by western and southern waters, clearly demonstrating the influence of Pearl River discharge, especially during the summer when the Pearl River discharge is at its peak. The relatively high levels of nutrients in Deep Bay may also be ascribed to the fact that it is a semi-enclosed bay with low flushing capacity.
- In Victoria Harbour where sewage is discharged, total nitrogen (0.18 mg/L), total phosphorus (0.02 mg/L), unionized ammonia (0.001 mg/L) and total inorganic nitrogen (0.095 mg/L) concentrations are also high.
- Eastern waters and Mirs Bay are relatively nutrient poor since these waters are bathed by oceanic waters and far away from both the Pearl River and sewage discharges.
- Level of total nitrogen in Tolo Habour and Channel (0.22 mg/L) is generally higher than that in Mirs Bay (0.17 mg/L) and Eastern waters (0.14 mg/L).

2.2.3 Phytoplankton biomass in Hong Kong waters is regulated by a combination of physico-chemical and biological factors that are related to the seasonal influence of the Pearl River discharge and oceanic waters, sewage effluent inputs, and strong hydrodynamic mixing from southwest monsoon winds in summer and the northeast monsoon winds in winter.

2.2.4 High levels of *E. coli* are found in Victoria Harbour, indicating faecal pollution caused by sewage discharge into the Harbour. Levels of *E. coli* in inner Deep Bay were also high, followed by western waters, indicating faecal pollution also presented in inner Deep Bay. *E. coli* counts are generally low in southern waters, Mirs Bay and Tolo Harbour and Channel, and the lowest levels are found in eastern waters.

2.2.5 EPD's water quality monitoring data show that the 2008 overall WQO compliance rate of the whole territory achieved 81%, approximately same as that in 2007 (80%). The rate is based on the combined individual compliance rates of all stations in the territory for the four important marine WQOs, namely DO, TIN, unionized NH_3 and *E. coli* bacteria. Figure 2.3 shows the annual WQO compliance rates in Hong Kong and the water quality trends for NH_3-N, TIN, *E. coli*, BOD_5 and orthophosphate phosphorus from 1986 to 2008.

2.2.6 Figure 2.4 – 2.6 show the water quality trends of Deep Bay, Tolo Harbour and Victoria Harbour from 1986-2008. The inner Deep Bay has relatively poor water quality, with low WQO compliance in terms of DO, TIN and unionized NH_3. With the implementation of the Tolo Habour Action Plan and other pollution control measure, there is a gradual recovery of the water environment in Tolo Harbour. The HATS Stage 1 led to a general improvement of water quality in the eastern Victoria Harbour, whereas the western harbour area around the Stonecutters Island Sewage Treatment Works outfall continued to have elevated levels of *E. coli* bacteria.

2.2.7 The EPD conducts long-term monitoring of phytoplankton monthly at 25 stations covering nine WCZs. An analysis of the monitoring data collected during the period 1991-2006 (CITYU, 2008) recorded a total of 235 species (121 diatoms, 82 dinoflagellates and 32 others). Results showed that Deep Bay, Tolo Harbour, Victoria Harbour, Mirs Bay and Port Shelter frequently showed distinct differences in phytoplankton composition as compared to other sampling stations from 1991 to 2006. The major spatial assemblages of phytoplankton community were, to a large extent, defined by geographical areas. In general, the following spatial pattern was delineated: Tolo Harbour and Channel, Port Shelter and Mirs Bay, Victoria Harbour, southern waters, and northwestern waters and Deep Bay.

2.2.8 In terms of phytoplankton cell density, Tolo Harbour and Channel are relatively higher (>3,000 cell/mL), compared with Mirs Bay (2,001-2,500 cells/mL) and other water bodies in Hong Kong (1,001-2,000 cells/mL).

2.2.9 Algal blooms including red tides are phenomena occasionally associated with nutrients enrichment of waters. In Hong Kong, red tides occurred more frequently in the eastern and southern waters than in Deep Bay where the waters are comparatively nutrients rich. Figure 2.7 shows the number of red tides incidents in Deep Bay, southern waters, Port Shelter, Tolo Harbour and Mirs Bay. Despite the high levels of TIN in Deep Bay and southern waters, other factors seem to be dominating and other site-specific conditions, e.g. water currents, water temperature, salinity, light intensity, etc., sometimes play a more important role in the phenomena.

2.2.10 Hong Kong's infaunal benthos are largely homogeneous (Shin et al., 2004), with exceptions for places such as in Victoria Harbour, Tolo Harbour and Channel, Deep Bay and Urmston Road, and Tai Long Wan (Sai Kung). Polychaete annelids, crustaceans and bivalves are the most abundant animal groups. Seasonal variations are minimal.

2.2.11 A study undertaken by EPD (CITYU, 2006) on the epibenthos of Hong Kong waters revealed that the highest species number is found in eastern waters, followed by southern waters, western waters, Deep Bay, Mirs Bay, Tolo and Victoria Harbour. The dominant epibenthic species are sea pens, gastropods, bivalves, shrimps, mantis shrimps and crabs. Separate epifaunal communities can be found in Deep Bay, western waters and northeastern waters. The epifauna in southern, eastern and Tathong Channel waters also form a distinct community.

2.2.12 The 13-month fisheries resource survey commissioned by AFCD in 1997 (ERM, 1998) provided a comprehensive and quantitative analysis as well as spatial and temporal comparison on both demersal and pelagic fish populations in the entire Hong Kong waters. The survey data showed that the highest species number of demersal fish was found in Deep Bay, followed by Double Haven and Sharp Island, Lung Kwu Chau and Lamma. Lowest species number is found in inner and outer Tolo Harbour and Mirs Bay. For pelagic fish, a total of 91 species of fish were reported from AFCD's gillnet survey (ERM, 1998). The largest number of fish species was captured at the Ninepins, and low numbers were recorded at Double Haven, Inner Tolo Harbour, Kat O, and Peng Chau.

2.2.13 In general, the following spatial difference in demersal species composition is evident:

- **Deep Bay**: Largest catches were Sciaenidae (croakers).
- **Southern and western waters** (Stanley, South Lamma, South Cheung Chau, Sokos, South Lantau, Lamma, Brothers and Lung Kwu Chau): Siganidae (rabbit fish), Sciaenidae (croaker), Gobiidae (Goby), and Apogonidae (cardinal fish) were common.
- **Eastern waters** (Basalt, Ninepines, Waglan): Apogonidae (cardinal fish) and Sciaenidae (croaker) were most abundant.
- **Northeastern waters** (Double Haven, Outer Tolo, Inner Tolo, Long Harbour, Mirs Bay and Sharp Island): Siganidae (rabbit fish) and Gobiidae (goby) predominated.

Table 2.2 Summary on physical characteristics and water quality of the 7 water bodies of Hong Kong

Characteristics	Water bodies (see Figure 2.1 and notes at the end of this table)						
	1	2	3	4	5	6	7
	Deep Bay	**Western waters**	**Southern waters**	**Victoria Harbour**	**Eastern waters**	**Mirs Bay**	**Tolo Harbour & Channel**
Physical Characteristics (Data are presented as median followed by the minimum and maximum values, as appropriate)							
Water circulation	Moderate (average tidal speed: 0.3-0.5 m/s in dry season, 0.6-0.9 m/s in wet season ; max: 1 m/s; flushing time: 23.4 days in inner bay; 2.5 days in outer bay)	Moderate (average tidal speed: 0.25 m/s; max: 0.79 m/s)	Moderate (average tidal speed: 0.15 m/s; max: 0.54 m/s)	Good (average tidal speed: 0.35 m/s; max: 0.88 m/s; flushing time: 1.5 – 2.5 days in the wet season and 5 – 7 days in the dry season)	Moderate (average tidal speed: 0.11 ms/ max: 0.34 m/s)	Moderate (average tidal speed: 0.19 m/s; max: 0.4 m/s)	Poor (average tidal speed: 0.01 m/s; max: 0.24 m/s; flushing time in inner Tolo Harbour: 38 days in the dry season and 14.4 days in the wet season)
Bathymetry	Shallow (1- 5 m)	4 – 40 m	15 – 46 m	8 – 40 m	15 – 25 m	6 – 75 m	Shallow in harbour (4 m), moderate in channel (16 m)
Stratification	No	Yes	Yes	Yes	Yes	Yes	No in harbour; Yes in channel
Temperature (ºC)	25.3 13.0 32.4	24.5 15.1 31.3	24.4 15.3 30.0	24.1 15.5 30.4	23.2 14.8 32.0	23.7 15.1 31.7	24.4 13.0 31.3
Salinity (‰) (median)	25.2	31.3	32.8	32.9	33.2	32.9	32.4
pH	7.8 6.5 9.3	8.0 7.3 8.6	8.2 7.0 9.1	7.9 7.8 7.9	8.2 7.2 8.8	8.2 7.4 8.9	8.2 6.8 8.8
Chlorophyll-*a* (µg/L)	2.2 0.2 260.0	1.9 0.2 42.0	1.9 0.2 55.0	1.8 0.8 2.7	1.6 0.2 39.0	2.0 0.2 53.0	4.1 0.3 95.0
Suspended Solids (mg/L)	13.0 2.2 230.0	7.4 0.9 150.0	4.6 0.5 210.0	7.2 2.6 110.0	1.6 0.5 210.0	2.0 0.5 79.0	1.8 0.5 170.0

Characteristics	Water bodies (see Figure 2.1 and notes at the end of this table)						
	1	2	3	4	5	6	7
	Deep Bay	Western waters	Southern waters	Victoria Harbour	Eastern waters	Mirs Bay	Tolo Harbour & Channel
Dissolved oxygen (mg/L, depth average)	5.4 0.2 12.9	6.2 2.1 10.3	6.6 1.6 11.6	6.6 5.3 7.1	6.5 1.1 10.7	6.6 0.5 12.7	6.5 1.0 11.2
Dissolved oxygen (mg/L, bottom)	5.6 2.7 10.2	6.1 2.1 10	6.4 1.6 11.6	5.55 1.3 10.9	6.4 1.1 9.2	6.45 0.5 12.7	6.3 1 11
Nutrients (Data are presented as median followed by the minimum and maximum values)							
Total Nitrogen (mg/L)	1.53 0.01 15.02	0.53 0.12 2.54	0.27 0.05 1.46	0.18 0.09 0.51	0.14 0.05 0.80	0.17 0.05 1.21	0.22 0.08 1.51
Unionized Ammonia (mg/L)	0.017 0.000 0.760	0.005 0.000 0.047	0.002 0.000 0.034	0.001 0.000 0.005	0.001 0.000 0.020	0.001 0.000 0.048	0.002 0.000 0.053
Total Inorganic Nitrogen (mg/L)	1.360 0.230 10.020	0.390 0.010 2.300	0.140 0.010 1.210	0.095 0.020 0.290	0.040 0.010 0.620	0.040 0.010 0.580	0.050 0.010 0.420
Total Phosphorus (mg/L)	0.130 0.030 1.300	0.040 0.020 0.220	0.030 0.020 0.160	0.020 0.020 0.060	0.020 0.020 0.130	0.020 0.020 0.200	0.020 0.020 0.300
Orthophosphate Phosphorus (mg/L)	0.094 0.005 0.880	0.024 0.002 0.087	0.010 0.002 0.040	0.012 0.006 0.029	0.007 0.002 0.045	0.006 0.002 0.120	0.006 0.002 0.057
Silica (mg/L as SiO_2)	3.40 0.05 12.00	1.20 0.05 8.90	0.68 0.05 6.20	0.48 0.37 0.62	0.53 0.05 3.20	0.49 0.05 3.00	0.66 0.05 3.00
Bacteria (Data are presented as median followed by the minimum and maximum values)							
Escherichia coli (cfu/100 ml)	515 2 360000	300 1 23000	3 1 11000	310 1 21000	1 1 1300	1 1 4600	1 1 3200

Characteristics	Water bodies (see Figure 2.1 and notes at the end of this table)						
	1	2	3	4	5	6	7
	Deep Bay	**Western waters**	**Southern waters**	**Victoria Harbour**	**Eastern waters**	**Mirs Bay**	**Tolo Harbour & Channel**
Major sources of pollution							
Major sources of pollution	Shenzhen River, Yuen Long Creek, Xin Zhou River, Pearl River	Treated effluents from Stonecutters Island STWs, San Wai and Pillar Point STWs.	Influenced by the discharge from the Pearl River	Treated effluents from Stonecutters Island STW, and Sha Tin and Tai Po STWs, and urban non-point sources	Non-point sources from runoff and waste from mariculture	Non-point sources from runoff and waste from mariculture	Non-point sources from runoff and waste from mariculture, Emergency discharges from Sha Tin and Tai Po STWs during heavy rain

Notes:

1. Pollution level (median values) was derived from EPD's water quality monitoring data from 2003-2007. (Data compiled from EPD's monitoring programme; http://epic.epd.gov.hk/ca/uid/marinehistorical).
2. The delineation of water bodies is based on the hydgrographic and bathymetric conditions, potential pollution sources, levels of contaminants, location of marine biota and sensitive receivers. *Victoria Harbour covers the coastal waters of Tsing Yi, the harbour, Junk Bay and east of Tung Lung Chau. Eastern waters zone covers the southern part of Mirs Bay and Port Shelter. Mirs Bay confines to the Mirs Bay waters and extends as far as Shek Ngau Chau and Wong Mau Chau.
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10. Blackmore and Rainbow (2000)
11. Leung (1992)
12. Shin (1985)
13. Taylor and Shin (1989)
14. Taylor (1992)
15. Binnie (1995a)
16. ERM (1998)
17. SEPB and EPD (2008)
18. Qian (2003)

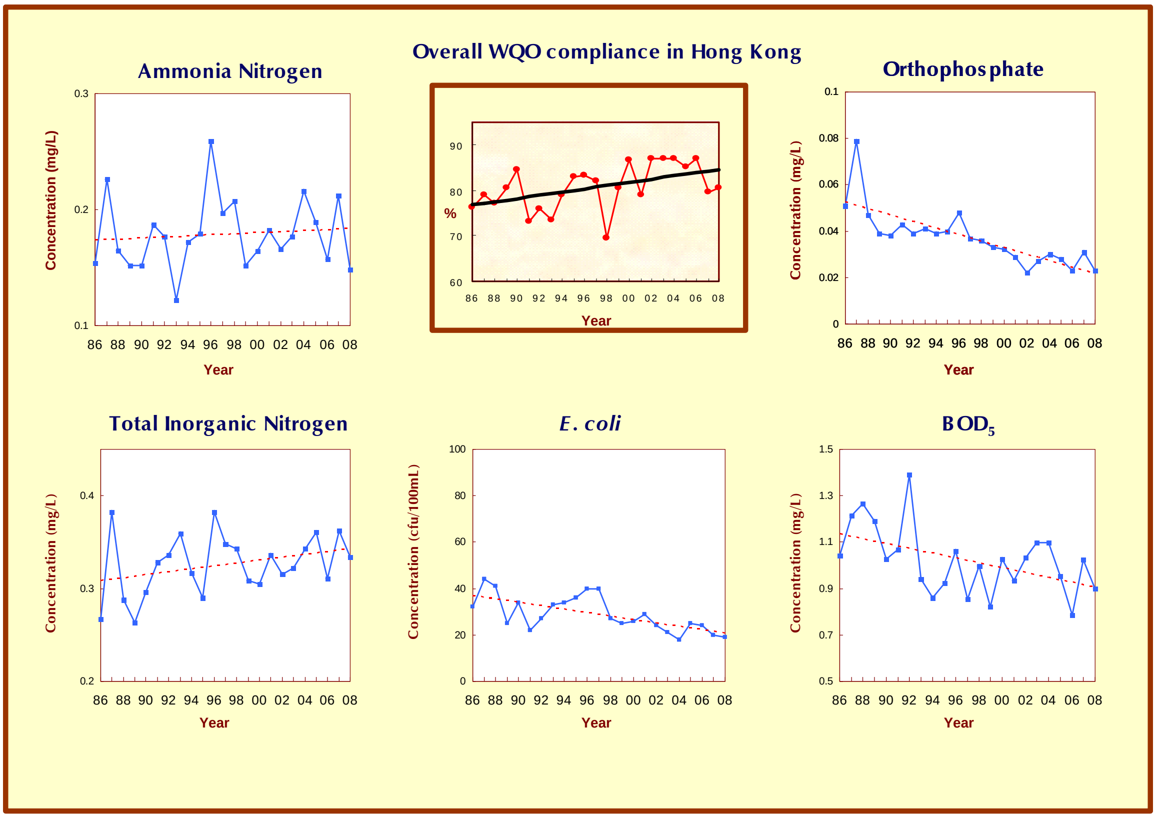

Figure 2.3 Water Quality Changes in Hong Kong, 1986 - 2008

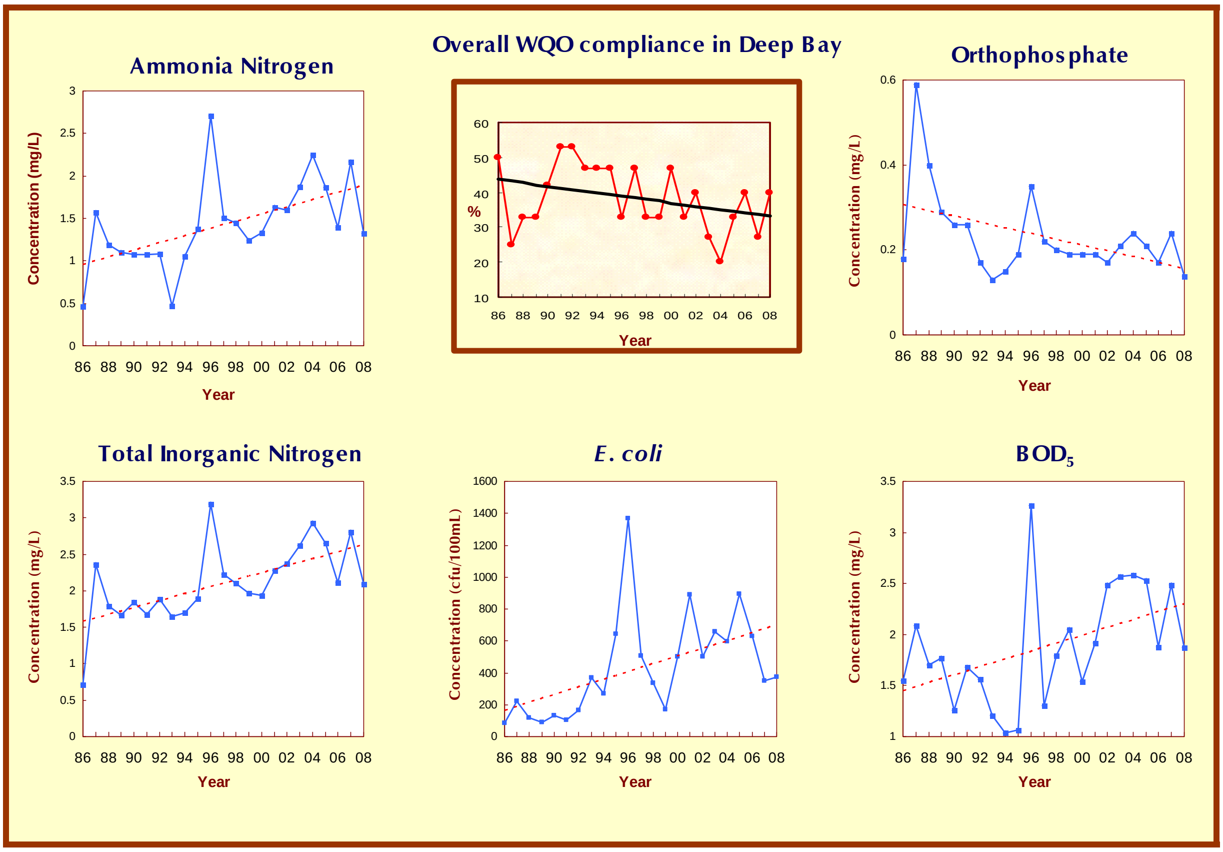

Figure 2.4 Water Quality Changes in the Deep Bay Water Control Zone, 1986 – 2008

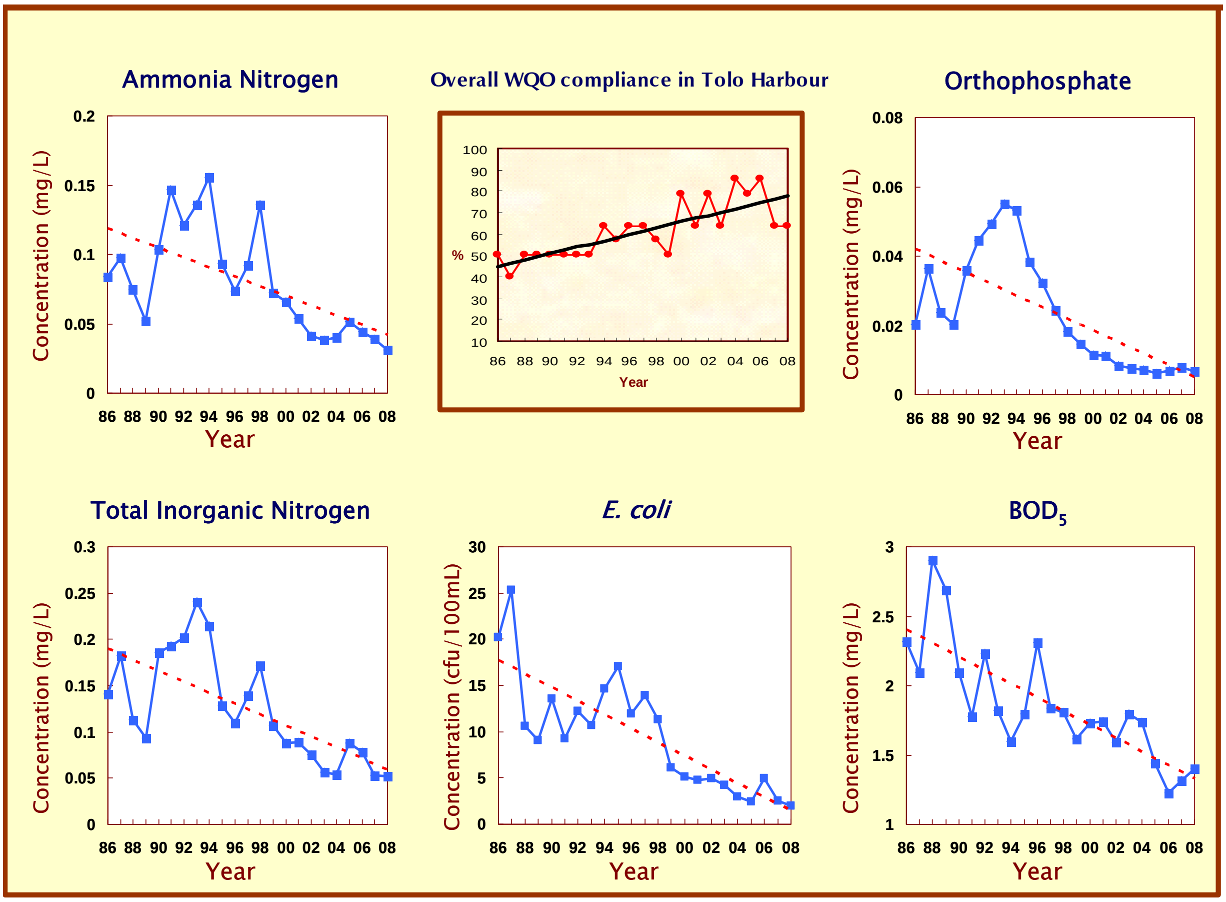

Figure 2.5 Water Quality Changes in the Tolo Harbour and Channel Water Control Zone, 1986 – 2008

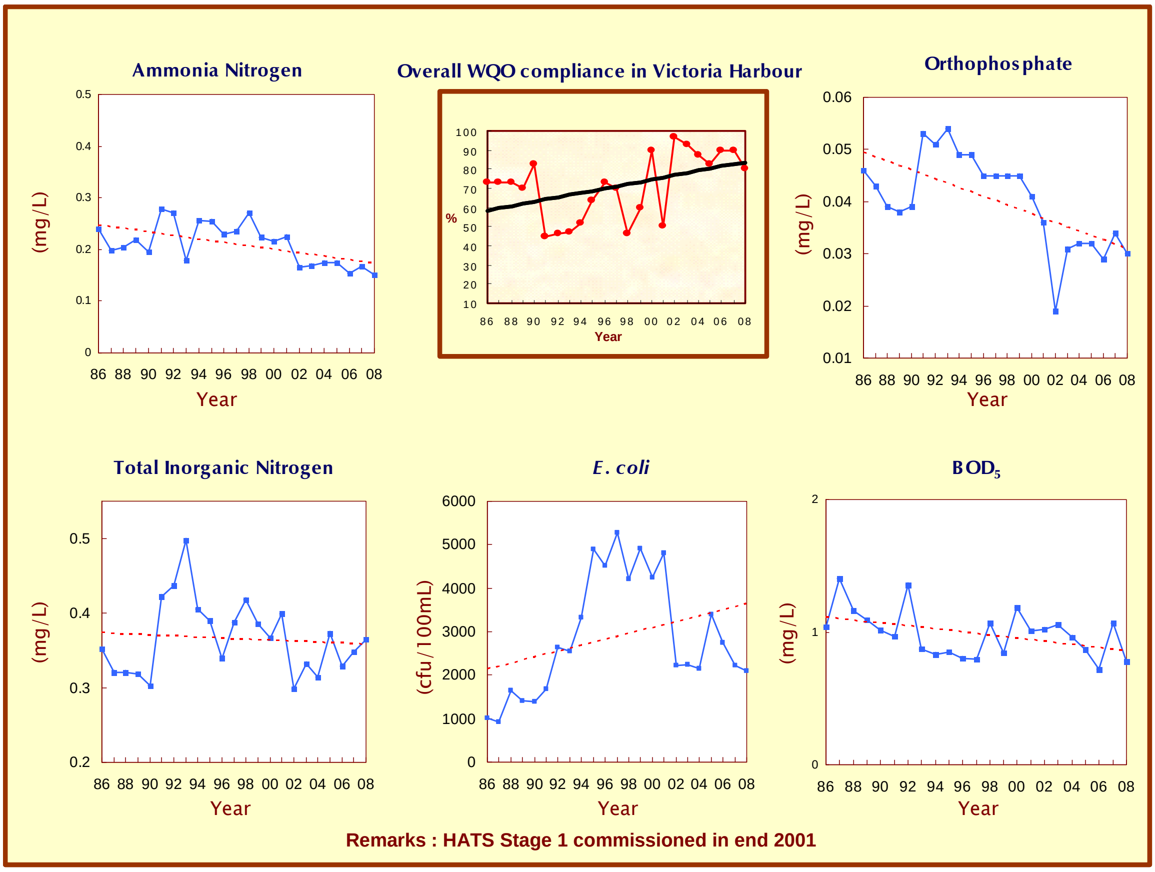

Figure 2.6 Water Quality Changes in the Victoria Harbour Water Control Zone, 1986 - 2008

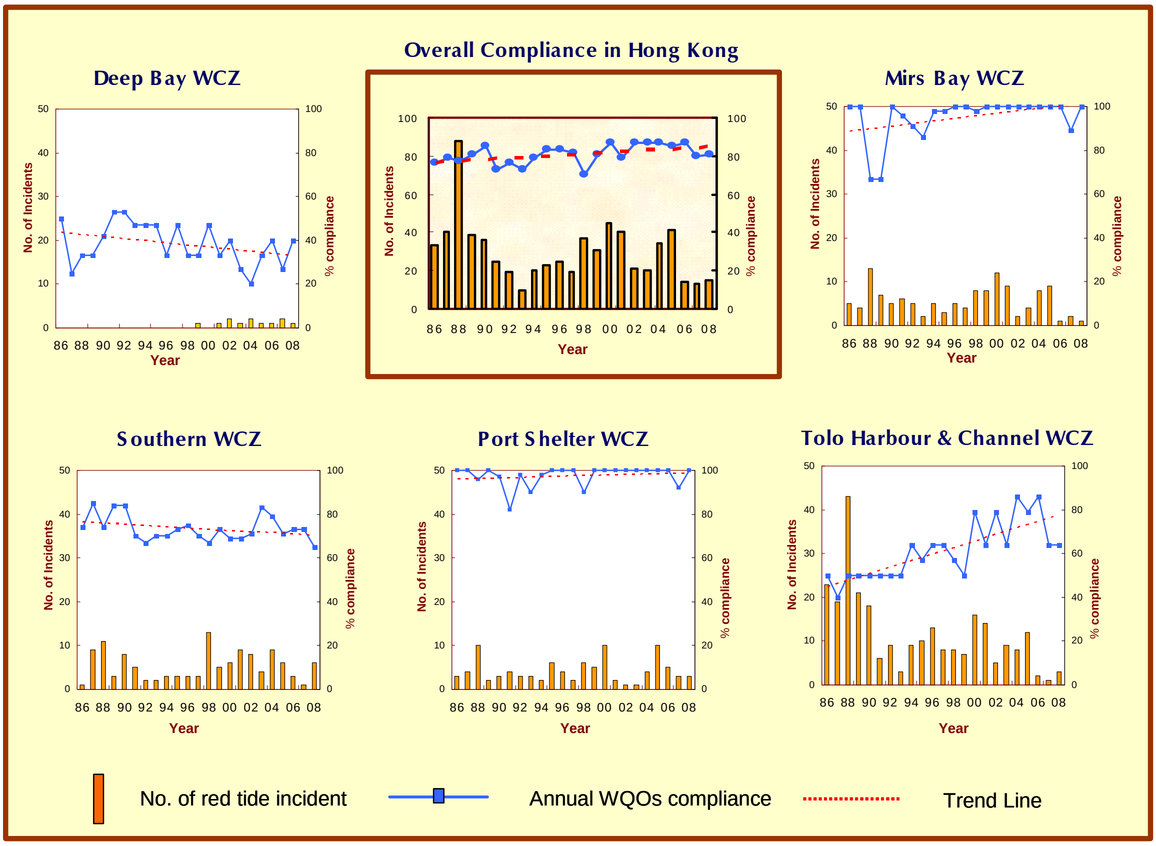

Figure 2.7 Red Tide Incidents and WQO Compliance in Hong Kong Waters, 1986 - 2008

2.3 Characterization of pollution sources and levels

2.3.1 In Hong Kong, the major pollution sources come from more than 2 million m^3 of sewage effluent daily discharged by the population of some 7 million people (Xu et al., 2008) through 25 major sewage treatment works scattered throughout Hong Kong.

2.3.2 The review of the Deep Bay Water Pollution Control Joint Implementation Programme.(HKGJWG 2008) reported that the water quality of the outer Deep Bay is strongly influenced by the Pearl Estuary flow where more than 50% of the nutrients input, in terms of nitrogen and phosphorus, are contributed by non-Bay sources. The influence of the Pearl Estuary flow diminishes towards the inner bay area. Figure 2.8 shows the nutrient contributions by the Pearl Estuary flow to Deep Bay.

2.3.3 For toxic substances, direct discharges of these pollutants by the local industry are currently uncommon due to relocation of the industry to the Mainland since early 1980s'. Chau (2006) concluded that the local source of organochlorines is not significant. The recent study of Kueh and Lam (2008) also pointed out that air deposition or regional pollution, rather than local discharges, are the major contributor to the dioxins/furans, dioxin-like PCBs, PAHs and PCBs found in the local marine environment.

2.3.4 EPD commissioned in 2004 a long-term programme for monitoring toxic substances (Figure 2.9) in the marine environment, focusing on chemicals of potential ecological and health concern identified from the EPD's study on Toxic Substance Pollution in Hong Kong (EPD 2003). Figures 2.10 - 2.15 show the graphical presentation of the data on marine water, sediments and biota collected in 2004-2006. Twenty-four priority chemicals were measured, including dioxins/furans, dioxin-like PCBs, Total PCBs, PAHs, DDTs, HCHs, TBTs, phenol, nonylphenol (NP), NP ethoxylates, PBDEs and metals. Results indicated that toxic substances in Hong Kong marine environment were within the range reported for the coastal waters in China and other regions, but were generally low compared with the Pearl River Estuary (Kueh and Lam 2008).

2.3.5 Yang et al. (2006) reported wide distribution of organo-tin compounds, dioxins/furans, PAHs and nonylphenol ethoxylates in the local marine waters but they concluded that the levels of which were not of toxicological concern. Potential ecological risk on benthic communities was however, found in several "hot spots" such as Victoria Harbour, Deep Bay, and Tolo Harbour and Channel. However, they considered that sediments accumulated from local sewage effluents in the past decades were the major sources of most heavy metals and trace organics, whereas air deposition is only a relatively minor contributor of toxic organic compounds to the local marine environment.

Figure 2.8 Influence of Pearl Estuary Flow on Deep Bay Water Quality

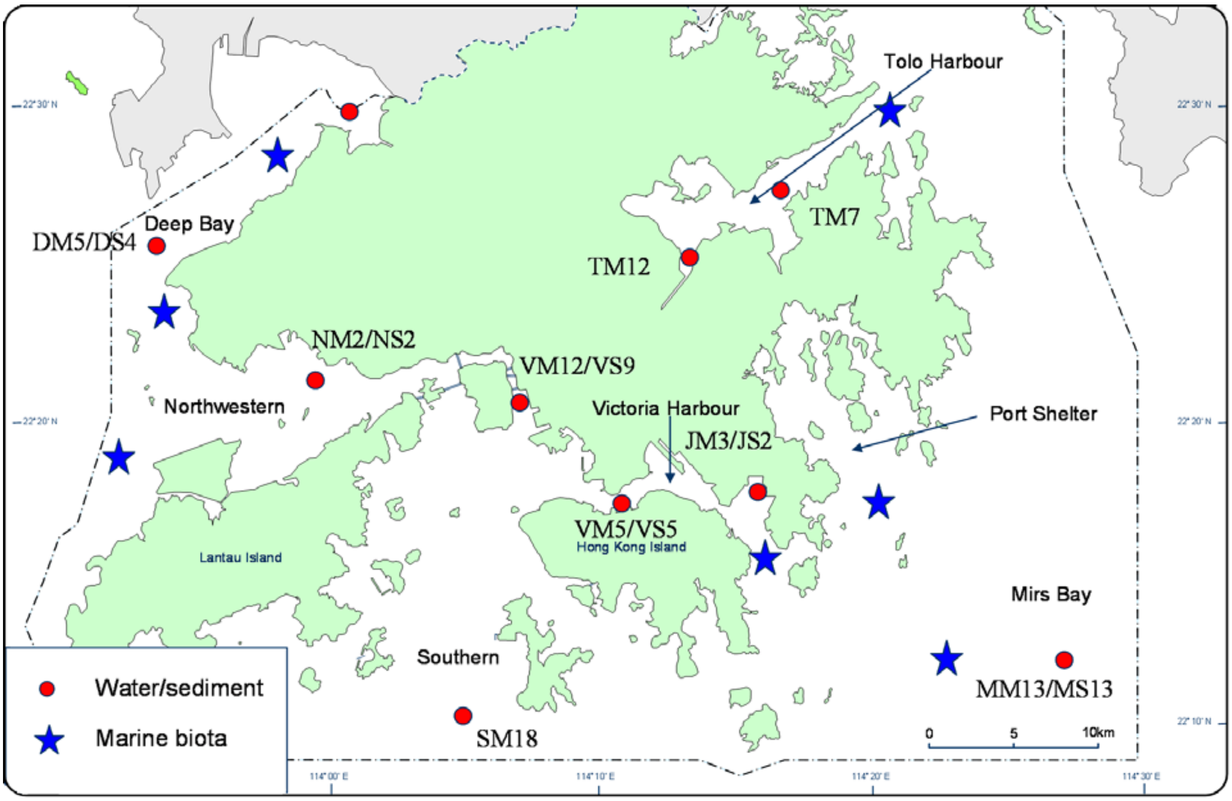

Figure 2.9 Sampling Locations for the Marine Environment under EPD's Toxic Substances Monitoring Programme

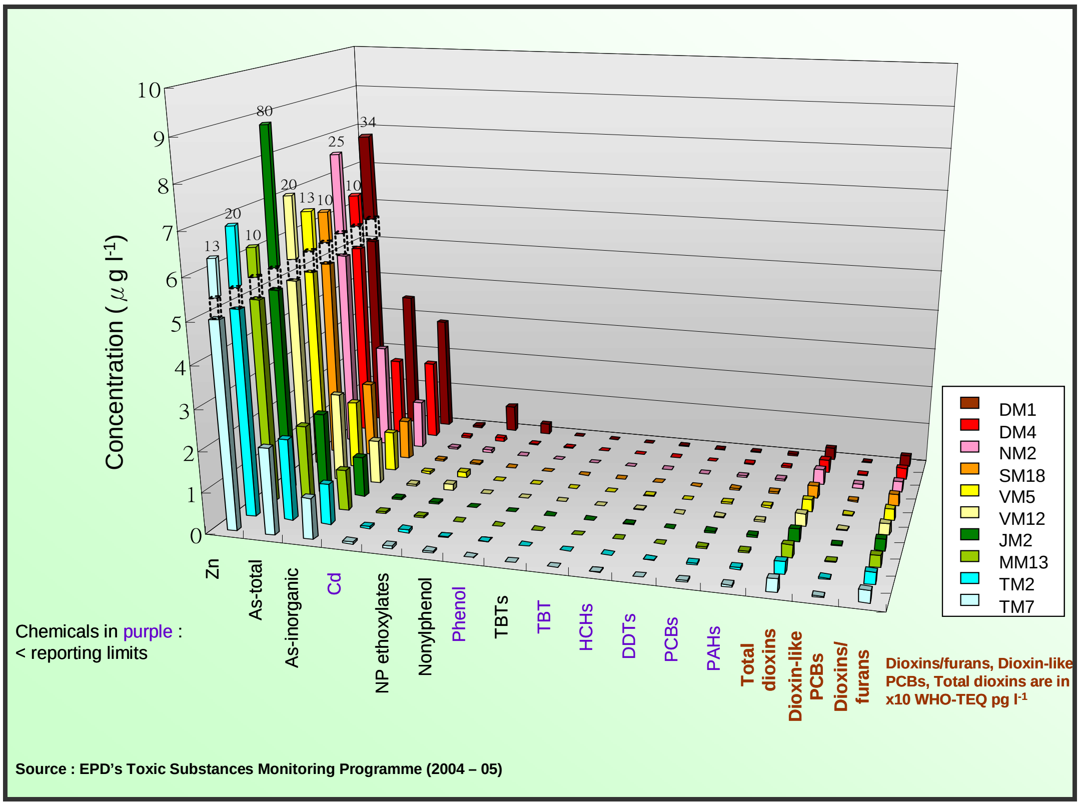

Figure 2.10 Levels of Toxic Substances in Hong Kong's Marine Water

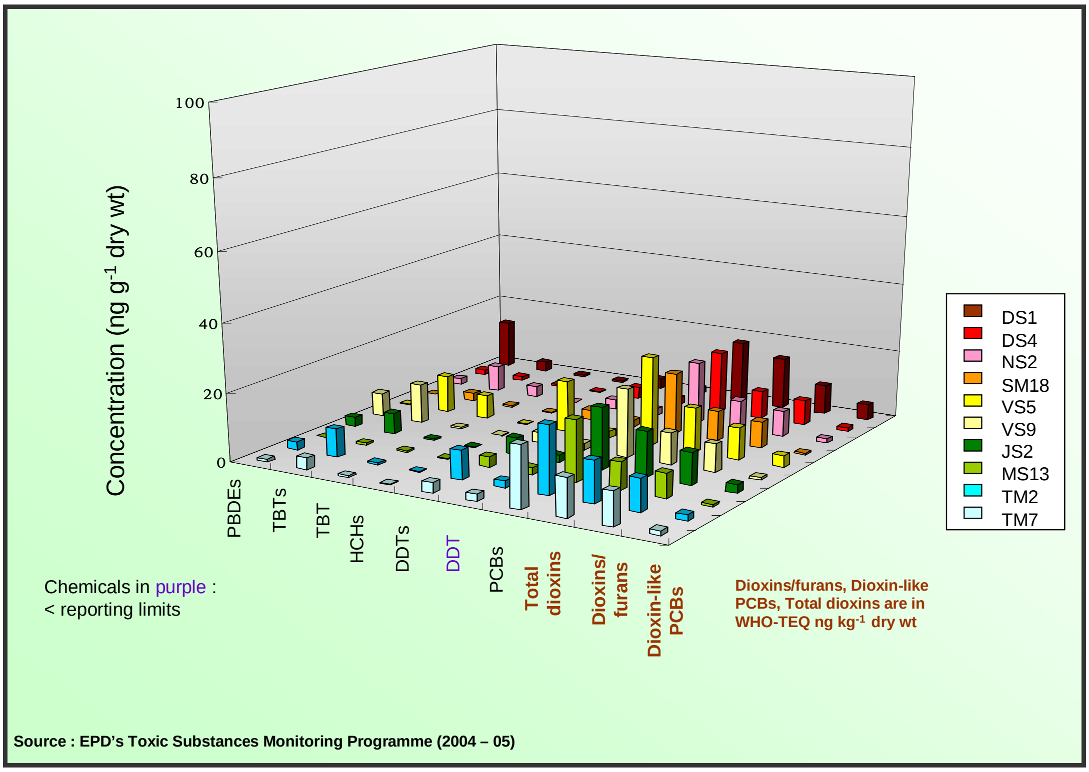

Figure 2.11 Levels of Trace Organic Compounds in Hong Kong's Marine Sediments

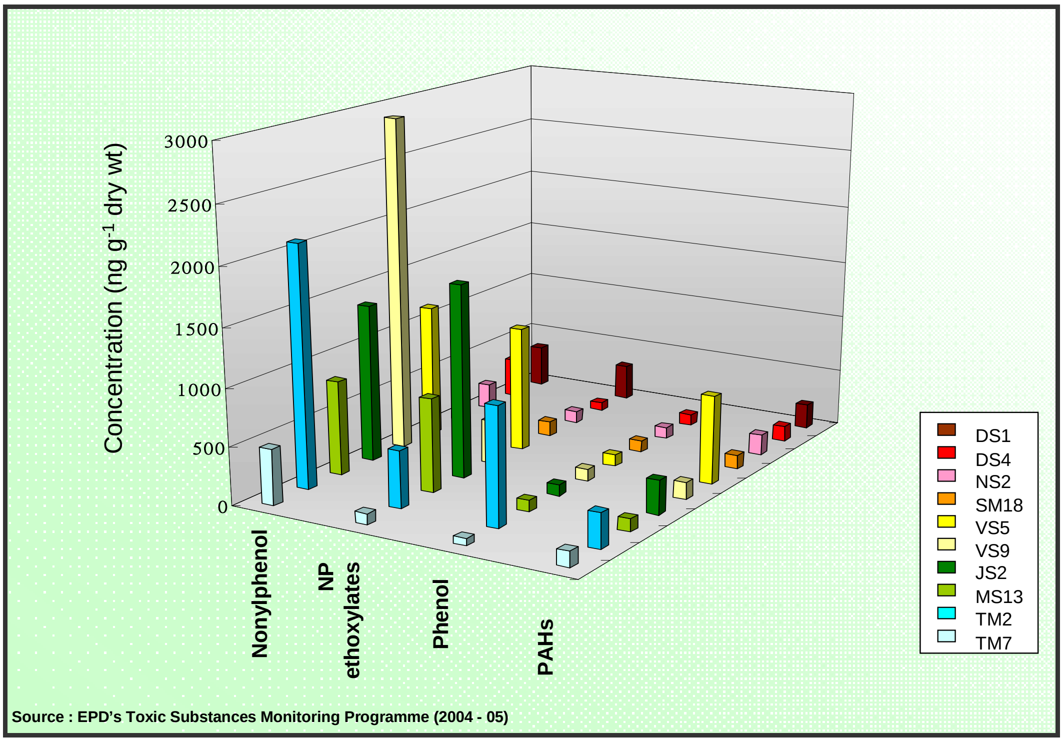

Figure 2.12 Levels of Organic Compounds in Hong Kong's Marine Sediments

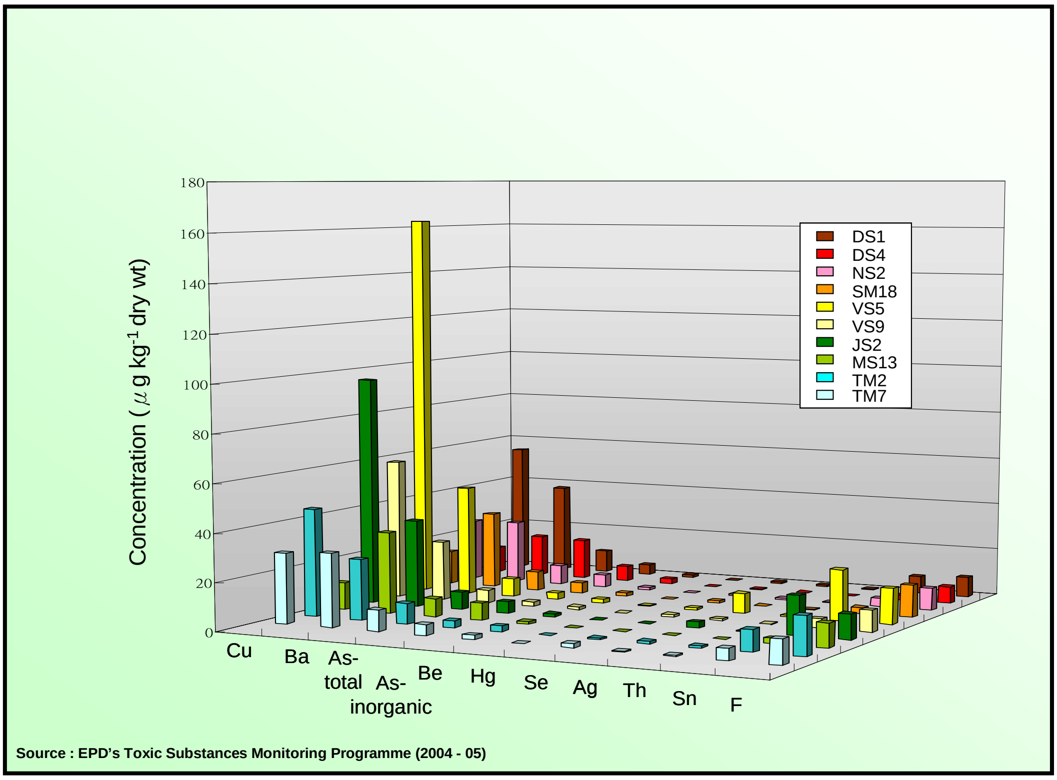

Figure 2.13 Levels of Metal and Inorganic Compounds in Hong Kong's Marine Sediments

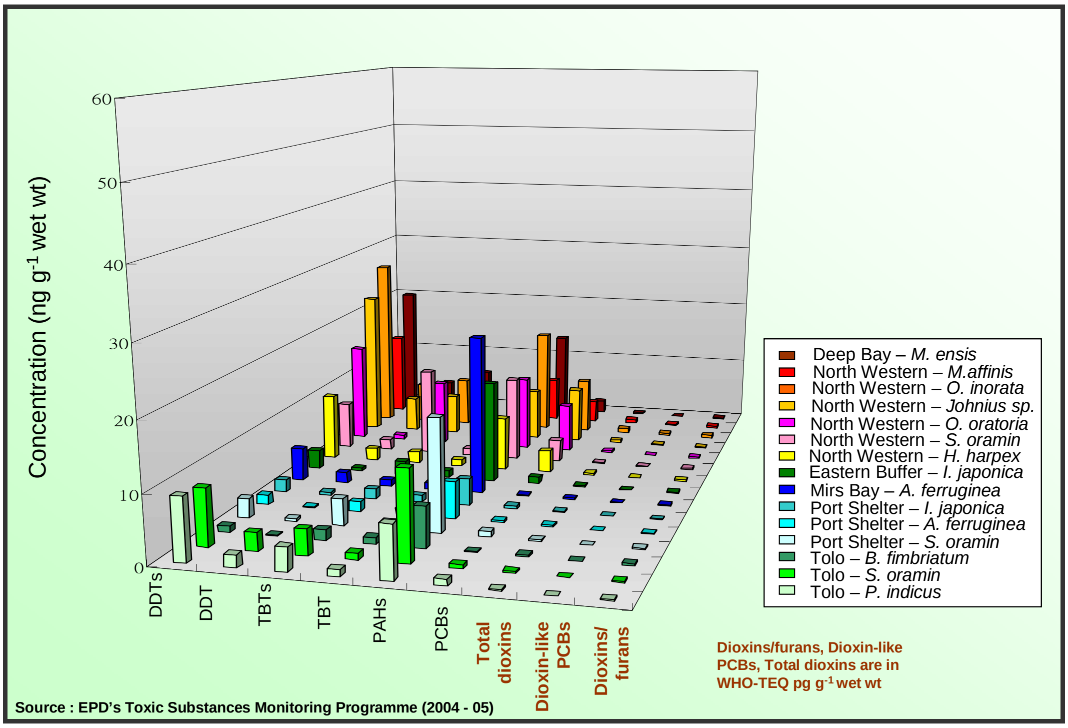

Figure 2.14 Levels of Trace Organic Compounds in Marine Biota collected from Hong Kong

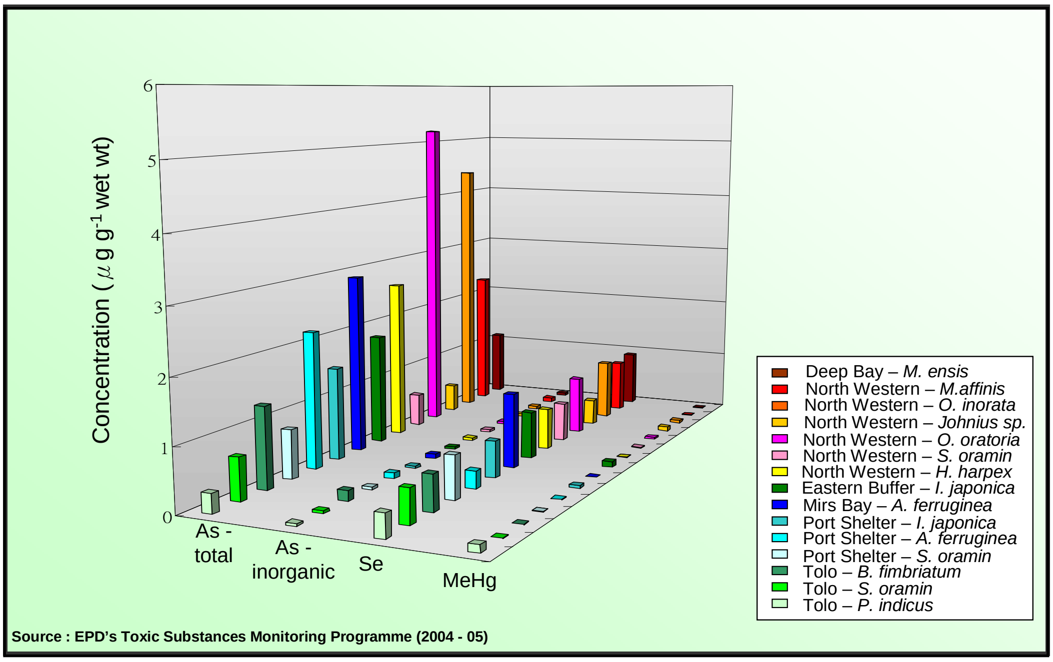

Figure 2.15 Levels of Metal and Metallic Compounds in Marine Biota collected from Hong Kong

3 Existing Water Quality Objectives

3.0.1 Water Quality Objectives (WQOs) are benchmarks which collectively define the water quality of a water body, and they should be achieved and maintained in order to promote the conservation and best use of a water body.

3.0.2 WQOs are established by the Secretary for the Environment (SEN) under the Water Pollution Control Ordinance (WPCO, Cap 358), upon consultation with the Advisory Council on the Environment (ACE). SEN can amend the WQOs after consultation with the ACE.

3.0.3 Based on the WQOs, the Government plans and develops major infrastructures in a suitable way which minimise their impact on the quality of a specific water body, plan and implement sewage infrastructure programmes to intercept pollution sources, and formulate and implement pollution control strategies, with a view to protecting the marine waters from pollution.

3.0.4 WQOs can be numeric or narrative, and include various parameters to describe the physical, chemical and biological properties of the marine environment. The WQOs currently in use in Hong Kong were established in the 1980's. A summary table of WQOs is listed in "page A-11, Appendix A, 2007 Marine Water Quality in Hong Kong"[1]. For details of the WQOs for each Water Control Zone, the reader can visit the following website http://www.legislation.gov.hk/eng/home.htm (and input Chapter: 358).

3.0.5 Over the years, there have been significant scientific advancement in and water science and water quality management technology, and emergence of new uses of our waters such as marine parks and reserves for conservation and education purposes, etc. In light of these, a number of areas of improvement, and changes for the WQOs are identified and discussed in paragraphs below.

3.1 Areas of improvement, and changes identified

3.1.1 *Need for updating the WQOs in light of the latest scientific evidence, overseas practices and local conditions:*

- While most WQOs (e.g., dissolved oxygen, unionized ammonia, nutrients, chlorophyll-*a*, SS) were developed according to the then best available information, they may need to be updated with respect to the latest scientific knowledge and overseas practices, and local conditions.

- *Some of the WQOs may be more conservative*: For example, the current WQO for unionized ammonia is set at 21 µg ammonia-N/L. Compared with most countries, the current WQO for ammonia appears to be stringent (e.g., for protection of ecosystem: 910 µg/L total ammonia-N and for protection of aquaculture: 100 µg/L (unionized-ammonia) in Australia and New Zealand (ANZECC and ARMCANZ, 2000a); for freshwater: 766 µg/L total ammonia-N in Canada (CCME, 1996) and 1270 µg/L total ammonia-N in USA (USEPA, 1986). Furthermore, this ammonia standard is applied for all WCZs in Hong Kong regardless of the BUs (except Tolo Harbour and

[1] Link : http://www.epd.gov.hk/epd/english/environmentinhk/water/marine_quality/mwq_report.html

Channel). Nevertheless, it is noted that Mainland's WQO for unionized ammonia is also set at 20 μg ammonia-N/L for all places.

- *Some of compliance requirements require further review*: The current DO standard is based on 90% compliance, and depth average and bottom level values. It is believed that such consideration is to take into account natural fluctuations. Unlike other water quality parameters, mass mortality may occur within hours when DO falls beyond the critical tolerance level of marine animals. Thus, the minimum DO, but not the current 90% compliance, is the primary concern for ecosystem protection. In an eutrophic system where hypoxia is likely to occur, DO may be very high at the surface of the water column but very low in the bottom waters. There is a need to review the present approach of presenting the compliances in terms of depth average values, taking into account natural fluctuations commonly found in local marine waters.

- The limiting factor(s), including levels of nutrients, that trigger algal bloom can be very different in different parts of Hong Kong waters. For example, there is evidence to suggest that the trigger value for nutrients in Hong Kong should be site specific, and nutrients may not be a limiting factor in Victoria Harbour and its vicinity, according to the more updated researches (Ho et al., 2008; Yin and Harrison, 2008). On the other hand, the southern and western waters, are subject to more regional background influence of the Pearl River (Chau and Jiang, 2003; Chau, 2005; 2006; Wurl et al., 2006; EPD, 2007).

- The present WQOs for toxic substances are narrative, and quantitative benchmarks, which become more common overseas practices, are not available.

- *Absence of Biological criteria:* At present, almost all WQOs (except *E. coli*) are based on chemical and physical parameters. However, measurements of physical and chemical parameters *per se* may not be sufficient because pollutants typically exist in different chemical forms, while the bioavailability, toxicity and environmental impact of a chemical differ from one form to another. It has been well recognized that physical and chemical parameters are indirect measures of the health or state of the environment and that the best way to protect environments is to monitor the biology of the environments directly (e.g., ANZECC and ARMCANZ, 2000a). It is for this reason that greater emphasis is now being placed on biomonitoring as a means of determining the health of ecosystems and that biomonitoring is now being built into the water quality management systems of many developed nations.

Alternative microbiological standards for bathing beaches.

3.1.2

- The WHO bathing water guidelines published in 2003 recommended the use of enterococci as a faecal indicator for marine bathing waters. This was derived from risk of bathers to marine waters in temperate northern European waters, and revealed that intestinal enterococci showed a clear dose-response relationship between faecal pollution and the risk of the bathing-related illnesses. The Singapore and Western Australian governments apply the WHO guidelines, and the US and EU also adopt enterococci (or a combination of both enterococci and coliform group bacteria indicators) as the microbiological indicators of marine water quality for bathing.

- The existing WQOs ($\leq$ 180 count/100ml *E. coli*) and grading system for bathing beaches were set by reference to the then WHO guidelines, and the results of the epidemiological studies jointly conducted in late 80's and early 90's by EPD and the University of Hong Kong. In light of the international trend of adopting the WHO guidelines or alternative bacteria indicators (e.g. enterococci), the existing WQOs and bacteria indicators need to be revisited to see if they are still fit for long-term protection of our bathing beaches. The need for and feasibility of adopting enterococci as an alternative/supplementary bacteria indicator will also be examined.

WQOs for supporting certain BUs are not available or not comprehensive

3.1.3 The need for current review of WQOs can be exemplified by the following concerns.

- The existing WQOs were established in 1987 or before. Since then, a number of new sensitive receivers, e.g., marine parks and marine reserve, marine mammals and SSSIs have been identified/ established, and currently there is no WQO to support these sensitive receivers. Water quality requirements for supporting marine parks, marine reserve, SSSI, oyster culture grounds, marine fish culture, marine mammals, mangroves, corals are likely to be very different, but these requirements have not been examined thus far.

- The WQOs for mariculture are less comprehensive as compared with some overseas standards. Some overseas practices have included parameters for toxicants or persistent chemicals to enhance protection of waters for seafood culture and harvest from the human health perspective.

3.1.4 Major changes have occurred since the first declaration of the WCZs and establishment of the current WQOs. The most significant changes include:

- Since 2001, the Harbour Area Treatment Scheme (HATS) has commenced to collect the sewage produced from over 4 million people from northern shores of Hong Kong Island and southern shores of Kowloon peninsula, and to discharge the collected sewage from the Stonecutters STW after removing 70% of BOD, 80% of SS and some nutrients using a chemically-enhanced-primary-treatment (CEPT) process. The water quality in the Harbour, in particular the Eastern Harbour, has improved considerably. But the water quality near Tsing Yi and the Tsuen Wan beaches is less ideal than without the plume.

- The water quality in Tolo Harbour has improved considerably after implementation of the Tolo Harbour Action Plan in 1987. Details of the plan, and its environmental benefits is outlined in the ACE paper 30/97 presented to the Advisory Council on the Environment on 26 May 1997[2].

- In the last two decades, the majority of local industries that produce wastewater discharges have moved to the Mainland. Coupled with a tighter pollution control, pollution loading from the local industry to our marine waters has been substantially reduced.

- The increase in environmental awareness and hence a higher environmental quality is expected from the general public.

[2] Link : http://www.epd.gov.hk/epd/english/boards/advisory_council/files/ace_paper9730.pdf

4 Review of overseas practices for marine water quality objectives

4.0.1 This section describes and compares the rationales, scientific basis and methodologies adopted by various jurisdictions in deriving WQOs. Particular emphasis is given to the pros and cons, as well as limitations and constraints of the different approaches used.

4.0.2 The term "Water Quality Objectives" (WQOs) used in Hong Kong is termed "water quality criteria" (WQC: USA), "water quality guidelines" (WQG: Singapore, Australia, and Canada), "water quality standards" (WQS: PR China, Malaysia), and "environmental quality standards" (EQS: Japan, EU and European countries) in other jurisdictions. WQOs are always formulated in terms of what functions the water is being used for (i.e., "beneficial uses", "intended uses" or "environmental values") and hence what uses are being protected by the WQOs.

4.0.3 The most common and traditional approach for deriving WQOs has been measurements of physical and chemical parameters, and assuming that if these physical and chemical parameters can be maintained at certain level, the aquatic environment will be protected. However in more recent years it has been recognized that these are largely indirect measures of the state or health of the environment, and the alternative way is to monitor the biology of the environments directly (e.g., ANZECC and ARMCANZ, 2000a). Nevertheless, the WQOs still play an essential role in preserving the health of aquatic ecosystems, as the parameters concerned are easier to measure and monitor than most bioindicators. The review will cover at least over 40 water quality parameters or indicators which are listed in Appendix A1.

4.0.4 Water quality objectives can be an important component of any framework for water resources management. In very broad terms, there are three different approaches to water resources management adopted by overseas jurisdictions (CCME, 2003):

1) **The technology-based approach**: where limits on the release of chemicals are based on some definition of what can reasonably be achieved technically/economically. As such the standard for discharge into the receiving waters primarily depends on the effectiveness of the treatment technology and the dilution capacity available, whilst little or no consideration is given to establish WQOs. This approach is generally adopted by jurisdictions such as Germany, Japan, Malaysia, etc.

2) **The use-protection approach**: that essentially involves the designation of beneficial uses/ environmental values to a water body, and an appropriate mix of management options are applied to ensure these uses/values are not compromised. In this approach WQOs are the basis for assessing whether the designated uses/values are being adversely affected. They can also be used to back calculate to a corresponding effluent concentration. This approach is commonly adopted by jurisdictions such as Australia, Canada, Europe, and US.

3) **The non-degradation approach**: where discharge limits are established based on the natural background levels of substances of concern at the site. This approach is in fact the strictest form of the "use-protection approach", and has generally been restricted to waters of high environmental value.

4.0.5 Most jurisdictions defined beneficial uses (or intended uses or functional uses or environmental values) to some extent and established associated WQOs for a number of parameters. This highlights the importance and prominence of the use-protection approach and justifies in particular the setting of WQOs.

4.0.6 In practice, a mix of management approaches is usually used. WQOs can be of assistance in benchmarking individual technology-based approaches, and technology-based approaches are likely to be included in the mix of management strategies used to achieve WQOs. WQOs can also form part of the non–degradation approach if the framework for establishing WQOs is broad and flexible, as in the case of Australia (ANZECC and ARMCANZ, 2000a) and the EU (European Commission, 2000). In the Australian state of NSW, and many other jurisdictions, all three approaches can be in use at the same time depending on the location and situation.

4.0.7 Throughout all of the jurisdictions, different types of methodologies are used for deriving WQOs, for each of the three kinds of parameters of interest: toxic chemicals, physico-chemical characteristics (including nutrients), and microbiological indicators. While there appears to be a consensus in the methods used for derivation of WQOs for the latter parameters (physical, nutrients and microbiological), there are more disparate opinions and ways of estimating WQOs for toxic substances. This fact reflects the many gaps in knowledge about ecotoxicology, and consequently translates in many uncertainties that make the task of regulation and water policy quite difficult.

4.1 Nutrients and physical characteristics

4.1.1 The most common method, and the one adopted by a majority of countries around the world, is to establish a "**baseline**" of values for reference sites against which to compare the quality of the waters. The resulting WQOs usually consist of upper and lower limits within the natural range of variation for some parameters, or just upper limits for others. Separate WQOs may be established to cater for the seasonal variations.

4.1.2 The sources of information that can be used to establish the baseline or reference condition can include: historical data collected from sites of interest; spatial data collected from sites or areas nearby that are uninfluenced (or not as influenced) by the disturbance being assessed; or data derived from other sources (ANZECC and ARMCANZ, 2000a). The latter might be considered for instance as an interim measure if there are neither suitable historical data nor comparable reference sites available. It could include identifying the reference condition from published literature, from modelling or from expert opinion. For modified ecosystems, use of the "best available" reference sites may be the only option available.

4.1.3 At its simplest, the approach involves taking a percentile of the reference distribution as the WQO. The approach can, however, also include or lead to consideration of site specific modifying factors, development of empirical relationships between parameters, use of predictive modelling and assessment of sustainable loads.

4.1.4 In theory, an advantage of Hong Kong over many other countries is the uniformity of climatic conditions throughout its relatively small area (1,651 km^2 of seawater), which minimises the variability between sites and may make it possible to establish the same baseline dataset for the entire territory. Different percentiles of this data set, for example, could then be used to establish WQOs for different levels of ecosystem protection. In this way, the 80th percentile, as recommended in Australia (ANZECC and ARMCANZ, 2000a), could be used slightly to moderately disturbed zones whereas a less stringent percentile, perhaps the 90th or 95th percentile, could be used for highly disturbed water bodies. The different seasons will probably need to be treated separately.

4.1.5 In practice, the main difficulty with the approach outlined above is the size, the proximity and the influence of the Pearl River. Natural conditions in the western approaches will be more variable and superimposed on this variability is the pattern of contamination from the PRD and local sources.

4.2 Toxic substances

4.2.1 The European countries and Canada (and to some extent the USA) are applying a mix of methods to deal with persistent chemicals (all of which are organic chemicals or POPs) that show bioaccumulation in organisms. Those methods that specifically address bioaccumulation are appropriate for setting WQOs for protection of wildlife predators, human consumers of seafood and aquaculture products. For non-persistent toxic chemicals, metals and persistent chemicals not related to bioaccumulation, there is still debate in scientific circles as to the best way to set quality guidelines or standards.

4.2.2 There are differences in the statistical methods adopted by various jurisdictions used to estimate the protective thresholds for all species. A common problem is that the toxicological data available have been derived for a few species tested under laboratory conditions and the bulk of the data are acute toxicity (LC_{50} and EC_{50}) values, rather than chronic no-observable-effect concentrations (NOECs). This variability in sensitivities is accounted for in part in the statistical procedures used to estimate the thresholds from the laboratory data. These are as follows:

- The **Assessment Factor** (AF) / Safety Factor (SF) approach was the traditional method used to derive early WQOs by the USEPA and others. The factors were usually applied to the most sensitive data point. The factors were applied to convert from acute or LOEC data to chronic NOEC figures (10 – 100, as in Canada), and also to account for variations in quantity and quality of data (between 10 and 10,000, as in Europe). This approach is still used to derive WQGs in some jurisdictions, even in those that prefer the SSD approach (EU, Australia), usually to adjust the SSD figure for further uncertainties.

- The **Triangular distribution** approach, which is only used by the USEPA and is an early approximation of later SSD approaches; it uses all available NOEC data for a chemical and fits a triangular distribution to the data to protect a nominated percentage of species.

- The **Species Sensitivity Distribution (SSD)** approach, which is the preferred method by many developed countries (e.g., The Netherlands, EU, Australia), although a variety of SSD curves have been used. Newman et al. (2000) reported that many toxicity datasets do not fit the typical sigmoid curve of the SSD, but the Australian use of the Burr distribution curves largely overcomes this problem (ANZECC and ARMCANZ, 2000a; Campbell et al., 2000; Shao et al., 2000).

- **Bootstrapping** is a universal method, applicable to any distribution of toxicity data (Grist et al., 2002), and developed to address some of the limitations mentioned by Newman et al. (2000); European countries can use it in addition to the SSD method. It is simpler mathematically than the early SSD curves, although it requires computing power. Again, the Burr distribution software (ANZECC and ARMCANZ, 2000a) may be simpler to use and do the same job.

4.2.3 Warne (1998) and ANZECC and ARMCANZ (2000a) have reviewed the first three methods, and determined that the SSD approach was more consistent with risk principles, particularly that of more data giving greater confidence in the WQO figure. Both the SSD and bootstrapping statistical methods are scientifically sound and produce similar results. The AF method has been criticised for being too subjective (Chapman et al., 1998; Warne, 1998). Indeed, the factors used are based on limited scientific evidence, while large factors may generate threshold values lower than the standard analytical capabilities of most laboratories, causing problems with compliance. Kwok et al. (2007) recommended an additional factor of 10 when applying temperate data to tropical systems, when data are limited.

4.2.4 The critical process is to determine what degree of protection from chemical pollution the threshold values would provide to an ecosystem. The aim would be to ensure that any concentration of toxicants in water and sediment do not reduce the populations of most or all the species that form an integral part of a particular ecosystem and do not impair the overall structure or function of the ecosystem. For instance, Canadian guidelines aim at protecting 100% of all species everywhere from long-term exposure, whereas European countries, Australia and USA aim at protecting a percentage of species, usually 95%, sometimes 99% (pristine areas) or 80% (heavily modified ecosystems).

4.2.5 In addition to all the above, the European countries and the USA have two sets of thresholds: one for chronic effects (called AA-EQS in Europe and CCC in the USA) and another one for acute effects (called MAC-EQS and CMC respectively). It is debatable whether such distinction may be practical in terms of protection to the ecosystem, but it may help regulatory authorities in their monitoring since no-compliance with the acute thresholds is often indicative of accidental spills or misuse of toxic chemicals (pesticides, waste discharges, etc.), which are likely to be temporary and relatively easy to deal with, whereas no-compliance with chronic thresholds may be indicative of deeply entrenched contamination problems which require an investigation and tough decisions. It should be noted that the methodologies for deriving the short-term exposure protection figures are not as robust as for long-term exposure, the protection levels are less certain, and there are monitoring difficulties to consider.

4.3 Biological criteria

4.3.1 The overseas practices of development and use of biological criteria are summarized below:

Australia

4.3.2 The Australian national guidelines (ANZECC and ARMCANZ, 2000a) put an emphasis on assessing aquatic biological communities. ANZECC and ARMCANZ (2000b) view bioassessment "*as a vital part of assessing changes in aquatic ecosystems, and as a tool in* *assessing achievement of environmental values and attainment of the associated water quality objectives*". The biological information is an integration of many natural and human disturbances. Guidelines for biological assessment, outlined in the Australian document, are intended to determine substantial ecosystem effects, including: "*changes to species richness, community composition and/or structure; changes in abundance and distribution of species of high conservation value or species important to the integrity of ecosystems; and physical, chemical or biological changes to ecosystem processes*".

4.3.3 Protocols are provided for some bioassessment methods and new ones are being developed with improved indicators, experimental design, sampling approaches, decision criteria (i.e., acceptable level of change) and analysis. Biological assessment can have several different aims (with accompanying different experimental designs). Common among these are: broad-scale assessment (e.g., for rapid screening or coverage on broad geographical scales); early detection of changes; and assessment of biodiversity to determine adverse effects at population, community and ecosystem levels (e.g., determining ecological sustainability of human activity).

European Union

4.3.4 The European Union has established environmental objectives that are defined to a large extent in terms of biological quality elements (see Article 4 and Annex V of European Commission, 2000). To assess compliance, member states need, among other things, to establish type-specific biological reference conditions that represent high ecological status. For coastal waters this needs to be done for three biological quality elements:

- Composition, abundance and biomass of phytoplankton;
- Composition and abundance of other aquatic flora (macroalgae and seagrasses); and
- Composition and abundance of benthic invertebrate fauna.

The reference conditions for each then form the basis of a classification system that is used to assess whether surface water status is high, good, moderate or poor. For most water bodies member states are required to "*protect, enhance and restore (...)with the aim of achieving good surface water status at the latest 15 years after the date of entry into force of this Directive*" (i.e., 2015). Progress on adoption of this Directive is illustrated in the UK's Technical Advisory Group (UKTAG, 2005), where the biological parameters are being integrated with the water quality and chemical pollutant standards.

Canada

4.3.5 The concept of ecosystem-based management is basic to the Canadian approach to site-specific application of environmental quality guidelines (EQGs) (CCME, 2003). This concept incorporates integrated management of natural landscapes, ecological processes, physical and biological components, and human activities. These 2003 guidelines form the "*scientific basis for developing site-specific environmental quality objectives*", which in turn influence water management strategies that incorporate social and economic factors. The site-specific WQOs incorporate measurement of biological indicators of ecosystem health and integrity, along with traditional physical and chemical indicators. CCME (2003) recognises that no single method can adequately address all requirements for developing WQOs but information on "resident species" is an important component of overall evaluation, identifying their range of sensitivity and factors that influence chemical bioavailability.

US

4.3.6 Biological criteria, or biocriteria, in the USA are "*numerical measures or narrative descriptions of biological integrity*", which set the biological quality that must be present to support a desired condition in a water body. Biocriteria are derived from biological assessments of reference waterbodies and involve integrated measures (indices) of the composition, diversity, and functional organization of a reference aquatic community. Physico-chemical water quality data and biological data are collected to define the baseline conditions of each type of water body, and numerical biological criteria are then developed. This reference condition approach is a similar approach to the EU system described above. Five approaches for estuaries and coastal marine waters are available, which depend on the degradation status of the water body and the amount and quality of historical data. The criteria are estimated using the indicator variables as follows:

- For waters in excellent condition, the median values of the indicator variables are used;
- For degraded sites, criteria are defined by the upper quartile;
- For significantly degraded areas with reference sites, the intercept value on a regression or distribution curve is used;
- For degraded areas with insufficient historical records, the intercept is used as above but a model is required to extrapolate back; and
- For coastal waters in general, an index site approach and models are required.

4.3.7 Biological criteria are adopted on a State-by-State basis to protect aquatic life uses of the waterway. Chemical, physical and biological integrity, as defined by the Clean Waters Act (Section 101(a)), is taken to "*define the overall ecological integrity of an aquatic ecosystem*". Biological assessment results from State surveys on the presence, condition and numbers of types of fish, insects, algae, plants, and other organisms are compared with the biocriteria established for that water body. State biological assessment data are used to evaluate the effectiveness of management actions, as reflected in the responses and improved conditions of biological communities.

4.3.8 USEPA (2000a) has provided technical guidance for development of biocriteria and bioassessment programs by the States. The main measures of ecosystem condition are benthic infauna (macroinvertebrates), fish, aquatic macrophytes and phytoplankton, while measures for zooplankton, epibenthos and preserved remains (palaeoenvironmental reconstruction) are being developed and draft methods are provided. Data can be developed into indices of condition or indicator taxa evaluated.

Hong Kong

4.3.9 At present, there is absence of biological WQO for Hong Kong. In light of the international trend to employ biological criteria and indicators to enhance conservation of aquatic community, the review will explore the feasibility of developing biological WQOs for Hong Kong waters. The criteria formulation needs local data of aquatic organisms' responses to inhabiting water conditions and pollution levels. EPD has implemented a biological indicator monitoring programme to collect the required data.

4.4 Microbiological WQOs for bathing waters

4.4.1 Expert review of existing epidemiological studies is the underlying method used to derive WQOs (and guidelines and standards) for recreational waters. Jurisdictions either derive their own WQOs directly, or after considering what recent developments have been made in the field, decide to adopt or adapt the WQOs developed by others. The World Health Organization (WHO) and the European Commission (EC) are the jurisdictions that have most recently developed their own WQOs (WHO, 2003; European Commission, 2006b). The respective approaches (and outcomes) are similar and differ from what was common practice previously. Both have taken a risk based approach and provide a series of numerical values that are used to classify water quality status. Their respective approaches also include a requirement to evaluate the likelihood of faecal contamination. This is to be done by means of a sanitary inspection or "*bathing water profile*". Australia has adopted the World Health Organization approach with minimal changes (NHMRC, 2008). Singapore has also used the World Health Organization approach but they have simplified it by selecting one value from the series as a threshold value.

4.4.2 WHO (2003) provides a review and assessment of the health hazards encountered during recreational use of coastal and fresh water environments. Guidelines for recreational use of marine waters are provided in WHO publication *Guidelines for safe recreational water environments* (WHO, 2003). The primary aim of the guidelines is the protection of public health. The specific guidelines that are given to address microbiological quality relate to activities where whole-body contact takes place (i.e., those in which there is a meaningful risk of swallowing some water). There are no corresponding guidelines covering secondary contact recreation which would involve, for example, wading, boating and fishing.

4.4.3 Of the water quality aspects, the main concern (and most specific guidance) relates to faecal pollution. Compared with earlier guideline approaches to faecal pollution the principle focus has expanded from retrospective numerical compliance assessment to include real-time management and public health protection. One of the main outcomes of this is a classification system for recreational waters based on a combination of sanitary inspections and microbial measurements.

4.4.4 An important consideration was the "Annapolis Protocol" (WHO, 1999) which recommended:

- A move away from reliance on numerical values of faecal indicator bacteria as the sole compliance criterion to the use of a two component qualitative ranking of faecal loading supported by direct measurement of appropriate faecal indices.

- Allowance for the impact of actions to discourage water use during periods, or in areas, of higher risk (e.g., advice to avoid swimming after rainfall events).

These recommendations that led to a classification of recreational water environments recommended in WHO (2003). This classification is essentially a matrix formed by the outputs of a sanitary inspection (the "ranking of faecal loading") and the results of microbiological monitoring (the "direct measurement of appropriate faecal indices").

4.4.5 A series of randomised controlled trials performed in the temperate northern European waters (e.g. United Kingdom) formed the key studies for the derivation of numerical guideline values for the microbiological quality of bathing waters (WHO 2003). The study revealed that for marine waters, intestinal enterococci (faecal streptococci) showed a dose-response relationship in bathers for both gastrointestinal illness and acute febrile respiratory illness (AFRI).

4.4.6 WHO Guidelines for the selected contaminants are included in Appendix A5. Numerical guideline values for numbers of intestinal enterococci per 100mL are expressed in terms of the 95th percentile and represent readily understood levels of risk based on the exposure conditions of key studies. WHO advised that the guidelines are flexible, and in devising local bathing standards, the country/region should take into consideration account socio-cultural (immunity, illness rates of population), environmental (climate, hydrology) and economic conditions to suit regional, national and/or local circumstances.

4.4.7 A summary of bacterial water guideline/standards for bathing waters adopted by some overseas jurisdictions is given in Table 4.1. The existing WQOs (≤ 180 count/100ml *E. coli*, calculated as the geometric mean for all samples collected during the bathing season) and grading system for Hong Kong beaches were based on the results of the epidemiological studies jointly conducted in late 80's and early 90's by EPD and the University of Hong Kong, making reference to the then WHO's report. This benchmark corresponds to a swimming-associated illness rate of 10 cases per 1000 swimmers. In addition, the beach rating system sets an upper limit of 610 *E. coli*/100 mL corresponding to a swimming-associated illness rate (i.e. health risk) of 15 cases per 1000 swimmers, which is comparable to overseas practices, such as those adopted by the USEPA (19 cases per 1000 swimmers)[3] and WHO (50 cases per 1,000 swimmers)[4]. The health risk approach for deriving the current WQOs is similar to overseas practices.

4.4.8 Nevertheless in light of the international trend to adopt the WHO guidelines and the application of enterococci as the bacterial indicator, the review will revisit if the existing WQOs and bacteria indicators (*E. coli*) are still fit for long-term protection of bathing beaches in Hong Kong. It will also examine whether the variation of enterococci level in water would correlate well with the changes in pollution levels normally encountered in local beach water (which is sub-tropical in nature), and the acceptable risk level for human health, as well as the need and feasibility of adopting enterococci as an alternative/supplementary bacteria indicator.

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[3] The risk rate (19 cases per 1000 swimmers) is used in the USEPA's Final Rule on "Water Quality Standards for Coastal and Great Lakes Recreation Waters", 16 November 2004.

[4] The WHO guidelines classify the microbial water quality into four categories: A, B, C and D. Category B (corresponding to a gastrointestinal illness rate of 50 cases per 1000 swimmers) is generally taken as the acceptable swimming-associated health risk level.

Table 4.1 Summary of bacterial water guidelines/standards for bathing waters

Country/Region/Organization	Water quality guidelines/standards for bathing water (per 100 mL) for bathing water
WHO (Note: Four categories of microbial quality, A, B, C and D)	For marine waters (Category B) Intestinal enterococci ≤ *200* (95th percentile)
	For fresh waters *E. coli* (guideline value not yet derived)
E.C. Directive (Note: Four classes of beaches: Excellent, Good, Sufficient and Poor)	For marine and transitional waters (for "Good" beach) *E. coli* ≤ *500* (95th percentile) Intestinal enterococci ≤ *200* (95th percentile)
	For fresh waters (for "Good" beach) *E. coli* ≤ *1000* (95th percentile) Intestinal enterococci ≤ *400* (95th percentile)
Hong Kong	For marine waters ("Fair" beach) *E. coli* ≤ *180* (geometric mean of all samples collected in a bathing season)
USEPA	For marine waters Enterococci ≤ *35* (geometric mean of at least five samples) For fresh waters *E. coli* ≤ *126* (geometric mean of at least five samples) Enterococci ≤ *33* (geometric mean of at least five samples)
Australia	For Marine and Fresh waters Faecal coliforms ≤ 150 (median over the whole bathing season) or Enterococci ≤ *35* (median over the whole bathing season)

4.5 Water quality guidelines relating to bioaccumulation and mariculture

4.5.1 Some countries have developed guidelines for chemical substances that persist for long periods and bioaccumulate in organisms. It is only in recent years that approaches to developing guidelines or standards for these types of chemicals have become available and only a few countries have developed guidelines using these approaches.

4.5.2 Some guidelines are based on residues in tissues that would protect predators from secondary poisoning or humans from eating fishery products. In other instances such tissue residue guidelines have been related back to concentrations in water. The WHO/FAO food standards setting agency, Codex Alimentarius Commission, has established a code of practice for fish and fisheries products, stating the importance of site selection and growing water quality in the production of farmed fishery products that are safe for human consumption (Section 6.1). Information on these latter aspects are not dealt with here but can be accessed through the Codex Alimentarius website <http://www.codexalimentarius.net/download/standards/10273/CXP_052e.pdf>. The overseas practices for the WQOs relating to bioaccumulation and mariculture are summarized below.

Australia and New Zealand

4.5.3 The assumption for potentially bioaccumulating chemicals in ANZECC and ARMCANZ (2000a) is that at the low concentrations of the trigger values, significant magnification is unlikely to occur. In the absence of comprehensive guidance at the time, the protection level for such compounds was increased to 99% from the normal default of 95%. Australia and New Zealand have developed water quality guidelines (including toxicant parameters) for the protection of aquaculture species as well as human consumers of aquatic food.

4.5.4 The limits for chemicals in foods are set by the Food Safety Authority of Australia and New Zealand (ANZFA, 2000). However such limits bear no relation to concentrations in water. Given the uncertainty and limitations of adopting solely water quality standards for human health protection, the Australian and New Zealand official guidelines make it clear that the water quality guidelines mentioned in Section 4.5.3 above are not to guarantee the achievement of relevant food standards and they are to be used in conjunction with the food safety standards to protect the health of human consumers of aquaculture products (ANZECC and ARMCANZ, 2000a).

European Union (EU)

4.5.5 The European Union requires the evaluation of all available data to derive the environmental quality standards (European Commission, 2001). This includes protection of top predators and human health, and accounts for all direct and indirect exposure routes in aquatic systems including bioaccumulation. Earlier European Commission (2003) technical guidance follows the route from a Predicted Environmental Concentration in water towards a risk quotient for a top predator (bird or mammal), but the most recent guidance (Lepper, 2005) requires that a safe water concentration is calculated from a determined safe level for a predator.

EU approach for protection of predators

4.5.6 The source document for the EU methodology for protection against secondary poisoning from substances with a potential to bioaccumulate is Lepper (2005). The pathway for secondary poisoning is by uptake through the food chain, hence long-term feeding studies are appropriate. The results of these studies may be expressed as concentration in food (NOEC; mg/kg_{food}) or as dose (No Observed Adverse Effect Level; NOAEL; mg/kg body weight/day) causing no effect. For further calculation, NOEC oral is needed, and this can be derived by multiplying the NOAEL by a conversion factor, based on body weight/daily food intake. Lepper (2005; Table 7) provides a table of conversion factors for eight common test species, ranging from 8 to 40.

4.5.7 A quality standard (an interim figure in developing EQSs) is given as the concentration in food of the predator (QS_{spb} where "spb" = "secondary poisoning of biota"; this approximates the $PNEC_{oral}$, which is the "Predicted No Effect Concentration" for oral intake). QS_{spb} is derived from the $NOEC_{oral}$ by dividing by an assessment factor. Again, Lepper (2005; Table 8) provides assessment factors for extrapolation of mammalian and bird toxicity data that range from 30 to 3,000, depending on the type of test. If several NOEC oral for bird or mammal species are available, the lowest of the resulting QS_{spb} is used as the standard. As toxicity data for wildlife birds or mammals are generally not available, extrapolation from laboratory test species is often necessary.

4.5.8 It is feasible, for example for planning or design purposes, to transform quality standards in prey-tissue (QS_{spb}) to corresponding concentrations in water, which can be regarded as a surrogate standard ($EQS_{sp\ water}$). This can be done if there are reliable data on partition coefficients (K_{ow}; octanol-water partition coefficient), bioaccumulation factors (BCF) or biomagnification factors (BMF) of the chemical. Lepper (2005) accounts for the longer food chains in the marine environment by incorporating biomagnification in both the prey of predators (BMF_1) and in the prey of top predators (BMF_2). For marine water:

$$EQS_{sp\ water}\ [\mu g/L] = \frac{QS_{spb}\ [\mu g/kg]}{BCF\ [L/kg] * BMF_1 * BMF_2} \qquad \text{(Equation A)}$$

4.5.9 There are few measured BMF data available, so Lepper (2005; Table 9) provided default BMF values, which vary according to log K_{ow} of the organic chemical (up to 10 for log K_{ow} of 5 – 8). Lepper expressed caution at using the water quality standard because of uncertainties associated with both default and experimental bioaccumulation data, and hence expert judgment is required.

4.5.10 The same approach applies for metals but one must take into account that inverse relationships have been observed for metals where the highest BCF values were found in waters with the lowest metal concentrations, and vice-versa. Hence, BCFs should be calculated from studies conducted with environmentally relevant metal concentrations in the test media or by using bioaccumulation factors (BAFs) observed in the field (Lepper, 2005).

4.5.11 The European Commission (2006a; Annex I, parts A and B) provides EQSs for 41 nominated chemicals in water. Generally, these EQSs are thought to provide a sufficient basis to ensure comprehensive protection and effective pollution control. There are at this stage, however, three chemicals for which the EQSs for water may not be sufficiently protective and EQS for biota have been developed as well. For these chemicals, the residue concentration in prey tissue to protect predators against secondary poisoning should not exceed the following levels (all in wet weight) of fish, molluscs, crustaceans and other biota:

- 10 µg/kg for hexachlorobenzene
- 55 µg/kg for hexachlorobutadiene
- 20 µg/kg for methyl-mercury

<u>EU human health guidelines for consumption of fisheries/mariculture products</u>

4.5.12 The EU framework also provides for derivation of human health related quality standards for consumption of fisheries/mariculture products. The technical guidance, which is provided by Lepper (2005) and summarised below, recommends a "simple but practicable approach", given that there is currently no standard approach or protocol. By convention, the amount of chemical consumed in fishery/mariculture products should not exceed 10% of the relevant threshold level for humans (e.g. the acceptable/ tolerable daily intake [ADI / TDI] or NOAEL for oral intake).

4.5.13 This human health EQS, expressed as µg/kg fishery product, is calculated using the standard human body weight (bw) of 70 kg, and standard rate of consumption of fishery products of 115 g/day:

$$EQS_{hh\ food} = \frac{0.1 * \text{threshold level } [\mu g/kg\ bw] * 70\ kg\ (\text{human bw})}{0.115\ kg\ \text{seafood consumption}} \quad \text{(Equation B)}$$

4.5.14 This $EQS_{hh.food}$ can be transformed to the corresponding concentration in water ($EQS_{hh.food.\ water}$) by applying the same approach for transforming QS_{spb} above:

$$EQS_{hh.food.\ water}\ [\mu g/L] = \frac{QS_{hh.food}\ [\mu g/kg]}{BCF\ [L/kg] * BMF} \quad \text{(Equation C)}$$

4.5.15 For example, the European Commission (2001; amended 2002 and 2005) has set maximum levels of some metals in seafood for human consumption. These are:

- Lead: between 200 – 1,500 µg/kg, depending on the species
- Cadmium: 50 – 500 µg/kg
- Mercury: 500 – 1000 µg/kg

These human consumption figures do not directly relate to concentrations in water, due to human risk calculations that consider body weight and individual consumption of seafood. It is at least theoretically possible to convert them to water concentrations using Equation C in Section 4.5.14 above.

4.5.16 These approaches are the same for metals as for organic chemicals. The approach does not specifically consider possible high risk groups (which may be a relevant consideration in Hong Kong where seafood consumption per capita is amongst the highest in the world), although limiting the acceptable uptake of a substance to 10% of its threshold value gives an additional margin of safety.

Canada

4.5.17 The primary route of exposure for terrestrial mammals and birds that prey on aquatic life is through consumption of contaminated aquatic organisms such as fish, invertebrates, and aquatic plants. Canada (CCME, 1998b; 1999b) has developed tissue residue guidelines (TRGs) for protection of such wildlife, particularly mammals and birds. These are for highly persistent, bioaccumulative compounds and have been developed for DDT methyl mercury, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) and toxaphene. Such compounds tend to accumulate to a greater extent in organisms higher up the food chain and hence water quality guidelines may not be applicable.

4.5.18 These TRGs refer to the "*maximum concentration of a chemical substance in the tissue of aquatic biota that is not expected to result in adverse effects in wildlife*" (CCME, 1999b). TRGs can apply to any aquatic species consumed by wildlife, such as fish, shellfish, other invertebrates, or aquatic plants. To protect all wildlife, the guidelines should be applied to the aquatic species at the highest end of the trophic level. However, CCME (1999b) encourages the use of species-specific or site-specific objectives wherever possible. TRGs in Canada are used, for example, in contaminated sites remediation to help interpret biological monitoring data, and can be useful screening tools to assess the potential risk of exposure through consumption of contaminated prey items (CCME, 1999b).

4.5.19 The general method for TRG derivation (CCME, 1998b) is based on Newell et al. (1987), with significant modifications. TRGs are derived from evaluating physical properties of specific chemicals, such as fate, persistence, and their environmental concentrations, as well as toxicity studies that examine ecologically important adverse effects on the wildlife (e.g., reduced reproductive capabilities) from consumption of a contaminated diet. There are pre-set minimum data requirements, but interim TRGs may be derived. To calculate TRGs, a lowest effect threshold is calculated for each mammal and bird species. Reference concentration (RC) values (contaminant levels in prey items that are considered to be protective of predators) are then calculated from body size and food intake data for typical Canadian wildlife species. The lowest RC is recommended as the TRG.

US

4.5.20 The USEPA (1995) derived fish tissue residue guidelines (TRGs) to protect predatory wildlife from bioaccumulating chemicals by first calculating dietary threshold body burdens then back-calculating to fish tissue levels using food and chemical assimilation efficiencies. They proceeded to derive ambient water-based criteria by dividing the TRG value for the chemical by its bioaccumulation factor (BAF) or bioconcentration factor (BCF), recognising that BAFs and BCFs vary among different species. The USEPA (1995) provides a method for deriving an average BAF for each trophic level.

4.5.21 The more recent revisions (USEPA, 2000a) incorporate a better consideration of non-water sources of chemical exposure, including the preference for use of a bioaccumulation factor (BAF) over a bioconcentration factor (BCF); the BAF better reflects contaminant uptake from all sources (e.g., ingestion, sediment) by fish and shellfish, rather than just from the water column as for BCF. USEPA (2000a) provides detailed procedures and guidelines for estimating BAF values (based on field-measured data from local or regional fish), and equations and background support for calculating exposures and criteria.

4.5.22 USEPA is continuing to evaluate the feasibility of developing and implementing national criteria for highly bioaccumulative chemicals that are expressed as concentrations in tissues of aquatic organisms (tissue residue criteria). Again, a BAF or bioaccumulation model would be useful to relate chemical concentrations and loads in water and sediment to concentrations in tissues of fish and shellfish.

US human health methodology

4.5.23 The USEPA criteria for the protection of human health are designed to minimise the risk of adverse effects occurring to humans from lifetime exposure to chemicals through two exposure routes; both the ingestion of drinking water and consumption of fish obtained from surface waters. The former is not relevant to marine waters and, although it is assumed that "surface waters" refers mainly to freshwater, the criteria based on fish consumption should be broadly transferable to seafood generally.

4.5.24 The calculation of criteria to protect human consumption of fish involves a different procedure to that of Canada; it involves calculation of a threshold contaminant body burden in wildlife, then back-calculation to an equivalent concentration in fish or water using a complex combination of food and chemical assimilation efficiencies and bioconcentration/ bioaccumulation factors (CCME, 1999b).

4.5.25 USEPA (2000a) has developed similar methodology for deriving water-based criteria (Section 304(a) of the Clean Waters Act) to protect human health when consuming seafood. The initial focus was to develop criteria for chemicals that bioaccumulate, such as mercury, arsenic, PCBs, and dioxin. As at 2006, the fish consumption values for arsenic, PCBs, and dioxin were still based on the water column exposure. The optional methodology is intended to guide States and Tribes to derive their own site-specific ambient criteria and standards but will be also used to calculate national water quality criteria and as default factors to evaluate State standards.

4.5.26 The revised guidelines build on the methodology of the original guidelines (USEPA, 1980) for the protection of human health, which addressed three types of endpoints: cancer, non-cancer, and taste and odour (organoleptic) effects, producing guidelines for 64 pollutants or pollutant classes. USEPA (2000a) adopted a default fish consumption value for the general adult population of 17.5 g of fish/d, and for subsistence fishers, 142.4 g/d.

4.5.27 The criteria derived from non-cancer data were based on the Acceptable Daily Intake (ADI) (otherwise known as the reference dose [RfD]). ADI values were generally derived using a no-observed-adverse-effect level (NOAEL) from animal studies, although human data were used whenever available. The ADI was calculated by dividing the NOAEL by an uncertainty factor of 10, 100, or 1,000 (depending on the quality of the data) to account for uncertainties in extrapolating limited toxicological data to humans.

Microbiological WQOs for mariculture

4.5.28 Shellfish are able to accumulate viruses or pathogens in their gastrointestinal tracts, digestive glands and other tissues. The rate of accumulation is dependent on the microbiological species and the shellfish species. Most waterborne pathogens originate in human and animal faeces, and include a wide variety of viruses, bacteria, and protozoa.

The transmission of viral disease is a key health concern associated with consumption of shellfish. Pathogens or viruses that infect humans following consumption of aquatic food are mostly of human origin, having entered aquatic ecosystems via sewage effluent discharges. These enteric viruses or pathogens are able to remain viable in the aquatic environment for certain period of time. Because of the difficulty and expense associated with the direct detection of pathogens, bacterial indicator organisms (e.g. *E. coli*, faecal coliforms) are widely used as indicator organisms to signal the extent of faecal pollution and possible presence of pathogenic organisms.

4.5.29 The microbiological WQOs for protecting mariculture are generally developed based on the Quantitative Risk Assessment Approach (Ministry for the Environment, 2003). In brief, the process would start with the definition of acceptable health risk by consuming fish and/or shellfish which are contaminated with a certain degree of faecal indicator bacterial species. Subsequently, the threshold ambient concentration of the indicator bacteria organisms in seawater can be estimated through empirical relationships which consider information such as the accumulation and depuration rates of bacteria, natural range of bacteria concentrations and pathogen concentrations in the fish/shellfish as well as safety factors. Some of the Mainland and overseas microbiological guidelines/standards for mariculture are given in Appendices A2 to A7.

Complementary measures to enhance protection of human consumers of seafood

4.5.30 The sole relying of water quality criteria for protection of human consumers of mariculture products have the following limitations :

- Difficulty in ascertaining the level of bioaccumulation and bioavailability of toxicants in cultured species, and the mechanisms of the chronic effects of the toxicants and carcinogens.
- Great uncertainty and limitation of extrapolating laboratory toxicity data to aquaculture environment under a wide range of environmental conditions.
- Tolerance to individual toxicants is highly species specific and variable among different aquaculture species, and usually only a few representative species can be selected for assessment.
- In addition to the culturing water, the harvested mariculture products are generally subject to various sources of contamination such as the sources of species fries, feeding materials, etc.

4.5.31 Given the uncertainty and limitations of adopting solely water quality standards for human health protection, a two-tier approach to enhance protection of human health associated with seafood consumption, through direct control on the relevant food safety standards that specify indicator levels in product flesh, and monitoring of the quality of culturing waters, is commonly adopted by jurisdictions such as Australia, New Zealand, the US, and the EU. In particular, this approach applies to the control of shellfish[5] products which are of greater health risk concern because: (i) sshellfishes are filter feeders which may

[5] Shellfish is a fishery term of aquatic invertebrate used as food, including various species of molluscs (clams, mussels, oysters, winkles, and scallops) and crustaceans (shrimp, prawn, lobster, crayfish, and crabs).

accumulate pathogens, toxic organics and metals from water; and (ii) it is popular for some of the shellfish products (e.g. oysters) used for direct raw consumption.

4.5.32 In addition to the two-tier approach of applying water quality and food safety standards mentioned above, some jurisdictions further implement complementary measures to enhance the safety of shellfish products, and reliance is generally on preventative and management approaches. These include control of the siting and classifications of shellfish growing waters according to sanitary surveys and bacteriological monitoring, requiring further treatment (e.g. depuration[6] or relaying[7]) of shellfishes harvested from certain classes of culturing waters, shellfish quality assurance programmes which cover control of the harvesting, processing, marketing or export of shellfish products.

4.6 Summary of the Mainland and overseas practices for WQOs

4.6.1 The amount and type of information available varied from jurisdiction to jurisdiction and, even when comprehensive information was available, it was still difficult to make simple and direct comparison on the basic approaches used, legislative and policy framework, level of protection, derivation methods, periodic review, and compliance monitoring and reporting. Table 4.1 summarizes these aspects for each jurisdiction studied. It is advisable that this table only be used in conjunction with the text of this review and the original source documents as appropriate.

[6] Depuration means the process of reducing the pathogenic organisms that may be present in shellstock by using a controlled aquatic environment as the treatment process.

[7] Relay means to transfer shellstock from a growing area classified as restricted or conditionally restricted to a growing area classified as approved or conditionally approved for the purpose of reducing pathogens as measured by the coliform indicator group or poisonous or deleterious substances that may be present in the shellstock by using the ambient environment as the treatment process.

Table 4.2 Summary of approaches, legislative framework and policies, methods of derivation of WQOs, practices of review and compliance for marine waters amongst the Mainland and overseas jurisdictions.

	Approach	Legislative framework	Protection[1] and derivation	Periodic review	Monitoring & reporting
PR China	Uses given values.	Apparently a mix of mandatory and non-mandatory. Implemented by Provinces, Autonomous Regions, Municipalities and Fisheries Authorities.	Ecosystems, aquaculture (production aspects) and human consumers *No information on derivation*	5 year plan	National and local; annual statistics reported on MEP website.
Australia	Uses mix of given values, site specific/ reference site data, and biological assessment. Flexible and risk based.	Not mandatory. Resource for and implemented by States & Territories. Basis for policy.	Ecosystems (various levels) *Toxicity data (statistical distribution-SSD), reference site data* Recreation (whole body/primary contact and aesthetics) *Primarily WHO* Aquaculture (production aspects) *Expert review* Human consumers *Food standards (tissue concentrations) are largely used.*	Informal ~ 10 years	Site-specific guidance given; risk based approach; implemented by States.
EU	Uses mix of given values[2], site specific/ reference site data, and biological assessment. Flexible and risk based.	Mandatory. Certain water quality classifications must be achieved by specified dates. Implemented by Member States.	Ecosystems (various levels) *Toxicity data (AF/SF3+ statistical distribution - SSD), reference site data* Recreation (primarily whole body/primary contact) *Expert review* Human consumers *Largely provided by ecosystem protection approach*	Directives in 2019/2020; some aspects every 4 – 6 years	Monitoring by Member States; annual summary.

	Approach	Legislative framework	Protection[1] and derivation	Periodic review	Monitoring & reporting
Canada	Uses mix of given values, site specific/ reference site data, and biological assessment. Flexible.	Not mandatory. Resource for and implemented by Provinces & Territories. Basis for policy.	Ecosystems *Toxicity data (AF/SF3), reference site data, and fate and persistence* Recreation *Expert review(and implied future move to WHO)*	~ 3 – 4 years; On-going updates	Site-specific guidance given; Provinces and Territories apply.
USA	Uses mix of given values[2], site specific/ reference site data, and biological assessment. Flexible.	Not mandatory. Resource for and largely implemented by States and Tribes. Basis for policy and enforcement.	Ecosystems *Toxicity data (triangular distribution) and reference site data* *Recreation (primarily whole body/primary contact)* *Expert review* Aquaculture *Provided by ecosystem protection above* Human consumers *See Section 4.2.8*	Rolling review; US EPA reviews State WQSs	States implement and report to USEPA.
WHO	Only recreation. Uses mix of given values and site specific information. Flexible and risk based.	Not mandatory. Resource for and implemented by any interested jurisdictions.	Recreation (primarily whole body/primary contact) *Expert review*	Review as new data available	Up to local jurisdiction. Regular reporting to public important. Suggestion that there be 100 samples over 5 year rolling period.

1. Approximates underlying "protection intended to offer" in the context of this table, it focuses on beneficial uses to be protected. Individual jurisdictions may use different terminology and compartmentalization.
2. Addressing both short duration events and long term condition.
3. Application factors/safety factors.

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6 Appendices

A1 **List of water quality parameters and indicators to be investigated**

The Mainland and Overseas WQOs

A2 **People's Republic of China**

A3 **Australia**

A4 **European Union**

A5 **Canada and USA**

A6 **World Health Organization**

A1 List of water quality parameters and indicators to be investigated

Forty-eight parameters or indicators listed below would be investigated in this review. The following information help understand the Mainland and overseas WQO values given in Tables A2 to A7 in the Appendices.

I. Nutrients-related

1. Narrative nutrient WQOs are not included in the tables as they are of little help in setting numerical standards for Hong Kong.
2. Inorganic N (µg/L) refers to the total ammonia (NH_3), nitrate and nitrite (NO_x) compounds; it is often expressed as a range in accordance with the types of waters found within a country/region.
3. Total nitrogen (µg/L) includes all inorganic and organic N compounds.
4. Total phosphorus (µg/L) also includes all inorganic and organic P compounds.
5. Chlorophyll-*a* (µg/L) – guideline values found only in Singapore and Australia.
6. Silica (µg/L) – guideline values are found only in Malaysia.
7. Turbidity is measured in Nephelometric Turbidity units (NTU) unless indicated otherwise.
8. Dissolved oxygen (DO) is expressed either as a percentage of the saturation level or in mg/L, as indicated in each table.

II. Physical and Chemical

9. Aesthetics (narrative).
10. Dangerous substances (narrative).
11. Settleable material (narrative).
12. Suspended solids (mg/L) indicate the maximum amounts allowed.
13. Dissolved oxygen (DO) is expressed either as a percentage of the saturation level or in mg/L, as indicated in each table.
14. Turbidity is measured in Nephelometric Turbidity units (NTU) unless indicated otherwise.
15. Colour is expressed as mg/LP of Pt-Co meter, unless indicated otherwise.
16. Light penetration is indicated by the depth, in metres, of visible Secchi disc.
17. pH units are expressed as a range.
18. Salinity is usually indicated as a maximum percentage of the normal range in the waters concerned, unless indicated otherwise.
19. Temperature (oC) is most commonly expressed as a range of variation (±) with respect to the average seasonal temperature, unless indicated otherwise.
20. Arsenic (µg/L) is most commonly referred to as the total forms, but Australia and Florida have provisions for As III and As V as well, and guidelines for these are indicated separately in the tables.
21. Cadmium (µg/L).
22. Chromium (µg/L) can be expressed as the total forms, as Cr III or Cr VI, and guidelines for these forms are indicated separately in the tables.
23. Copper (µg/L).
24. Lead (µg/L).
25. Mercury (µg/L) is most commonly referred to as the total inorganic and organic forms, but because the organic mercury (i.e. methyl-mercury) is of more concern there are two separate entries in the tables.
26. Nickel (µg/L).
27. Silver (µg/L).

28. Zinc (µg/L).
29. Phenol (µg/L) is considered not a chemical but a group of chemicals, and therefore the guidelines usually specify values for particular phenolic compounds, as indicated in the footnotes of the tables.
30. Polycyclic Aromatic Hydrocarbons (PAHs in µg/L) can be considered as a total or individually for specified compounds, and this is indicated by the separate entries in the tables.
31. Tributyltin (µg/L) is referred by most countries as TBT, but in Australia there is a guideline for Sn as well. The TBT figure is usually expressed as µg Sn/L.
32. Polychlorinated biphenyls (PCBs in µg/L) indicate the total PCBs.
33. DDT (µg/L) usually refers to 1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane and its degradation forms combined (i.e. DDE and DDD).
34. Dioxins (µg/L).
35. Hexachlorobenzene (HCB in µg/L).
36. Ammonia (µg/L) is indicated separately as total N, unionised as N or unionised as NH3.
37. Cyanide (µg/L).
38. Sulphide (µg/L).
39. Surfactants (µg/L).
40. Oil and grease (µg/L).
41. Total petroleum hydrocarbons (µg/L) – numerical guidelines only in China and the Netherlands.
42. Total residual chlorine (µg/L).
43. Chlorination by-products (µg/L) – only reported by Canada as ‘insufficient data’.

III. Microbiological

Microbiological standards are expressed as the geometric mean of the number of counts in five 100 mL water samples (cfu/100 mL) unless indicated otherwise in the respective tables.

44. *Escherichia coli*: some countries (most Asian countries and the Netherlands) do not have specific guidelines for *E. coli* but instead they have for total coliforms, in which case this has been indicated in the Tables of the Appendices.
45. Enterococci.
46. Faecal streptococci.
47. *Clostridium perfringens*.
48. Faecal coliforms.

A2 People's Republic of China

	Parameters	Units	China		
			Ecosystem	Recreational	Aquaculture
1	Nutrients	narrative			
2	Inorganic N	µg/L	200 – 500	150 – 1,000[a]	
3	Total Nitrogen	µg/L			
4	Total Phosphorus	µg/L	15 – 45 [b]	20 – 50	1 [c]
5	Chlorophyll-*a*	µg/L			
6	Aesthetic	narrative			
7	Dangerous subst.	narrative			
8	Settleable material	narrative	nil [d]	nil [d]	nil [d]
9	Suspended solids	mg/L	10 – 150 [e]		10 [e]
10	Dissolved oxygen	mg/L	3 – 6	3 – 5	3 – 5
11	Turbidity	NTU			
12	Colour	mg/LPtCo	nil	< 25	nil
13	Light penetration	Secchi (m)		0.5 – 1.2	
14	pH		6.8 – 8.8	6.5 – 8.5	7 – 8.5
15	Salinity				
16	Temperature	^oC	< 1 – 4 [f]	< 2 – 4 [f]	
17	Silica	µg/L			
18	Arsenic (total)	µg/L	20 – 50		50
18a	As III	µg/L			
18b	As V	µg/L			
19	Cadmium	µg/L	1 – 10		5
20	Chromium (total)	µg/L	50 – 500		100
20a	Cr III	µg/L			
20b	Cr VI	µg/L	5 – 50		
21	Copper	µg/L	5 – 50	10 – 100	10
22	Lead	µg/L	1 – 50		50
23	Mercury (total)	µg/L	0.05 – 0.5		0.5
23a	Mercury organic	µg/L			
24	Nickel	µg/L	5 – 50	50 – 100	50
25	Silver	µg/L			
26	Zinc	µg/L	20 – 500	100 – 1000	100
27	Phenol	µg/L	5 – 50	5 – 100	5
27a	Phenolics	µg/L			10 [g]
28	PAHs (total)	µg/L			
28a	PAHs as specified	µg/L	0.0025 [h]		
29	Tributyltin (TBT)	µg/L			
29a	TBT as Sn	µg/L			
30	PCBs	µg/L			
31	DDT	µg/L	0.05 – 0.1		1
32	Dioxins	µg/L			
33	Hexachlorobenzene (HCB)	µg/L			
34	Ammonia – total as N	µg/L		500 [i]	
34a	Ammonia – unionised as NH_3	µg/L			50
34b	Ammonia – unionised as N	µg/L	20	20 – 200	20
35	Cyanide	µg/L	5 – 200		5

A2 People's Republic of China (continued)

	Parameters	Units	China		
			Ecosystem	Recreational	Mariculture
36	Sulphide (total)	µg/L	20 – 250		200
37	Surfactants	µg/L	10 – 30	200	
38	Oil & grease	µg/L			
39	Total Petroleum Hydrocarbons	µg/L	50 – 500		50
40	Chlorine – total residual	µg/L			
41	Chlorination by-products	µg/L			
42	*Escherichia coli*	cfu/100 mL	1,000	1,000	70, (50 – 500 [j])
43	Enterococci	cfu/100 mL			
44	Faecal streptococci	cfu/100 mL			
45	*Clostridium perfringens*	cfu/100 mL			
46	Faecal coliforms	cfu/100 mL	200	200	14

a: NO_2 only
b: reactive phosphorous
c: yellow phosphorous
d: oil, foam or other floating substance
e: above level in natural ambient
f: range of variation above monthly average of last 10 years
g: volatile phenols
h: benzo[a]pyrene
i: for temperatures above 20ºC and pH>8
j: total coliforms

A3 Australia

	Parameters	Units	Ecosystem						Recreation	Aquaculture	Consumption
			99% species[a]	95% species[a]	90% species[a]	80% species[a]	Inshore[j]	Offshore[j]			
1	Nutrients	narrative									
2	Inorganic N	µg/L									
3	Total Nitrogen	µg/L					100	100			
4	Total Phosphorus	µg/L					15	10			
5	Chlorophyll-*a*	µg/L					0.7 -1.4[k]	0.5 – 0.9[k]			
6	Aesthetic	narrative							e		
7	Dangerous substances	narrative							f		
8	Settleable material	narrative							e		
9	Suspended solids	mg/L							e	10	
10	Dissolved oxygen (DO)	% saturation					>90%	>90%	>80%	>5[p]	
11	Turbidity	NTU					1 - 20[l]		e		
12	Colour	mg/L Pt-Co							e	30 – 40	
13	Light penetration								e		
14	pH						8.0 – 8.4	8.2 – 8.2	6.5 - 8.5	6 – 9	
15	Salinity									33,000 – 37,000[r]	
16	Temperature	°C							16 - 34	± 2[h]	
17	Silica	µg/L									
18	Arsenic (total)	µg/L								30	
18a	As III	µg/L	ID[b]	ID[b]	ID[b]	ID[b]					
18b	As V	µg/L	ID[b]	ID[b]	ID[b]	ID[b]					
19	Cadmium	µg/L	**0.7**	5.5	14	36				0.5 – 5	
20	Chromium (total)	µg/L								20	
20a	Cr III	µg/L	8	**27**	50	90					
20b	Cr VI	µg/L	0.14	**4.4**	20	85					
21	Copper	µg/L	0.3	**1.3**	3	8				5	1,000
22	Lead	µg/L	2.2	**4.4**	6.6	12				1 – 7	
23	Mercury (total)	µg/L	**0.1**[i]	0.4	0.7	1.4				1	
23a	Mercury - organic	µg/L									
24	Nickel	µg/L	**7**	70	200	560				100	
25	Silver	µg/L	0.8	**1.4**	1.8	2.6				3	
26	Zinc	µg/L	7	**15**	23	43				5	5000
27	Phenol	µg/L	270	**400**	520	720					1,000 - 10,000
27a	Phenolics	µg/L	11[m]	22[m]	33[m]	55[m]					various
28	PAHs (total)	µg/L									
28a	PAHs as specified	µg/L	50[n]	70[n]	90[n]	120[n]					1000[n] q
29	Tributyltin (TBT)	µg/L								0.01	
29a	TBT as Sn	µg/L	0.0004	**0.006**	0.02	0.05					
30	PCBs	µg/L	ID[b]	ID[b]	ID[b]	ID[b]				2	
31	DDT	µg/L	ID[b]	ID[b]	ID[b]	ID[b]					
32	Dioxins	µg/L	ID[b]	ID[b]	ID[b]	ID[b]					
33	Hexachloro-benzene (HCB)	µg/L	ID[b]	ID[b]	ID[b]	ID[b]					
34	Ammonia - total as N	µg/L	500[c]	**910**[c]	1200 [c]	1700 [c]				1,000	
34a	Ammonia - unionised as NH_3	µg/L								100	
34b	Ammonia - unionised as N	µg/L									
35	Cyanide	µg/L	2[d]	**4**[d]	7 [d]	14 [d]				5[d]	
36	Sulphide (total)	µg/L	ID[b,d]	ID[b,d]	ID[b,d]	ID[b,d]				2[d]	

	Parameters	Units	Ecosystem						Recreation	Aquaculture	Consumption
			99% species[a]	**95% species[a]**	**90% species[a]**	**80% species[a]**	**Inshore[j]**	**Offshore[j]**			
37	Surfactants	μg/L	ID[b]	ID[b]	ID[b]	ID[b]			e		
38	Oil & grease	μg/L							e		
39	Total Petroleum Hydrocarbons	μg/L							e		
40	Chlorine - total residual	μg/L	ID[b]	ID[b]	ID[b]	ID[b]				3	
41	Chlorination by-products	μg/L									
42	*Escherichia coli*	cfu/ 100 mL									
43	Enterococci	cfu/ 100 mL							g		
44	Faecal streptococci	cfu/ 100 mL									
45	*Clostridium perfringens*	cfu/ 100 mL									
46	Faecal coliforms	cfu/ 100 mL									14[o]

Values in bold are the trigger values applying to typical slightly-moderately disturbed systems.

a: 95th percentile of monitoring data (or maximum if data set is small) is compared against the respective guideline values; values in bold recommended for slightly to moderately disturbed systems
b: insufficient data - low reliability figures only
c: at pH 8.0
d: un-ionised
e: aesthetically acceptable
f: levels that do not cause toxic effects or irritation. If have concerns do risk assessment. Actually relates to chemical hazards/substances generally, not just "dangerous substances".
g: risk based assessment framework developed around results of sanitary inspection and 95th percentile levels of enterococci
h: over 1 hour
i: inorganic mercury
j: default values for tropical Australia; inshore and offshore not defined; median of monitoring data is compared against guideline values
k: the lower values are typical of clear coral dominated waters while the higher values typical of turbid macrotidal systems
l: low values indicative of offshore coral dominated waters. Higher values for estuarine waters.
m: values for pentachlorophenol; ID[b] for other compounds
n: values for naphthalene; ID[b] for other compounds
o: median should be below this value in units of MPN/100mL with no more than 10% of samples exceeding 43 MPN/100mL
p: mg/L
q: acenaphthene 20
r: total dissolved solids (TDS)

A4 European Union

	Parameters	Units	EU		
			Ecosystem AA-EQS[a]	Ecosystem MAC-EQS[a]	Recreational
1	Nutrients	narrative	b		
2	Inorganic N	µg/L	b		
3	Total Nitrogen	µg/L	b		
4	Total Phosphorous	µg/L	b		
5	Chlorophyll-*a*	µg/L	b		
6	Aesthetic	narrative			
7	Dangerous substances	narrative			
8	Settleable material	narrative			
9	Suspended solids	mg/L	b		
10	Dissolved oxygen (DO)	% saturation	b		
11	Turbidity	NTU	b		
12	Colour	mg/L Pt scale			
13	Light penetration	Secchi (m)	b		
14	pH				
15	Salinity		b		
16	Temperature	°C	b		
17	Silica	µg/L			
18	Arsenic (total)	µg/L			
18a	As III	µg/L			
18b	As V	µg/L			
19	Cadmium	µg/L	0.2	0.45 – 1.5 [c]	
20	Chromium (total)	µg/L			
20a	Cr III	µg/L			
20b	Cr VI	µg/L			
21	Copper	µg/L			
22	Lead	µg/L	7.2		
23	Mercury (total)	µg/L	0.05 [d]	0.07 [d]	
23a	Mercury - organic	µg/L			
24	Nickel	µg/L	20		
25	Silver	µg/L			
26	Zinc	µg/L			
27	Phenol	µg/L			
27a	Phenolics	µg/L	0.01 – 0.4 [e]	1-2 [e]	
28	PAHs (total)	µg/L			
28a	PAHs as specified	µg/L	0.002 – 1.2 [f]	0.1 – 1[f]	
29	Tributyltin (TBT)	µg/L	0.0002	0.0015	
29a	TBT as Sn	µg/L			
30	PCBs	µg/L			
31	DDT	µg/L	0.01, 0.025 [g]		
32	Dioxins	µg/L			
33	Hexachlorobenzene (HCB)	µg/L	0.01	0.05	
34	Ammonia - total as N	µg/L			
34a	Ammonia - unionised as NH_3	µg/L			
34b	Ammonia - unionised as N	µg/L			
35	Cyanide	µg/L			

A4 European Union (continued)

	Parameters	Units	EU		
			Ecosystem AA-EQS[a]	Ecosystem MAC-EQS[a]	Recreational
36	Sulphide (total)	µg/L			
36a	Un-ionised H_2S	µg/L			
37	Surfactants	µg/L			
38	Oil & grease	µg/L			
39	Total Petroleum Hydrocarbons	µg/L			
40	Chlorine - total residual	µg/L			
41	Chlorination by-products	µg/L			
42	*Escherichia coli*	cfu/100 mL			h
43	Enterococci	cfu/100 mL			h
44	Faecal streptococci	cfu/100 mL			
45	*Clostridium perfringens*	cfu/100 mL			
46	Faecal coliforms	cfu/100 mL			

a: AA-EQS and MAC-EQS = annual average and maximum acceptable concentrations, respectively. EQSs for metals are dissolved metal concentrations. EQS for organic pollutants are total concentrations
b: member states to assess ecological status with respect to nutrient conditions, transparency, oxygenation conditions, salinity & thermal conditions based on findings at type-specific reference sites; reference sites may be different for artificial and heavily modified water bodies.
c: range for five different water classes
d: total Hg and its compounds
e: octylphenol, nonylphenol and pentachlorophenol
f: range for different PAHs.
g: p-p-DDT and total respectively
h: assessment and classification based on levels of enterococci and *E. coli* (as 90th & 95th percentiles), supplemented by development and regular review of the bathing water profile

A5 Canada and USA

	Parameters	Units	Canada		USA		
			Ecosystem	Recreational	Ecosystem CMC	Ecosystem CCC	Consumption
1	Nutrients	narrative	a				
2	Inorganic N [$NH_3 + NO_x$]	μg/L	16,000 [b]				10,000 [b]
3	Total Nitrogen	μg/L					
4	Total Phosphorous	μg/L				0.1	
5	Chlorophyll-*a*	μg/L					
6	Aesthetic	narrative		c			
7	Dangerous substances	narrative					
8	Settleable material	narrative	c	c			
9	Suspended solids	mg/L	a		a	a	a
10	Dissolved oxygen (DO)	mg/L	>8				
11	Turbidity	NTU	a	50	a	a	a
12	Colour	Pt-Co mg/L	g	d	a	a	a
13	Light penetration	Secchi (m)		1.2			
14	pH		7.0 – 8.7	6.5 – 8.5		6.5 – 8.5	5.0 – 9.0
15	Salinity		<10% [d]				250,000
16	Temperature	°C	± 1	≤30			
17	Silica	μg/L					
18	Arsenic (total)	μg/L	12.5 [e]		69	36	0.018
18a	As III	μg/L					
18b	As V	μg/L					
19	Cadmium	μg/L	0.12		40	8.8	
20	Chromium (total)	μg/L					
20a	Cr III	μg/L	56 [e]				
20b	Cr VI	μg/L	1.5		1,100	50	
21	Copper	μg/L			4.8	3.1	1,300
22	Lead	μg/L			210	8.1	
23	Mercury - inorganic	μg/L	0.016 [e]		1.8 [k]	0.94 [k]	
23a	Mercury - organic	μg/L	0.004 [f]				0.3 [q]
24	Nickel	μg/L			74	8.2	610
25	Silver	μg/L			1.9		
26	Zinc	μg/L			90	81	7,400
27	Phenol	μg/L					21,000
27a	Phenolics	μg/L	0.7 [m]		7.0 - 13 [s]	1.7 – 7.9 [s]	0.27 – 1,800 [v]
28	PAHs (total)	μg/L	ID				670 – 8,300 [w]
28a	PAHs as specified	μg/L	1.4 [e,n]				0.0038 [x]
29	Tributyltin (TBT)	μg/L	0.001 [e]		0.42	0.0074	
30	PCBs	μg/L				0.03 [p]	0.000064 [p]
31	DDT	μg/L			0.13	0.001	0.00022
32	Dioxins	μg/L					5×10^{-9} [y]
33	Hexachlorobenzene (HCB)	μg/L	ID				0.00028

A5 Canada and USA (continued)

	Parameters	Units	Canada		USA		
			Ecosystem	Recreational	Ecosystem CMC	Ecosystem CCC	Consumption
34	Ammonia - total as N	µg/L			s,t	s,t	
34a	Ammonia - unionised as NH_3	µg/L					
34b	Ammonia - unionised as N	µg/L					
35	Cyanide	µg/L			1	1	140
36	Sulphide – H_2S	µg/L				2	
37	Surfactants	µg/L					
38	Oil & grease	µg/L		nil [g]	a	a	a
39	Total Petroleum Hydrocarbons	µg/L					
40	Chlorine - total residual	µg/L	0.5 [r]		13	7.5	
41	Chlorination by-products	µg/L	ID				
42	*Escherichia coli*	cfu/100 mL		200			
43	Enterococci	cfu/100 mL		35			35 [z]
44	Faecal streptococci	cfu/100 mL					
45	*Clostridium perfringens*	cfu/100 mL					
46	Faecal coliforms	cfu/100 mL		200			

ID = insufficient data
a: narrative
b: NO_3^- only, equivalent to 3,600 µg N L^{-1}
c: aesthetically acceptable = absence of debris, scum or other matter
d: not significantly increased above natural background
e: interim guideline
f: freshwater guideline
g: not detectable by sight or smell
h: 24 h and mean for 30-d average, respectively
i: instantaneous and 30-d average, respectively
j: 30-d average and maximum limit, respectively
k: total mercury
l: proportion of total Hg
m: nonylphenol TEQ
n: naphthalene
o: benzo[a]pyrene
p: total PCBs congeners
q: µg/g wet weight in fish/shellfish
r: hypochlorous acid and monochloramine
s: pH dependent
t: range depending on temperature for 20 g/kg salinity
u: median and maximum for crustacean harvesting, respectively
v: pentachlorophenol, chlorophenols, dinitrophenols and nonylphenols
w: anthracene, pyrene, acenaphthene
x: benzo(a)pyrene, benzo(a)anthracene, benzo(a)fluoranthene, indeno(1,2,3-cd)pyrene
y: 2,3,7,8-TCDD
z: recreational guideline; maximum values should not exceed the range 104-500 cfu/100 mL depending on frequency of use

A6 World Health Organization (WHO)

	Parameters	Units	Recreational		Parameters	Units	Recreational
1	Nutrients	narrative		25	Silver	µg/L	
2	Inorganic N	µg/L		26	Zinc	µg/L	
3	Total Nitrogen	µg/L		27	Phenol	µg/L	
4	Total Phosphorous	µg/L		27a	Phenolics	µg/L	
5	Chlorophyll-*a*	µg/L		28	PAHs (total)	µg/L	
6	Aesthetic	narrative	a	28a	PAHs as specified	µg/L	
7	Dangerous substances	narrative	b	29	Tributyltin (TBT)	µg/L	
8	Settleable material	narrative	a	29a	TBT as Sn	µg/L	
9	Suspended solids	mg/L	a	30	PCBs	µg/L	
10	Dissolved oxygen (DO)	% saturation	a	31	DDT	µg/L	
11	Turbidity	NTU	a	32	Dioxins	µg/L	
12	Colour	Pt-Co units	a	33	Hexachlorobenzene (HCB)	µg/L	
13	Light penetration	Secchi (m)	a	34	Ammonia - total as N	µg/L	
14	pH			34a	Ammonia - unionised as NH_3	µg/L	
15	Salinity			34b	Ammonia - unionised as N	µg/L	
16	Temperature	^oC		35	Cyanide	µg/L	
17	Silica	µg/L		36	Sulphide (total)	µg/L	
18	Arsenic (total)			36a	Un-ionised H_2S	µg/L	
18a	As III	µg/L		37	Surfactants	µg/L	
18b	As V	µg/L		38	Oil & grease	µg/L	
19	Cadmium	µg/L		39	Total Petroleum Hydrocarbons	µg/L	
20	Chromium (total)	µg/L		40	Chlorine - total residual	µg/L	
20a	Cr III	µg/L		41	Chlorination by-products	µg/L	
20b	Cr VI	µg/L		42	*Escherichia coli*	cfu/100 mL	
21	Copper	µg/L		43	Enterococci	cfu/100 mL	c
22	Lead	µg/L		44	Faecal streptococci	cfu/100 mL	
23	Mercury - inorganic	µg/L		45	*Clostridium perfringens*	cfu/100 mL	
23a	Mercury - organic	µg/L		46	Faecal coliforms	cfu/100 mL	
24	Nickel	µg/L					

a: Strictly speaking no guidelines established but ideally water should be free from visible materials that will settle to form objectionable deposits, floating debris, oil, scum and other matter, substances producing objectionable colour, odour, taste or turbidity, and substances and conditions that produce undesirable aquatic life. Ideally water in swimming areas should also be clear enough to estimate depth and see subsurface hazards.
b: Strictly speaking no guidelines established but where there are potential concerns about chemical contaminants it is suggested that drinking water guidelines can be used as a starting point for deriving values that could used to make a screening level risk assessment. This relates to chemical hazards/substances generally, not just "dangerous substances".
c: Risk based assessment framework developed around results of sanitary inspection and 95^{th} percentile levels of enterococci.