Western Indian Ocean

Strategic Framework for Coastal & Marine Water Quality Management

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EXECUTIVE SUMMARY

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

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

In terms of coastal and marine water quality management (C&MWQM), it is expected that through improved capacity and the implementation of appropriate strategic frameworks ecosystem integrity can be improved leading to local socio-economic and environmental benefits, in addition to global environmental benefits. The development of a *Regional Strategic Framework for C&MWQM* would, therefore, provide a basis for adopting and integrating this into national coastal and marine water quality frameworks, acknowledging that countries are at different stages of development. Within this context the Contracting Parties to the Nairobi Convention urged the Secretariat to establish a Strategic Framework for C&MWQM for the region to fast-track implementation and which should build on- and refine previous initiatives on C&MWQM previously undertaken as part of the WIO-LaB Programme including:

- Guidelines for the Establishment of Environmental Quality Objectives and Targets in the Coastal Zone of the WIO Region
- Towards a Protocol for long-term monitoring of marine environmental quality in the Western Indian Ocean.

Two phases are envisaged for the development and implementation of C&MWQM, namely:

- Phase 1 - Development of a Strategic Framework for C&MWQM
- Phase 2 - Implementation of the Strategic Framework for C&MWQM at the national and sub-national levels.

The development of the Strategic Framework Strategic Framework for C&MWQM in the WIO region, together with a Situation Assessment on Marine Pollution and C&MWQM (UNEP et al. 2021a) and a revision of *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas in the WIO region* (UNEP et al. 2021b) constitute Phase 1 of this process.

In essence, the need for C&MWQM stems from a tension between the need to protect biodiversity (and associated socio-economic benefits) and the need for economic development in sectors which may contribute to sources of marine pollution. A Strategic Framework can provide direction in achieving effective C&MWQM, as conceptualised in Figure 1.

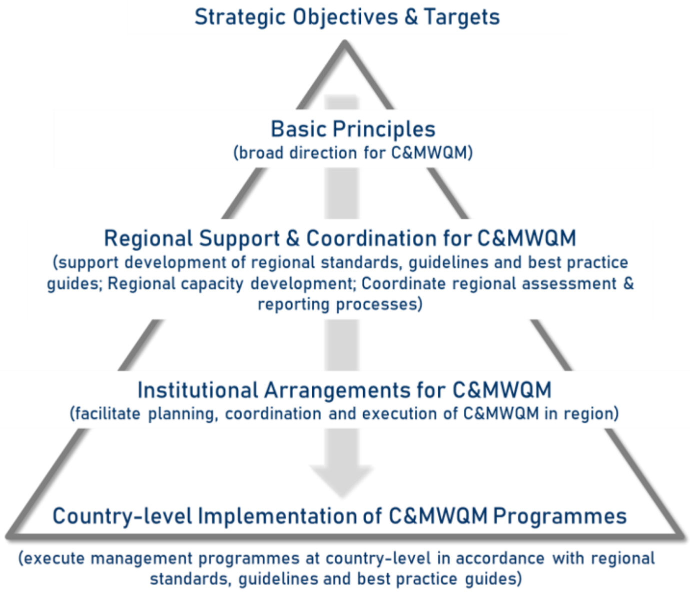

Figure 1 Conceptualisation of the Strategic framework for C&MWQM in WIO region

C&MWQM starts with establishment Strategic Objectives and Targets. The *Strategic Action Programme Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities* set the following Strategic Objective for water quality in the WIO region, to be achieved in an array of specific targets:

'Water quality in the WIO region meets international standards by year 2035'

Basic Principles provide broad direction within which to position implementation of C&MWQM. Five basic principles are recommended for the WIO region, namely:

- Principle 1: Pollution prevention, waste minimisation and precautionary approach
- Principle 2: Receiving water quality objectives approach
- Principle 3: Integrated, adaptive assessment approach
- Principle 4: Polluter pays principle
- Principle 5: Participatory approach.

Harmonisation of C&MWQM in the WIO region requires Regional Support and Coordination (e.g. through the Nairobi Convention Secretariat and partners), for example by coordinating the development of regional standards, guidelines and best practice guides, development of regional capacity, and regional reporting processes.

Reflecting on the Strategic Objectives and Targets of the WIOSAP (UNEP/Nairobi Convention Secretariat 2009) and the SAP WIO-LME (ACSLME et al. 2014), a number of regional standards, guidelines and best practice guides, as well as other support efforts relevant to C&MWQM have been identified, including:

- Regional standards for coastal and marine water quality
- Regional effluent discharge standards to facilitate harmonized approach across region
- Regional best practice framework models for municipal wastewater management
- Oversee adoption of Cleaner Production Technologies by industries at national-level
- Regional guidelines on oil spill contingency planning for inclusion in concession agreements
- Coordinate establishment of regional support structure for oil spill disaster management

- Establish regional capacity building programmes on oil spill contingency planning.

To date Regional-level achievements in terms of C&MWQM support include:

- Land Based Sources and Activities (LBSA) Protocol of the Convention (UNEP 2010)
- WIO Action Plan on Marine Litter (UN Environment 2018)
- African Marine Litter Monitoring Manual (African Marine Waste Network, Sustainable Seas Trust. - Barnardo and Ribbink 2020)
- WIO Marine Highway development and Coastal and Marine Contamination Prevention Project (2020)
- Regional oil spill preparedness in eastern Africa and WIO (UNEP et al. 2020a&b).

Regional State of the Coast Reporting (UNEP et al. 2015), as required by the Nairobi Convention, has also been undertaken, under the guidance of the Western Indian Ocean Marine Sciences Association (WIOMSA) in consultation with the Contracting Parties in terms of the political agendas. Ideally, in the case of future regional status reports, regional coordinators will be able to draw on national-level status reports produced as part of their C&MWQM implementation programmes. Also critical in a strategic framework is the establishment of appropriate Institutional Arrangements early on to facilitate and coordinate implementation across regional, national and hotspot scales (Figure 2).

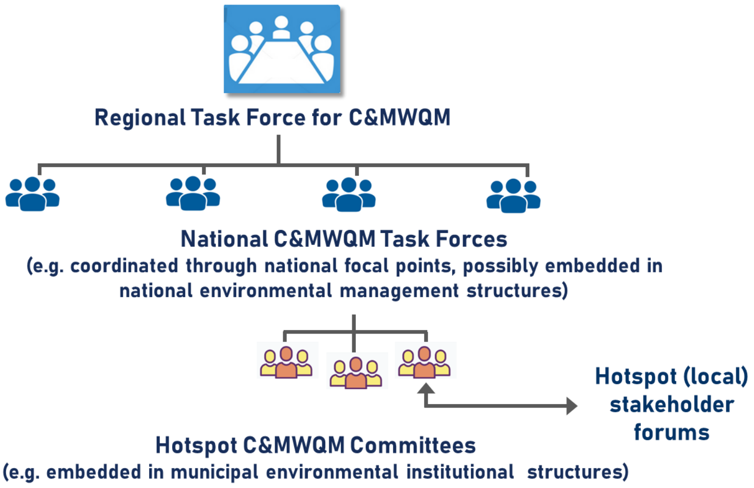

Figure 2 Proposed institutional arrangements to facilitate and coordinate implementation of C&MWQM in WIO region

At regional scale, the Regional Task Force (RTF) for Water, Sediment and Biota Quality has been established under the WIOSAP project. This provides an ideal platform for regional coordination in the future. However, oversight and coordination within countries will also require national structures (e.g. National Task Forces), preferable coordinated through national focal points to facilitate align with the RTF. National Task Forces (NTFs) need to be cross-sectoral, comprising not only of environmental authorities, but also other relevant authorities, such as urban development and tourism, agriculture, aquaculture and forestry, industry and mining, marine transportation and energy production. In turn, effective planning and implementation at the local (or hotspot) level necessitates local management. Dedicated local C&MWQM institutions are also ideally positioned to test the effectiveness and applicability of regional and national legislation and policies, and should be utilised by higher tiers of government as a mechanism incremental improvement policies, supporting the principle of adaptive management. In the spirit of *Principle 5: Participatory approach*, stakeholder collaboration is also essential. Therefore, stakeholder forums have proven to be great platforms through which to facilitate a participatory approach to decision-making and implementation.

The Implementation of C&MWQM Programmes primarily happens at country-level in marine pollution hotspots, ideally in accordance with regional policies, coordinated through the RTF, NTFs and Hotspot

C&MWQM committees, and in consultation with local stakeholder forums. Drawing on an existing model for Integrated Coastal Management (the broader domain within which C&MEQM is nested) an *ecosystem-based Implementation Framework for C&MWQM* are proposed for the region (Figure 3).

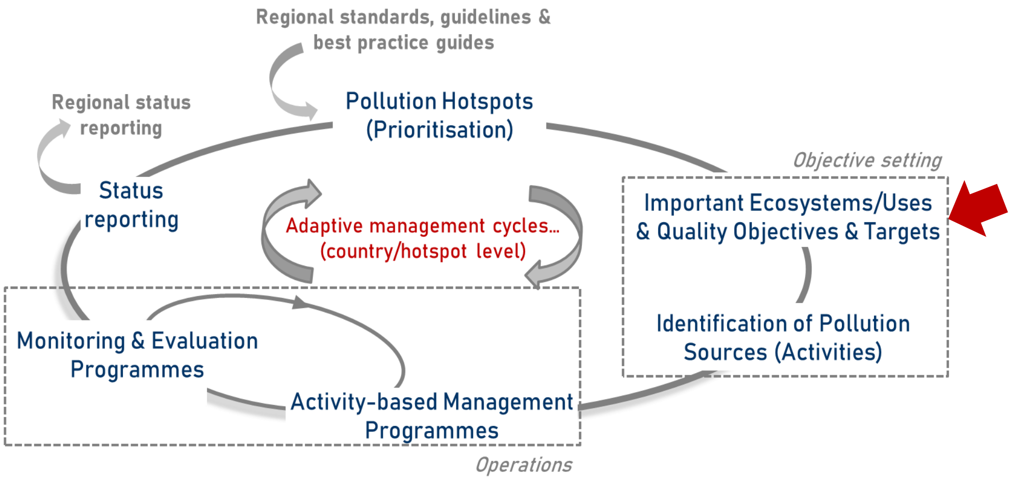

Figure 3 Ecosystem-based Implementation Framework for C&MWQM in WIO region, also showing context of Guidelines for setting sediment and water quality targets

To wisely apply human and financial resources, it is necessary to tackle C&MWQM in a phased approach. Here the identification of marine pollution hotspots or emerging hotspots provides a transparent mechanism to prioritise study areas most at risk or impacted by marine pollution. Marine pollution hotspots usually coincide with coastal urban centres (or cities) and coastal industrial nodes (e.g. UNEP et al. 2009a, UNEP et al. 2015). The identification and mapping of important ecosystems, and key socio-economic beneficial uses, as well as their environmental quality objectives and targets are key components in a C&MWQM programme. Internationally, beneficial uses, in terms of water and sediment quality, are typically divided into four broad categories, namely i) Protection of aquatic ecosystems; ii) Recreational use (including tourism); iii) Marine aquaculture (including the collection of seafood for human consumption); and iv) Industrial uses (e.g. intakes for desalination, cooling water intake and seafood processing). The *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas in the WIO region* can be used to derive water and sediment quality targets (QTs).The selected water and sediment quality constituents, as well as their relevance to the protection of aquatic ecosystems and other beneficial uses are indicated Table 1. A participatory process (*Principle 5: Participatory approach*) is important in the negotiation of these QTs as the livelihoods of local communities, as well as local economies may be affected. The aim is to negotiate and achieve a balanced outcome that is both environmentally and socio-economically sustainable through an integrated, consultative process (*Principle 3: Integrated assessment process*).

Another key component is the identification and characterisation of potential marine pollution sources (both land-based and sea-based) that may alter water and sediment quality. In setting limits for pollution sources, a hierarchy of decision-making, as advocated by *Principle 1: Pollution prevention, waste minimisation and precautionary approach*, should be applied.

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

TYPE OF CONTITUENT		PROTECTION OF AQUATIC ECOSYSTEM	RECREATION	MARINE AQUACULTURE	INDUSTRIAL USE
Water	Objectionable matter	●	●	Similar to Protection of Aquatic Ecosystems	Based on site-specific requirements of industries
	Physico-chemical properties	●	Refer to Drinking water guidelines		
	Nutrients	●			
	Toxicants	●			
	Microbiological indicators		●	●	
	Tainting substances			●	
Sediment	Toxicants	●		Similar to Protection of Aquatic Ecosystems	

Activity-based management programmes, involve effective operations of activities potentially contributing to marine pollution. These programmes often have a strong sectoral focus (i.e. activities are managed by different governing authorities through activity-specific statutory systems). However, even though sector-based, these programmes remain nested in an ecosystem-based approach subservient to the agreed environmental quality objective and targets for the study area (Figure 3). Importantly, the cost for managing and controlling such activities should follow the *Principle 4: Polluter pay principle*.

The design and implementation of environmental quality monitoring and evaluation programmes forms an integral and critical element Implementation Framework's operational phase (Figure 4). Important elements in such programmes include the definition of monitoring objectives (e.g. linked to the water and sediment quality targets for important aquatic ecosystems and other beneficial uses), as well as the selection of monitoring parameters (e.g. influenced by potential pollution sources). However, in C&MWQM monitoring and evaluation is a means to an end, providing data and information to inform activity-based management intervention, as is illustrated in Figure 3 by the feed-back loop to activity-based management programme (*Principle 3: Integrated, adaptive assessment process*). The data and information from these programmes also continuously renew understanding of the complexities of marine ecosystems and its uses, and so inform status assessments. In support of a transparent, participatory process (*Principle 5: Participatory approach*) findings from monitoring and evaluation programmes also need to be communicated and shared at regular intervals with the broader society.

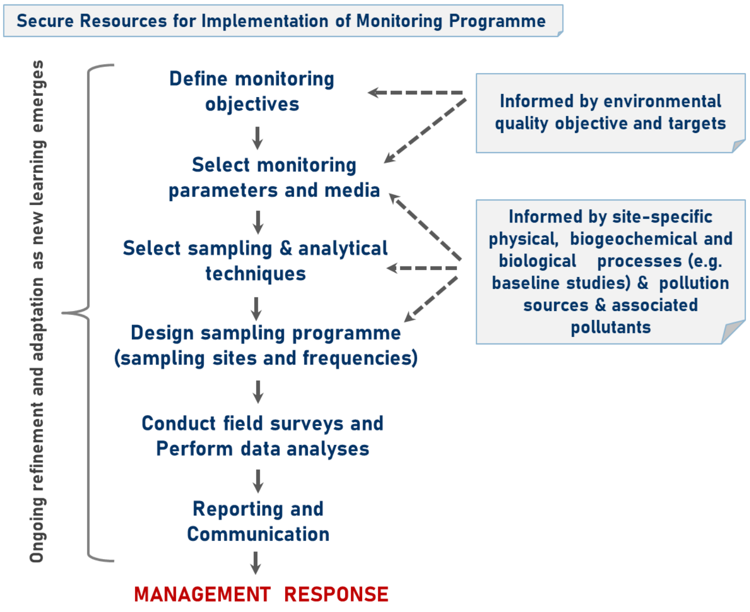

Figure 4: Key components of a monitoring and evaluation programme

Status reporting provides a mechanism for such feed-back giving a high-level reflection on progress, but also ensures transparency on issues of concern to be addressed in future (i.e. improving-by-learning, *Principle 3: Integrated, adaptive assessment process*). National status reports, in turn, can feed into overarching regional status reporting (e.g. WIO State-of-Coast Report). Although the Implementation Framework for C&MWQM largely is executed at the country-level (e.g. at selected hotspot), it requires overarching support and guidance from the regional level, thus acknowledging the importance of regional strategies.

Also important, is the acknowledgement of linkages between C&MWQM implementation and other initiatives within the WIO region. For example, while the Implementation Framework has unique elements specifically pertaining to the effective implementation of C&MWQM, elements within the framework are aligned with other, complimentary strategies and frameworks implemented in the WIO region (Figure 5). For example, the demarcation of important ecosystems/uses and location of activities contributing to marine pollution need to coordinate with outcomes from the marine spatial planning strategy, which in turn should align with biodiversity, conservation and fisheries strategies in terms of zoning. Further, outputs from monitoring and evaluation programmes can contribute to the regional ecosystem monitoring framework, in addition to informing C&MWQM actions and intervention. The implementation of C&MWQM, therefore, should acknowledge these linkages and operations should be coordinated wisely to prevent unnecessary duplication of effort.

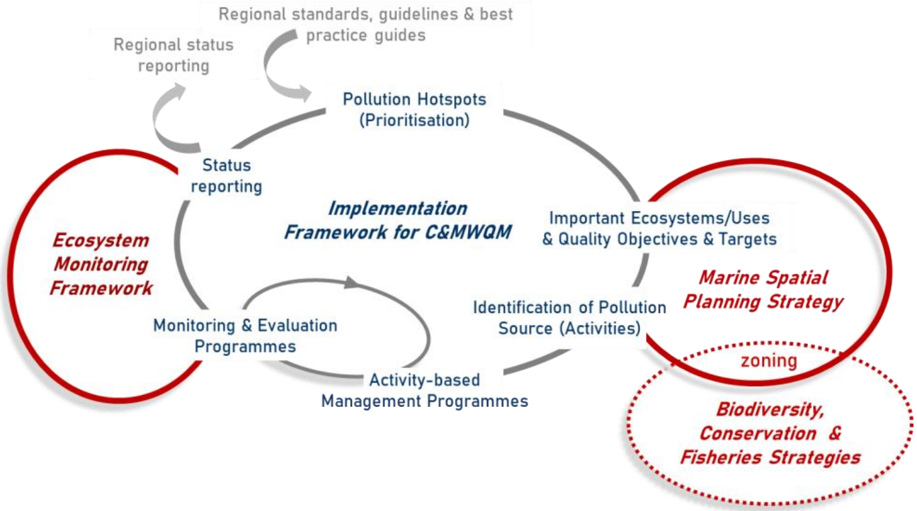

Figure 5 Alignment of elements in Implementation Framework for C&MWQM with other related strategies and frameworks within WIO region

Finally, towards initiating the effective operationalisation of C&MWQM in WIO region, the following policy recommendations are proposed for consideration by the Contracting Parties:

- Contracting Parties adopt the Strategic Framework for C&MWQM for the WIO region, including the *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas*.
- Contracting Parties formally establish a Regional Task Force (RTF) for C&MWQM (which is currently a project-level task force under the WIOSAP – RTF for Water, Sediment and Biota Quality).
- Contracting Parties establish national C&MWQM Task Forces to facilitate and coordinate C&MWQM at country-level, feeding into the RTF through national focal points.
- Contracting Parties adopt, as appropriate, the Strategic Framework for C&MWQM at country-level, including *the Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas.*
- Established national C&MWQM Task Forces to coordinate the identification of country-level hotspots, as well as the establishment of local C&MWQM committees to oversee the execution of 'hotspot' implementation programme.

- Established national C&MWQM Task Forces coordinate the compilation of country-level status reports that would feed into overarching regional status reports - coordinated by the RTF - to inform various regional processes (e.g. WIO State-of-Coast reporting, Ecosystem Monitoring Strategies).

The following technical recommendation is proposed for consideration by the Contracting Parties in support of effective operationalisation of the Strategic Framework:

- The Nairobi Secretariat work with partners to support capacity building programmes in support of the effective implementation of the Strategic Framework for C&MWQM, including the *Guidelines for the setting of Water and Sediment Quality Targets.*

Ultimately, the achievement of the Strategic Objectives set for coastal and marine water quality in the WIO region - *Water quality in the WIO region meets international standards by year 2035* – will rely on countries embracing this Strategic Framework for C&MWQM and adopting the proposed implementation into national policy and best practice, as appropriate. Also, this will require political commitment to assist in securing dedicated financial resources and the skilled personnel required in the execution of C&MWQM programmes.

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ACRONYMS

ASCLME	Agulhas Somalia Current Large Marine Ecosystem
ANZECC	Australia and New Zeeland Environment and Conservation Council
ACP	African, Caribbean and Pacific
BOD	Biological oxygen demand
C&MWQM	Coastal and Marine Water Quality Management
CSIR	Council for Scientific and Industrial Research (South Africa)
CTD	Conductivity-Temperature-Depth
DEA	Department of Environmental Affairs (South Africa)
DPSIR	Driver-pressure-state-impact-response
DWAF	Department of Water Affairs and Forestry (South Africa)
CEC	Council of European Community
EQO	Environmental Quality Objective
EQT	Environmental Quality Target
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GEF	Global Environmental Facility
IMO	International Maritime Organisation
MARPOL	The International Convention for the Prevention of Pollution from Ships
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration (USA)
OHMSCP	Oil and Hazardous Materials Spill Contingency Plans
PEMSA	Partnerships in Environmental Management for the Seas of East Asia
P	Phosphorus
QA	Quality assurance
QT	Quality Target
RTF	Regional Task Force
RWQO	Receiving Water Quality Objective
SoE	State of Environment
SPREP	Secretariat of the Pacific Regional Environment Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US-EPA	United States Environmental Protection Agency
WHO	World Health Organisation
WRc	Water Research Centre (UK)
WIO	West Indian Ocean
WIO LME SAPPHIRE	Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms
WIO-Lab	Addressing Land-based Activities in the West Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIOSAP	Western Indian Ocean Strategic Action Programme

1. INTRODUCTION

1.1 Purpose

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

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- Phase 1 - Development of a Strategic Framework for C&MWQM
- Phase 2 - Implementation of the Strategic Framework for C&MWQM at the national and sub-national levels.

This development of a Strategic Framework for C&MWQM in the WIO region forms part of Phase I pertaining to the status of coastal and marine water quality (or marine pollution) in the region, together with:

- A Situation Assessment on Marine Pollution and Marine Water Quality Management in the WIO region (UNEP et al. 2021a); and
- Revised *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas in the WIO region* (UNEP et al. 2021b).

1.2 Conceptualizing Strategic Framework for C&MWQM

In order to communicate a Strategic Framework for C&MWQM for the WIO region it is useful to conceptualise the various key elements envisaged within such a framework (Figure 1.1). C&MWQM starts with the establishment of Strategic Objectives and Targets for coastal and marine water quality in the region. Basic Principles provide broad direction C&MWQM. Harmonisation of C&MWQM in the WIO region requires Regional Support and Coordination (e.g. through the Nairobi Convention Secretariat and partners), for example coordinating the development of regional standards, guidelines and best practice guides, as well as regional reporting processes.

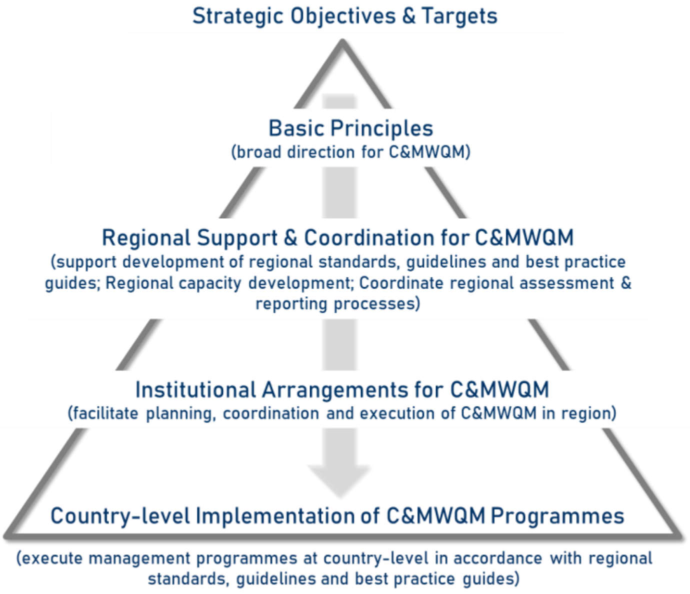


Figure 1.1 Conceptualisation of the Strategic Framework for C&MWQM in the WIO region

Also key in a strategic framework is the recognition for the establishment of appropriate Institutional Arrangements to facilitate ongoing implementation, alignment and coordination of effective C&MWQM in the WIO region. Finally, the Implementation on C&MWQM Programmes primarily happens at national-level, in accordance with adopted regional standards, guidelines and best practice guidance, as appropriate.

1.3 Structure of this Document

This document expands on the Strategic Framework for C&MWQM in the WIO region, addressing each of the key components as conceptualised in Figure 1.1. Specifically, Chapter 2 summarised the Strategic Objectives and Targets as defined in related programmes (e.g. WIOSAP and WIO LME SAPPHIRE) that pertain to C&MWQM. Thereafter, the Basic Principles are unpacked (Chapter 3), and institutional arrangements to facilitate and coordinate C&MWQM in the WIO region are proposed (Chapter 4). Chapter 5 touches on some of the key supporting and coordinating roles and responsibilities associated with C&MWQM at the regional level (e.g. Nairobi Convention Secretariat and partners). Guidance for the roll out of National-level implementation of C&MWQM programmes is provided in Chapter 6, presenting an Implementation Framework for C&MWQM as a practical tool for execution. Chapter 7 specifically focuses on the design of environmental monitoring programmes, a critical element without which effective C&MWQM would be impossible. Finally, towards initiating the effective operationalisation of C&MWQM in WIO region, Chapter 8 provides a number of key recommendations for consideration by the Contracting Parties.

2. STRATEGIC OBJECTIVES & TARGETS

The Strategic objectives and Targets pertaining to C&MWQM in the WIO region are primarily defined as per the *Strategic Action Programme Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities* (SAP WIO-LaB) (UNEP/Nairobi Convention Secretariat 2009). By 2010 the SAP WIO-LaB had been adopted by Contracting Parties, and thereafter the formally adopted requirements and agreements were translated and captured into a formal *Protocol on Land-Based Sources and Activities in support of the Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region* (UNEP 2010).

The SAP WIO-LaB set the following Strategic Objective for water quality in the WIO region:

'Water quality in the WIO region meets international standards by year 2035'.

This Strategic Objective will be achieved if (i.e. indicators of verification) if:

- Quality of coastal and marine waters in the WIO region meet regionally agreed standards
- Wastewater discharges adhere to agreed national and regional effluent standards
- Increased government budget allocations for pollution prevention.

The SAP WIO-LaB further identified a number of specific targets towards achieving these outcomes, focused mainly on mitigating and preventing impacts from land-based sources and activities:

- Effluent discharge standards developed and regionally harmonized
- Marine water standards developed and regionally harmonized (also referred to as *Guidelines for the development of Environmental Quality Objectives and Targets*)
- Regional best practice framework models for municipal wastewater management developed and adopted
- Collection, treatment and disposal of effluents undertaken in accordance with regional standards
- Environmental management systems and cleaner production technologies encouraged
- Stakeholders sensitized and political support harnessed in favour of pollution prevention.

In 2010, it was also decided to initiate a joint Transboundary Diagnostic Assessment and SAP process under ASCLME and SWIOFP pertaining to all issues pertinent to the coastal and offshore areas of the LMEs that have not fallen under the SAP WIO-LaB - The *Strategic Action Programme for the Sustainable Management of the Western Indian Ocean Large Marine Ecosystems* (SAP WIO-LME) was therefore published (ASCLME et al. 2014). To ensure a comprehensive ecosystem-based approach (watershed to outer offshore boundaries) the two SAPs need to be implemented in collaboration through a cooperative understanding, whilst recognising and respecting the mandates of the various management bodies and institutions.

The SAP WIO-LME also identified water quality degradation as a key concern in the region, and posed the following Ecosystem quality objectives (or Targets) that specifically pertain to C&MWQM:

- Restore ground and surface water quality and prevent further degradation occurring in the future
- Reduce microbiological contamination in coastal waters
- Reduce solid waste (marine debris) from shipping and land-based sources in coastal water

- Develop the capacity to prevent and mitigate the effects of oil spills at regional and national level.

In order to achieve these targets the SAP WIO-LME recommended the following actions pertaining to mitigation of water quality deterioration in coastal and offshore areas:

- Develop and adopt a general programme for long-term water quality monitoring (biochemical and physical) with the partners of the WIOSEA and ensure that such water quality monitoring programmes target vulnerable areas as well as point-sources (e.g. coral reefs and other critical habitats as well as marine aquaculture facilities)
- Review current capacity and then design and implement improved monitoring and evaluation systems for microbial contamination and for solid and liquid waste discharges both coastal and offshore (ship-based and platform based)
- Review existing vulnerability assessments to oil and hazardous chemical spills and develop an effective monitoring mechanism with specific indicators
- Develop and adopt a monitoring system for exotic, non-native and nuisance species
- Monitoring and reporting of microbial contamination; solid waste; oil and hazardous chemicals; run-off from agriculture and sewage, etc.
- Design, construction and function of various forms of waste reception facilities including oil and hazardous chemicals handling, sewage systems, etc.
- Use of oil and hazardous chemical spill clean-up equipment, response measures and rapid response contingency plans
- Development and adoption of effective and standardised Environmental Impact Assessment criteria, standards and regulations for watershed, coastal and offshore activities that could contaminate/pollute the marine ecosystem (including marine aquaculture and impacts from contamination, waste and potential invasive species)
- Review existing national plans for waste management and develop new plans and programmes as necessary including:
    - Development of appropriate port facilities for recycling and reuse of ship-borne wastes and
    - Implementation of incentive measures/mechanism for use of such facilities and implement an awareness and educational campaign
- Ratify and adopt International Maritime Organisation (IMO) protocols into all domestic legislation and regulations throughout participating countries
- Review existing national and regional Oil and Hazardous Materials Spill Contingency Plans (OHMSCP) and Oil Spill Response measures
- Prepare, adopt or modify/improve regional guidelines for OHMSCP and Rapid Response including the development and/or support any on-going process to adopt a regional response facility and emergency centre for Oil and Hazardous Materials
- Collaborate closely with the oil, gas, chemical and shipping industry and IMO to develop appropriate responses, equipment stockpiles and response coordination centre(s).

This Strategic Framework for C&MWQM is guided by the Strategic Objectives and Targets as set out above. Throughout the development of the framework, these were acknowledged and accommodated, as appropriate.

3. BASIC PRINCIPLES

Basic Principles provide broad direction within which to position a strategic framework for C&MWQM. Five basic principles are proposed for the WIO region, namely:

- Principle 1: Pollution prevention, waste minimisation and precautionary approach
- Principle 2: Receiving water quality objectives approach
- Principle 3: Integrated, adaptive assessment approach
- Principle 4: Polluter pays principle
- Principle 5: Participatory approach.

These principles are expanded on in Table 3.1:

Table 3.1: Basic Principles for C&MWQM in the WIO region

PRINCIPLE 1: POLLUTION PREVENTION, WASTE MINIMISATION AND PRECAUTIONARY APPROACH

When considering the management of potential coastal and marine pollution sources, a hierarchy of decision-making applies (aligning with concepts such as the 'Circular Economy'):

1) *Pollution Prevention, preventing waste production and pollution wherever possible.*
2) *Minimisation of pollution and waste at source, minimising unavoidable waste through:*
    - *Recycling*
    - *Detoxification*
    - *Neutralisation*
    - *Treatment and re-use of waste streams*
    - *Cleaner technologies and best management practices*
3) *Responsible disposal, applying the precautionary approach:*
    - *Apply wastewater standards as a minimum requirement*
    - *If wastewater standards are not sufficient, maintain fitness for use of the receiving water body in accordance with the Receiving Water Quality Objective approach (explained below)*

The above could be enforced through related legislation (e.g. standards) but could also be achieved through incentives for water quality management.

PRINCIPLE 2: RECEIVING WATER QUALITY OBJECTIVES APPROACH

Requirements of the aquatic ecosystem, as well as requirements of other beneficial uses of coastal and marine resources, determine the limits to be met in terms of pollution sources (rather than following a uniform effluent standard approach).

PRINCIPLE 3: INTEGRATED, ADAPTIVE ASSESSMENT APPROACH

The concept of Integrated Environmental Management that supports underpinning principles:

- *Acknowledging the concepts of Integrated Water Resource Management and Source-to-Sea*
- *Strategic adaptive management (i.e. 'improving-by-learning' and 'thinking strategically whilst implementing locally')*
- *Best Practice (to be developed by a regulator and obligatory implemented by the regulated community as a minimum for responsible source management)*
- *Consistent performance (i.e. all water users/impactors within the regulated community are required to ensure and strive for the same water quality goals at the same risk level)*
- *Flexibility in approach (i.e. the regulator has the flexibility to consider the application of different alternatives and approaches, provided each of these can meet the desired objectives and requirements of the Source Management Strategy*

Continuous improvement (encouraging continuous improvement in the actions and practices of both government and the regulated community).

PRINCIPLE 4: POLLUTER PAYS PRINCIPLE

The responsibility for environmental costs incurred for rehabilitation of environmental damage and the costs of preventive measures to reduce or prevent such damage will be shifted to the impactors through, for example, the implementation of a waste discharge charge system.

PRINCIPLE 5: PARTICIPATORY APPROACH

Transparent, ongoing stakeholder participation applies from early decision-making processes through monitoring and continuous assessments, using, for example, local management institutions. The inclusion and participation of women in environmental quality negotiation and decision-making is evident.

4. REGIONAL COORDINATION & SUPPORT

The Nairobi Convention aims to address the accelerating degradation of the oceans and coastal areas in the WIO region through sustainable management and use of these resources by those sharing these environments. The Secretariat of the Convention a key role in the regional coordination and provides support in achieving this aim. This includes overseeing the development of regional standards, guidelines and best practice guides so as to harmonise efforts across countries in the region, including those pertaining to C&MWQM.

Reflecting on the Strategic Objectives and Targets of the under the *Strategic Action Programme Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities* (UNEP/Nairobi Convention Secretariat 2009) and The *Strategic Action Programme for the Sustainable Management of the Western Indian Ocean Large Marine Ecosystems* (ACSLME et al. 2014), a number of regional standards, guidelines and best practice guides, as well as other support efforts, relevant to C&MWQM have been identified, including:

- Develop regional standards for coastal and marine water quality (e.g. the *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas*) (developed as part of this Strategic Framework for C&MWQM – UNEP et al. 2021b)
- Develop regional effluent discharge standards to facilitate harmonized approach across WIO region
- Develop Regional best practice framework models for municipal wastewater management
- Oversee adoption of Cleaner Production Technologies by industries at national-level
- Develop Regional guidelines on oil spill contingency planning for inclusion in concession agreements
- Coordinate the establishment of a regional support structure for oil spill disaster management
- Establish regional capacity building programmes on oil spill contingency planning

Regional-level achievements in terms of C&MWQM support to date include:

- Land Based Sources and Activities (LBSA) Protocol of the Convention (UNEP 2010)
- WIO Action Plan on Marine Litter (UN Environment 2018)
- African Marine Litter Monitoring Manual (African Marine Waste Network, Sustainable Seas Trust. - Barnardo and Ribbink 2020)
- WIO Marine Highway development and Coastal and Marine Contamination Prevention Project (2020)
- Regional oil spill preparedness in eastern Africa and WIO (UNEP et al. 2020a&b).

In the case of Regional State of the Coast Reporting, derived from requirements of the Nairobi Convention, the Western Indian Ocean Marine Sciences Association (WIOMSA) has in the past guided the technical process at the regional level together with experienced scientist, and in consultation with the Contracting Parties and their National Focal Points in terms of the political agendas. Ideally, in the case of future regional status reports, regional coordinators will be able to draw on national-level status reports produced as part of their C&MWQM implementation programmes which is addressed in greater detail in Chapter 6.

While, the execution of these regional targets and actions, are coordinated through the Secretariat, the outputs need to be approved and adopted by Contracting Parties for deployment in the region, e.g. through the national-level C&MWQM implementation programmes (see Chapter 6).

5. INSTITUTIONAL ARRANGEMENTS

The effective implementation of any environmental management programme at regional, national and local (e.g. in specific hotspots) levels cannot happen in an *ad hoc* manner. Rather it needs to be driven and coordinated through appropriate multi-sectoral management institutions with clearly defined roles and responsibilities (Taljaard et al. 2013). This also applies to the effective implementation of C&MWQM, nested within the broader integrated coastal and marine environment management structure (DEA RSA 2014b).

The key to success of an environmental institutional structure relies on, for example: (UNEP and GPA 2006):

- Governmental commitment to the environmental policies and allocation of financial resources required for long-term implementation
- Sufficient initial capacity within the responsible institutions to implement its policies and action plans
- Active support from a core of well-informed and supportive constituencies composed of stakeholders in both the private sector and other agencies
- A sound scientific information base, containing explicit scientific assumptions and outcomes, by which authorities, and local stakeholders, are empowered to partake in the decision-making process.

Proposed institutional arrangements for C&MWQM in the WIO region are illustrated in Figure 5.1.

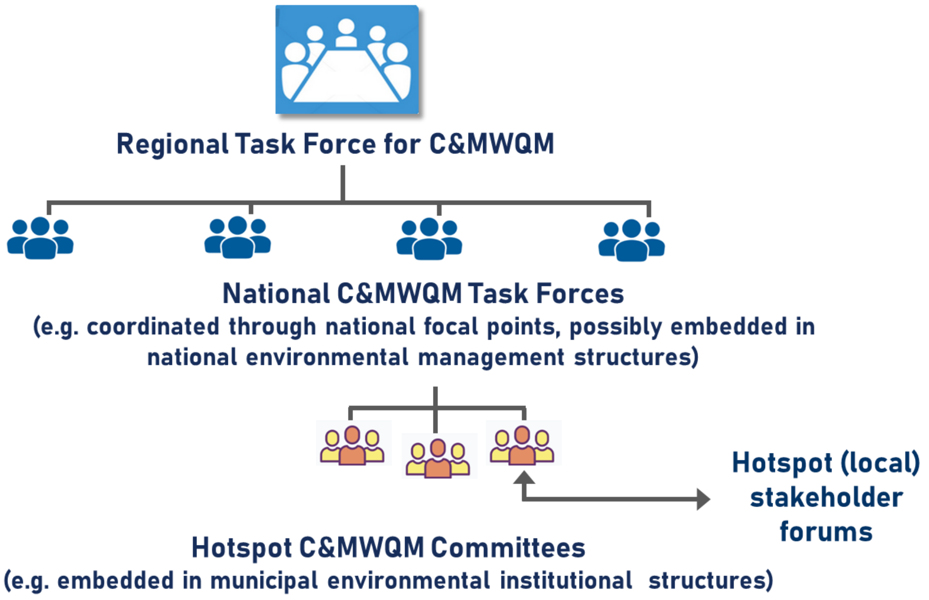


Figure 5.1 Proposed institutional structure for coordination and implementation of C&MWQM in the WIO region

The Regional Task Force (RTF) for Water Quality has already been established at the regional level and provides an ideal platform for regional coordination in the future. The oversight and coordination of C&MWQM within countries requires national institutional structures (e.g. National C&MWQM Task Forces), preferably coordinated through the national focal points to facilitate coordination and alignment with the RTF. These structures need to be cross-sectoral, comprising environmental authorities and those involved in activities potentially impacting on the coastal and marine environment, such as urban development and tourism, agriculture, aquaculture and forestry, industry and mining, marine transportation and energy production.

Experience in integrated coastal management (e.g. DEA RSA 2014b) has shown that it is usually not viable for national management structures to effectively implement environmental management at the local or site-specific level, or in this case, within identified pollution hotspots. Effective environmental planning and implementation at the local (or hotspot) level requires local management forums. Like the national structures these can also be mainstreamed through broader local (or municipal) environmental management structure but ensuring cross-sectoral representation. Being actively involved in C&MWQM at the local level, these structures are also ideally positioned to test the effectiveness and applicability of legislation and policies, which are normally developed at regional or national levels. Therefore, it is also important that higher tiers of government utilise these local institutions as mechanisms for improving legislative frameworks related to coastal management, supporting the principle of adaptive management.

In the spirit of *Principle 5: Participatory approach*, stakeholder collaboration and regular consultation are essential. Towards achieving this, local stakeholder forums have proven to be useful platforms through which to facilitate a participatory approach to decision-making and implementation (CSIR 2006). An example of a local C&MWQM forum is the Saldanha Bay Water Quality Trust Forum in South Africa (https://sbwqft.org.za/about-sbwqft/). These forums need to consider stakeholders that have an interest in the coastal and marine environment, or are reliant on coastal and marine resources, including:

- Local industries
- Scientific communities
- Tourism organisations
- Recreation clubs
- Traditional leaders and representative from local communities
- Non-government organisations.

Although stakeholder forums do not usually have executive powers, they provide powerful platforms for the execution of sound C&MWQM by:

- Securing buy-in of local interested and affected parties
- Establishing private/public partnerships
- Creating platforms for advancing education and awareness
- Fulfilling the important role of local ‘watchdogs’ or ‘custodians, holding authorities to account.

6. NATIONAL-LEVEL IMPLEMENTATION OF C&MWQM PROGRAMMES

Traditionally, management of natural resources and the environment, including the coastal and marine environment, has been organised around specific uses or sectors, such as fisheries, agriculture, water supply and demand, wastewater treatment and discharge, and housing development, each with their own governing structures (UNEP/GPA 2006). This sectoral approach has not only resulted in conflict among different uses, but also in ineffective and inappropriate utilisation of valuable, and often limited, human and financial resources. This led to the realisation that natural resources and the environment can be managed much more effectively, if the 'ecosystem' becomes central and management occurs through cooperative governance between different sectors. This is referred to as ecosystem-based management. In essence, ecosystem-based management recognises that plant, animal and human communities are interdependent and interact with their physical environment to form distinct ecological units called ecosystems (UNEP 2006b). At the largest scale is the Earth ecosystem, and although it is important that governance and management strategies be formulated at this large (international) scale, decentralisation to regional, national and local levels is logical since in many instances implementation occurs at the 'distinct ecological unit' (local or regional) level. The challenge in ecosystem-based management is to ensure sustainable development, which can be defined as: '*… development which fulfils the needs of the present generation without jeopardizing the possibilities of future generations to fulfil their needs*' (United Nations Assembly 1987). The ultimate goal in coastal ecosystem-based management, therefore, is to maintain functioning of coastal aquatic ecosystems (i.e. ecology) to protect biodiversity, as well as beneficial uses (or ecosystem services) (i.e. social and economic values). Nested within this broader goal, the primary focus of C&MWQM is 'water and sediment quality', more specifically the management of activities that can potentially alter the environmental quality of coastal and marine environments. In essence, the need for C&MWQM stems from a tension between the need to protect biodiversity (and associated socio-economic benefits) and the need for economic development in sectors which may contribute to sources of marine pollution. Importantly, 'water and sediment quality' is not disconnected from other influencing factors, e.g. changes in climate (ocean acidification) or stream flows (altering nutrient inputs) and the effect of such factors on coastal and marine water quality may also have to be considered in C&MWQM, where relevant.

Within this context, an ecosystem-based Implementation Framework for C&MWQM in the WIO region is recommended, drawing on a similar model previously proposed for Integrated Coastal Management (the broader domain within which C&MWQM is nested) (Taljaard et al. 2013) (Figure 6.1). This framework provides the template for the development and implementation of C&MWQM programmes (an example of the content of a C&MWQM Plan is provided in Appendix A). The Implementation of C&MWQM Programmes primarily happens at national-level at selected hotspots, in accordance with adopted regional standards, guidelines and best practice guidance, as appropriate. These programmes should be coordinated through the National Task Forces and Hotspot C&MWQM committees, in consultation of local stakeholder forums.

To wisely apply human and financial resources, it may be necessary to tackle C&MWQM in a phased approach. In this regard, the identification of marine pollution hotspots or emerging hotspots, provides a transparent mechanism to prioritise study areas where coastal and marine environmental quality is most at risk or impacted by human activities. In accordance with *Principle 2: Receiving water quality objectives approach*, the identification and mapping of important ecosystems, and key social and economic beneficial uses in a specific area, as well as their environmental quality objectives and associated water and sediment quality targets (QTs) are key components in a C&MWQM programme. The *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas in the WIO* *region* can be used to derive such site-specific water and sediment quality targets for aquatic ecosystems and beneficial uses (UNEP et al. 2021b). A participatory process (*Principle 5: Participatory approach*) is important in the negotiation of these objectives as the livelihoods of local communities, as well as local economies may be affected. The aim is to negotiate and achieve a balanced outcome that is both environmentally and socio-economically sustainable through an integrated approach (*Principle 3: Integrated assessment process*).

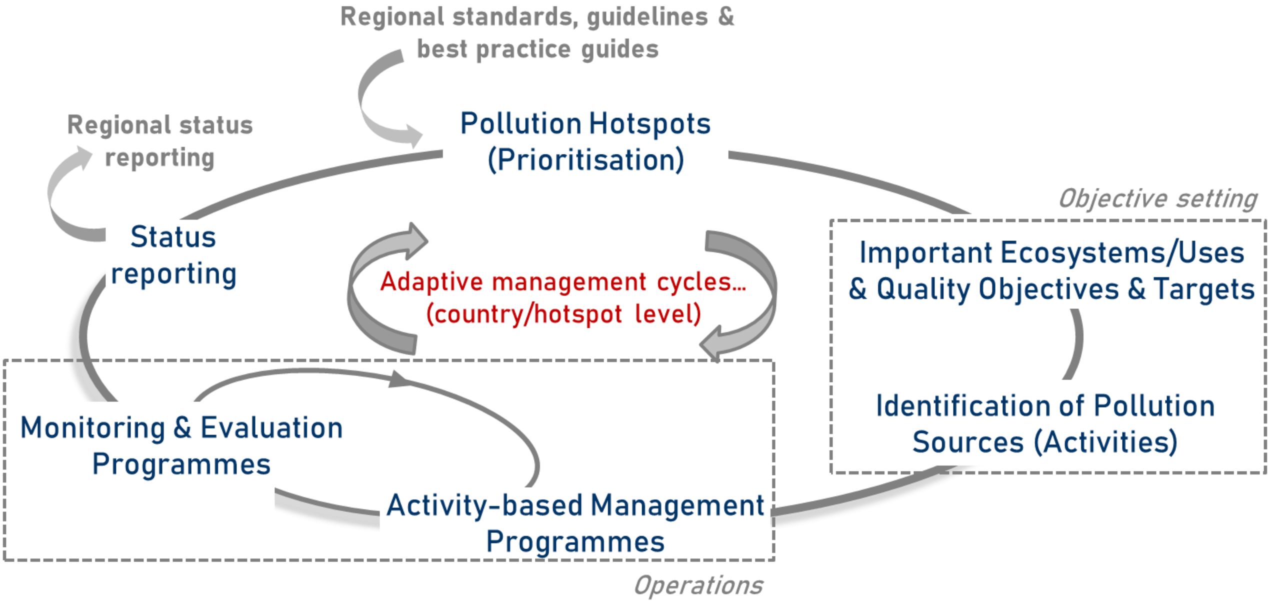


Figure 6.1 Ecosystem-based Implementation Framework for C&MWQM in the WIO region

Another key component of the objective setting phase is the identification and characterisation (including location and quantification) of potential marine pollution sources (both land-based and sea-based) that may alter water and sediment quality within a specific study area, as well as setting limits for such sources. In essence, the need for C&MWQM stems for the tension between biodiversity- and socioeconomic-driven environmental quality objectives and management and control of (mostly economic-driven) impacts from marine pollution sources. In setting limits for pollution sources, a hierarchy of decision-making, as advocated by *Principle 1: Pollution prevention, waste minimisation and precautionary approach*, should be applied. Activity-based management programmes involve the operational management of specific activities potentially contributing to marine pollution. These type of programme often show a strong sectoral focus (i.e. activities are managed by different governing authorities through activity-specific statutory systems). However, the implementation framework situates such sector-based (or silo) management programmes between an overarching objectives setting phase and monitoring and evaluation component. This implies that management programmes, even though sector-based, remain nested in an ecosystem-based approach subservient to the agreed environmental quality objective and targets for the study area (Taljaard et al. 2013). The cost of mitigating and controlling pollution sources should follow *Principle 4: Polluter pay principle*. The design and implementation of environmental quality monitoring and evaluation programmes forms an integral and critical element of the Implementation Framework's operational phase. However, in C&MWQM monitoring and evaluation is a means to an end, providing data and information to inform activity-based management intervention, as is illustrated in Figure 6.1 by the feed-back loop to activity-based management programme (*Principle 3: Integrated, adaptive assessment process*). The data and information from these programmes also continuously renew understanding of the complexities of coastal and marine ecosystems and their uses, and so inform status assessments. In support of a transparent, participatory process (*Principle 5: Participatory approach*) findings from monitoring and evaluation programmes, also need to be communicated and shared at regular intervals with the broader society. Status reporting provides for a high-level reflection on progress and ensures transparency on issues of concern needs to be addressed through a cycle of adaptive management (i.e. improving-by-learning) (*Principle 3: Integrated, adaptive assessment process*). In turn, national-level status reports feed into regional status assessment processes, such as the WIO State-of-Coast reporting.

Also important to understand are possible links between the implementation of C&MWQM and other initiatives within the WIO region. While the Implementation Framework has unique elements specifically pertaining to the effective implementation of C&MWQM, elements within the framework are aligned with other, complimentary strategies and frameworks implemented in the WIO region as is illustrated in Figure 6.2. For example, the demarcation of important ecosystems/uses and location of activities contributing to marine pollution need to coordinate with outcomes from the marine spatial planning strategy, which in turn should align with biodiversity, conservation and fisheries strategies in terms of zoning. Outputs from monitoring and evaluation programmes can also contribute into the ecosystem monitoring framework, in addition to informing C&MWQM actions and intervention. The implementation of C&MWQM, therefore, should acknowledge these linkages and coordinate operations wisely so as to prevent unnecessary duplication of effort.

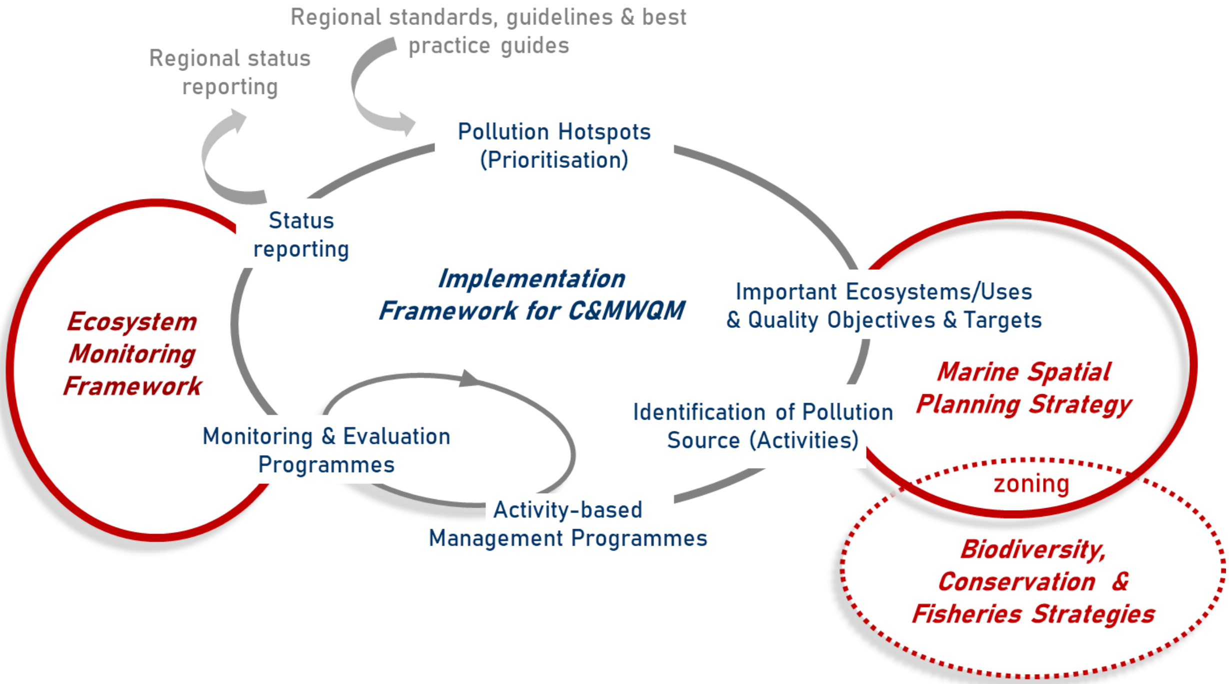


Figure 6.2 Visualising alignment of Implementation Framework for C&MWQM with other related strategies and frameworks within the WIO region

Although the Implementation Framework for C&MWQM is largely executed at the national-and sub-national level (e.g. pollution hotspot), it does reflect on the overarching support and guidance provided to countries at the regional level, acknowledging the importance of coordinated regional policies informing national-scale initiative. To assist environmental managers and decision-makers with the development and implementation of C&MWQM programmes at national-level, each of the key elements in the Implementation Framework is unpacked in the greater detail in the following sections.

6.1 Identification of Pollution Hotspots

Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) provide a useful definition of pollution hotspots: *'Marine pollution hotspots, or areas which receive severe pollution loads, is a known menace that often has disastrous effects. Found mainly in enclosed and/or semi-enclosed bodies of water like bays and river mouths, these areas are associated with highly urbanized and densely populated cities. They pose a constant threat to public health, coastal resources, and the integrity of coastal ecosystems'* (PEMSEA 2020).

Marine pollution hotspots usually coincide with coastal urban centres (or cities) and industrial nodes in coastal and marine areas. Remote sensing techniques have proven useful in identifying these hotspots in coastal and marine areas (e.g. Shaban 2008). The importance of demarcating manageable spatial units is a key learning point from the field of integrated water management (IWRM), where an entire river basin or catchment has often been recognised as too large a unit for effective management (e.g. Lankford and Hepworth 2010). Rather, smaller sub-units (e.g. wetlands) are recommended as 'manageable' building blocks towards full IWRM. In the case of C&MWQM, hotspots could be viewed as the manageable sub-unit building blocks towards achieving integrated C&MWQM (e.g. Taljaard et al. 2013). However, while sub-units provide greater manageability, potential influences from adjacent environments (e.g. river basins or oceanic waters) must still be recognised, e.g. considered as 'exchange' across management unit boundaries (Figure 6.2).

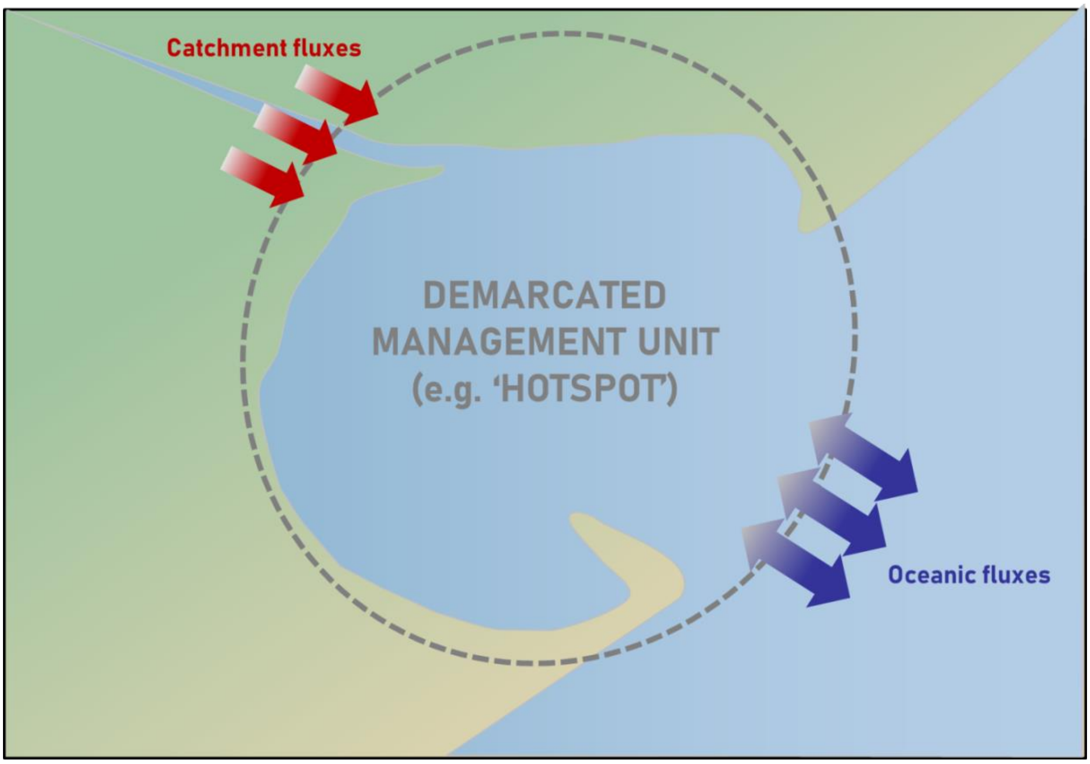


Figure 6.3 Contextualising local-scale demarcation of 'hotspot' boundaries (management units)

Within the context of a C&MWQM, the identification of pollution hotspots provides a means of prioritising management efforts in areas where human capacity and/or financial resources are a constraint. Therefore, the rationale is where resources are limited efforts should be concentrated in areas of greatest risk.

Once specific marine pollution hotspots have been identified, detailed spatial demarcation within which to focus C&MWQM effort is important. Such demarcation needs to consider interdependencies between the coastal fauna and flora and human communities, as well as their interaction with the physical coastal environment. Aspects that need to be considered include (CSIR 2006):

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

As a result, the boundaries of a marine pollution hotspot may include the entire coastal system within which it is situated (e.g. an entire embayment). Technologies, such as coupled hydrodynamic-water quality-ecological numerical models (e.g. DELFT 3D - https://oss.deltares.nl/web/delft3d) have been used successfully to inform spatial demarcation. These tools can integrate physical and biogeochemical processes and their interaction with pollution inputs over space and time, providing a quantitative means of determining the extent of significant influence. Together with GIS, this provides solid platforms to map hotspots.

Geographic Information Systems (GIS)

Geographic information systems (GIS) refer to frameworks for gathering, managing, and analysing data. Rooted in the science of geography, it allows for the geo-referenced integration and visualisation of various types of data and information. GIS software is a powerful tool to apply in the mapping components in C&MWQM.

Marine pollution hotspots have been identified previously in countries in the WIO region (UNEP et al. 2021a), although these need to be re-visited from time to time. As part of previous initiatives in the region (UNEP et al. 2009a) a classification system for pollution hotspots was developed and adopted to provide some resolution on the intensity of hotspots to inform prioritisation in management effort (Table 6.1).

Table 6.1: Evaluation criteria for rating of pollution hotspots in the WIO region (UNEP et al. 2009a)

		SEVERITY OF POLLUTION		
		1: Frequent non-compliance with EQTs	2: Seasonal non-compliance with EQT	3: Occasional non-compliance with EQTs
SIGNIFICANCE OF IMPACT	1 High	Category 1	Category 1	Category 2
	2 Medium	Category 1	Category 2	Category 3
	3 Low	Category 2	Category 3	Category 3
	Category 4: Emerging hotspot			

Given the rapid urbanisation occurring along WIO coastal regions, a category to cover Emerging hotspots (Category 4) was included (Table 6.1). These are defined as areas where:

- Compliance with environmental quality targets occurs at present, but there are emerging issues that pose potential risks to sensitive ecosystems or beneficial uses, and/or
- Insufficient data are available at present to perform a sensible rating, but there are emerging issues that pose potential risks to sensitive ecosystems or beneficial uses.

6.2 Important Ecosystems, Uses & Quality Targets

At the core of C&MWQM is the protection of valuable natural resources, and ultimately the biodiversity and socio-economic ecosystem services derived from these resources. Environmental quality objectives therefore need to be set in consultation with stakeholders to ensure that C&MWQM programmes are aligned with local expectations.

The identification and mapping of key coastal and marine ecosystems and beneficial uses in an area provide the basis for the determination of site-specific environmental quality objectives, and associated water and sediment quality targets. In addition to the protection of sensitive and important aquatic ecosystems, other beneficial uses reliant on acceptable water and sediment quality are typically grouped into (UNEP et al. 2009b):

- Recreational use
- Marine aquaculture
- Industrial uses (e.g. desalination and cooling water intake).

The demarcation of such beneficial uses in a particular area should not only consider existing uses, but also take into account any future uses planned for the area aligning with land-use and marine spatial planning strategies and outcomes. Also, the identification and demarcation of sensitive and important ecosystems and beneficial uses should not be done in isolation, but should be aligned with other spatial planning initiatives, undertaken as part of conservation planning, spatial development plans, as well as cross-sectoral marine spatial planning (e.g. linking to a Marine Spatial Strategy - see Figure 6.2). An example of an ecosystem and beneficial use map is provided in Figure 6.4.

Identification and mapping of important and sensitive ecosystems and beneficial uses provides the spatial context for setting site-specific environmental quality objectives and targets. Objectives can be set, for example, in terms of the abundance and diversity of biotic components, or as broad objectives for specific beneficial uses (e.g. 'safe for swimming'). They also need to be extended to measurable target values or ranges for specific chemical or microbiological constituents to be of use from a water quality management perspective. The *Guidelines for setting water and sediment quality a*re specifically developed to assist with setting such targets for the protection of aquatic ecosystems and beneficial uses (UNEP et al. 2021b).

Scientific assessment studies are required to assess whether a coastal ecosystem can support designated beneficial uses (e.g. as defined in terms of the water and sediment QTs), in addition to being subject to modifications associated with human activities and developments in the area (UNEP et al. 2009b). These assessments must consider complex environmental processes and natural variability. This requires data, information and understanding of physical, biogeochemical and biological characteristics and process scales.

Depending on the availability of scientific data and information on the area, scientific assessments may also include baseline field measurement programmes. The level of detail required for scientific assessment studies largely depends on the type of investigation and the purpose for which it is intended.

Numerical (predictive) modelling techniques have proven to be powerful tools in the management of coastal and marine water and sediment quality. Benefits of predictive models (provided they are properly calibrated and validated) are that (Monteiro 1999; DWAF RSA 2004):

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

6.2.1 Important aquatic ecosystems

One of the key purposes of C&MWQM is to protect sensitive and important ecosystems. The offshore environment (typically defined as the zone beyond the surf zone or breaker zone) extends over a large area and usually has strong, relatively uniform water circulation characteristics that allow for effective transport and dispersion of pollutants.

In contrast, physical processes in the surf zone and estuaries are often very complex and highly variable. Water exchange from these zones is also not very good. Therefore, these zones are often ecologically sensitive with very little assimilative capacity for anthropogenic inputs, such as land-derived wastewater. Estuaries are sheltered water bodies in which circulation patterns depend largely on the river inflow and the state of the mouth. Water exchange, therefore, ranges from 'very good' when river inflow is high, the mouth is open and water is continuously flushed from the system, to 'limited' or even 'no' water exchange when the mouth is closed. High complexity in circulation patterns of the surf zone and estuaries largely reduces the accuracy with which transport and dispersion processes can be quantified, which is a key requirement for assessing the suitability of using the marine environment for assimilating wastewater.

Impacts of pollution sources on the coastal and marine aquatic ecosystems typically relate to (UNEP et al. 2009b):

- Abnormal growth stimulation (e.g. excessive nutrients)
- Biological health (e.g. toxic compounds affecting, for example, the reproductive rate of organisms)
- External behavioural responses (e.g. pollutants affecting movement and burrowing habits of organisms or entanglement).

Therefore, these aspects should be taken into consideration when setting water and sediment quality targets for the protection of aquatic ecosystems (UNEP et al. 2021b). Coastal and marine environments of the WIO region support over 110 000 species of plants and animals from a diverse range of habitats. Some of the important marine aquatic ecosystems include mangrove forests, seagrass beds and coral reefs (UNEP et al. 2015).

Mangroves grow along sheltered shores of tropical and subtropical regions (UNEP et al. 2015), thriving in sedimentary lagoons, bays, estuaries and tidal creeks (Alongi 2002; UNEP et al. 2015). In the WIO region these ecosystems are found commonly along the coasts of all countries, except Reunion (France), covering a total area of about 1 000 000 ha (Table 6.2).

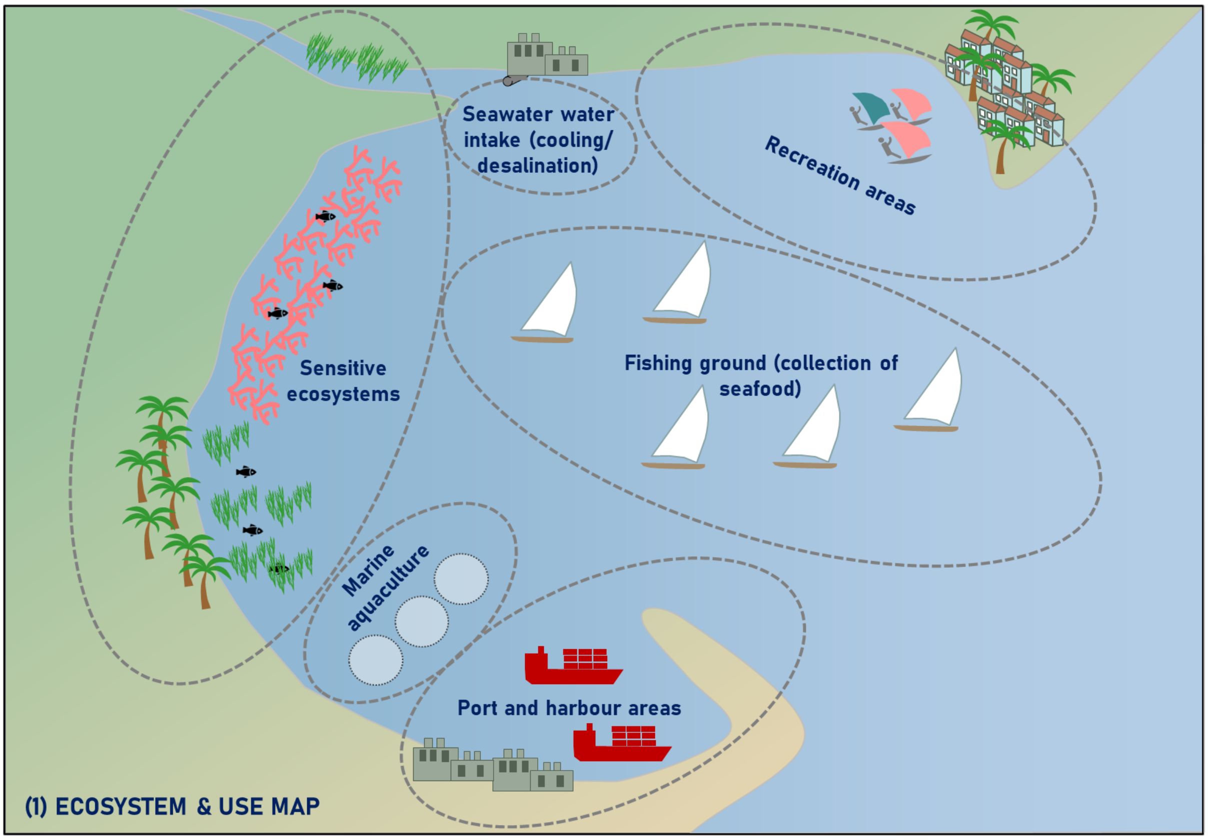


Figure 6.4 Illustration of demarcating important ecosystems & beneficial uses

However, 90% of coverage occurs in the estuaries and deltas of four countries (Mozambique, Madagascar, Tanzania and Kenya) (UNEP et al. 2009a; 2015) (Figure 6.5). The most dominant species found throughout the region are *Bruguiera gymnorrhiza*, *Ceriops tagal* and *Rhizophora mucronata* (UNEP et al. 2004b), but others include *Avicennia marina*, *Avicennia officionalis*, *Heritiera littolaris*, *Lumnitzera racemosa*, *Sonneratia alba*, *Xylocarpus granatum* and *Xylocarpus moluccensis* (UNEP et al. 2015). Mangrove forests are extremely productive ecosystems that support complex food webs consisting of both terrestrial and aquatic organisms. They are vital spawning and nursery grounds for numerous invertebrates, fish, reptiles and birds, and provide shoreline protection from storms (UNEP et al. 2015). Key taxa that typically associate with mangroves are bacteria, fungi, macro and micro-algae, invertebrate and vertebrate larvae, post-larvae and juveniles, polychaetes, bivalves, gastropods, crustaceans, fish, marine turtles and dugongs. The root systems of mangroves provide a habitat for epiphytic communities such as macro-algae and bacteria. In addition to these ecosystem services they also provide visual amenity and aesthetics, shoreline protection from severe wave action and erosion, trap sediment thereby reducing turbidity of coastal waters, and fix, trap and recycle nutrients. Within the WIO region these habitats support major fisheries, particularly in the estuaries of Mozambique, Tanzania and Kenya.

Table 6.2: Coverage of mangrove forests in the WIO region (Source: UNEP et al. 2015, unless otherwise indicated)

COUNTRY	AREA (ha)	LOCALITIES OF HIGHEST OCCURRENCES
Comoros	120	Moheli Island, especially in the region of Damou and Mapiachingo
Kenya	46 000 – 54 000	Lamu Archipelago, Tana Delta
Madagascar	279 078	West coast at Mahajanga bay, Nosy Be, and Mahavavy
Mauritius	120 - 145	Rodrigues, Agalega Islands
Mozambique	290 900 – 318 800	Save-Zambezi River complex

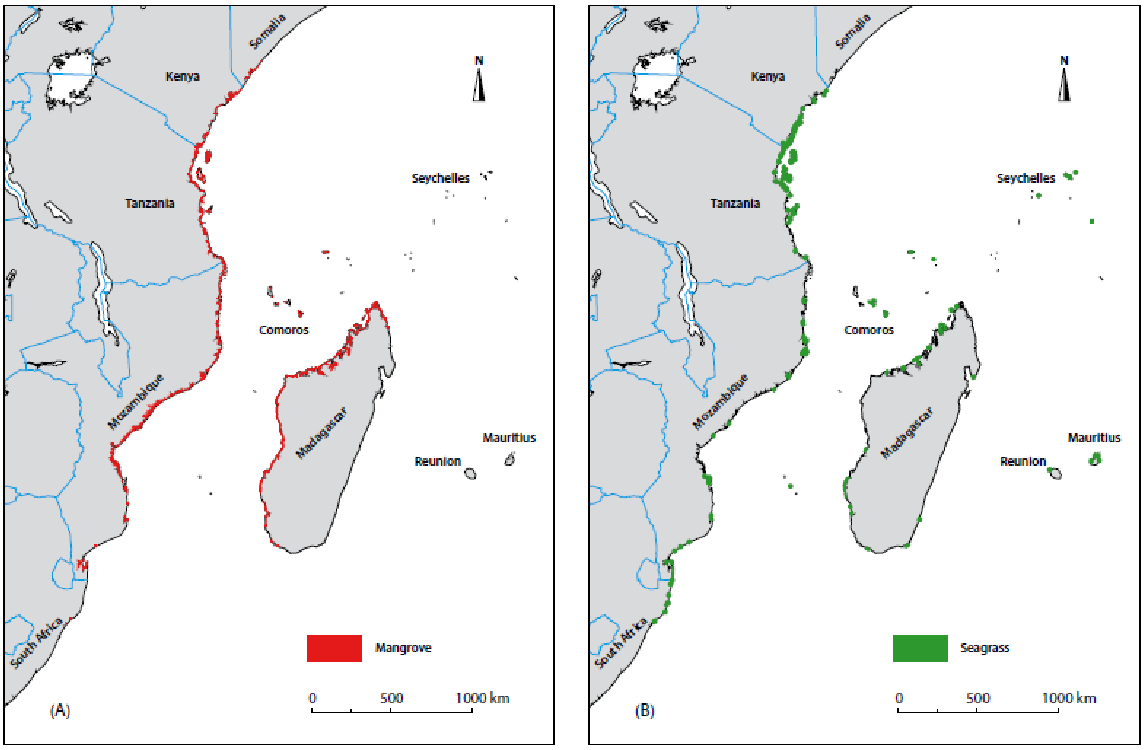
COUNTRY	AREA (ha)	LOCALITIES OF HIGHEST OCCURRENCES
Seychelles	2 900	Mahé, Praslin, Silhouette and La Digue
Somalia	1 000	Juba/Shebele Estuary
South Africa	1 631	Warm temperate, subtropical and tropical areas along east coast (Adams et al. 2016)
Tanzania	115 500 (Main land) 18 000 (Zanzibar)	Rufiji Delta, Pangani, Wami, Ruvu, Ruvuma Rivers

Sea grass beds are a predominant feature throughout the shallow waters of the WIO region and serve as a habitat for a wide diversity of marine organisms, ranging from algae and invertebrates through to the vertebrate classes. They are highly productive ecosystems covering approximately 0.1 – 0.2% of the global ocean (Duarte 2002) with at least 45 species distributed mainly in tropical and subtropical regions. Seagrass beds are a common feature throughout the shallow waters of the WIO region (Table 6.3, Figure 6.5).

Table 6.3: Occurrences of seagrass beds in the WIO region (Source: UNEP et al. 2015, unless otherwise indicated)

COUNTRY	LOCALITIES OF HIGHEST OCCURRENCES
Comoros	Mohéli Marine Park, Mitsamiouli, Malé and Ouroveni in Grande Comoro, and Bimbini and Ouani in Anjouan
Kenya	Kiunga, Malindi, Mombasa, Diani-Challe, Gazi Bay and Mida Creek
Madagascar	Shallow coast areas and lagoon throughout the island
Mauritius	Mauritius (55 ha), Rodrigues (649 ha)
Mozambique	Inhassoro and Bazaruto Island, Mecufi-Pemba, southern Quirimbas Archipelago, Inhaca Island
Reunion (France)	Reefal lagoons
Seychelles	Platte, Coetivy and Aldabra
Somalia	Adale to Ras Chiamboni, few beds along north coast
South Africa	Large permanently open estuaries (Adams et al. 2016)
Tanzania	Tanga coast, deltas of Ruvu, Wami and Rufiji rivers, Mafia Island, Songo Archipelago, Kilwa and Chwaka Bay

Figure 6.5 Distribution of mangrove forests and seagrass beds in the WIO region (Source: UNEP et al. 2015)



Twelve species of seagrasses from three different families being identified: *Cymodocea rotundata*, *C. serrulata*, *Enhalus acoroides*, *Halodule uninervis*, *Halophila ovalis*, *H. stipulacae*, *H. decipiens, H beccarii, Thalassia hemprichii*, *Thalassodendron ciliatum*, *Syringgodium isoetifolium* and *Zostera capensis*. The most dominant genera are *Thalassia*, *Halodule*, *Syringgodium*, *Halophila* and *Cymodocea* (UNEP et al. 2015; Adams et al. 2016).

Coral reefs are shallow subtidal ecosystems found in tropical and subtropical regions, thriving in shallow and nutrient limited waters up to depths of 20 to 30 meters (McClanahan 2002). Extensive and highly productive coral reefs fringe over 1 500 km of the WIO eastern coastline (Table 6.4).

Table 6.4: Coverage of coral reefs in the WIO region (Source: UNEP et al. 2015)

COUNTRY	AREA (km^2)	LOCALITIES OF HIGHEST OCCURRENCES
Comoros	430	Fringing and patch reefs around the island
Kenya	630	Northern and southern coasts of the country
Madagascar	2230	Fringing and patch reefs around the island and the barrier reef, Grand Récif de Toliara
Mauritius	870	Mahebourg barrier reef of Mauritius and patch reefs around the island
Mozambique	1 860	Quirimbas, Bazaruto, Inhaca, Inhambane
Reunion	<50	
Seychelles	1 690	Fringing and patch reefs around the island
Somalia	710	
South Africa	50	Fringing and patch reefs in Sodwana, St Lucia and Aliwal Shoal and Leadsman Shoal
Tanzania	3 580	Fringing reefs in Tanga, Pemba, Unguja, Mafia and patch reefs in the Zanzibar channel

There are four main classes of reefs, with fringing reefs, generally associated with shallow lagoons being the most common. The other three classes include patch reefs, atolls and barrier reefs (UNEP et al. 2015). Species of the genus *Acropora* are the most abundant and diverse group in the WIO region, although since the 1998 bleaching event the geographic range of *Acropora* has become limited to southern Tanzania and northern Mozambique. *Millepora*, once dominant in shallow coral communities, has also experienced a decline in these waters and is now represented in some regions by dead skeletons only. Previously dominant genera are now being replaced by less vulnerable to bleaching, such as *Porites* (Obura 2005). Other genera commonly found throughout the WIO region include *Astreopora*, *Alveopora*, *Cyphastrea*, *Echinopora*, *Favia*, *Favites*, *Galaxea*, *Goniastrea*, *Goniopora*, *Hydnophora*, *Leptoria*, *Montipora*, *Oxypora*, *Pavona*, *Platygyra* and *Pocillopora* (Fagoonee 1990; Obura 2005).

6.2.2 Recreational use

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

- Whole-body contact (primary contact) — activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wet by spray, and where it is likely that some water will be swallowed or inhaled, or come into contact with ears, nasal passages, mucous membranes or cuts in the skin (e.g. swimming, diving, surfing or white water canoeing).
- Incidental contact (secondary contact) — activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading), and including occasional and inadvertent immersion through slipping or being swept into the water by a wave.
- No contact (aesthetic uses) — activity in which there is normally no contact with water (e.g. angling from shore), or where water is incidental to the activity (such as sunbathing on a beach).

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

With respect to the recreational use of coastal and marine waters, the impacts of pollution sources typically relate to (UNEP et al. 2009b):

- Human health and safety (e.g. where bacteriological contamination can cause illnesses)
- Aesthetics or nuisance factors (e.g. pollutants causing discolouration of the sea)
- Mechanical interferences (e.g. where floating solid waste damages boat propellers).

These aspects should therefore be taken into consideration when setting water quality targets for the protection of recreational use areas (UNEP et al. 2021b).

6.2.3 Marine aquaculture

Marine aquaculture primarily refers to the farming of marine and/or estuarine organisms on land-based (referred to as ‘off-stream’ farming using piped seawater) or water-based (referred to as ‘in-stream’ farming). Marine aquaculture comprises an array of plant and organism type farming including:

- Seaweeds (e.g. *Gracilaria*)
- Molluscs (e.g. mussels and oysters)
- Crustaceans (e.g. prawns)
- Finfish (e.g. milkfish, seabream, mullet).

Within the context of C&MWQM, it is also important to protect areas used for the collection of seafood for human consumption, therefore:

- Commercial fisheries
- Recreational fisheries
- Subsistence fisheries
- General public for own consumption.

With respect to marine aquaculture and harvesting of seafood for human consumption, pollution impacts typically involve (UNEP et al. 2009b):

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

These aspects should, therefore, be considered when setting water and sediment quality targets for the protection of marine aquaculture farming areas, as well as areas used for the collection and harvesting of seafood for human consumption (see WIO guideline document).

6.2.4 Industrial uses

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

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

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

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

These aspects should therefore be taken into consideration when setting water quality targets for the areas where industries are using seawater (UNEP et al. 2021b).

Atmospheric Emissions:

Introduction of atmospheric pollutants, potentially ending up in the coastal and marine environment, originate from several sources, for example (UNEP et al. 2009a):

- Fossil fuel fires: a large majority of coastal communities in the WIO region use fossil fuel for their domestic energy needs (this is therefore also an issue linked to the energy production sector)
- Traffic emissions: motor vehicle emissions can contribute significantly to atmospheric pollution
- Forest burning for land clearing: urban development adds pressure on land for growth
- Sugar cane burning (e.g. South Africa and Mauritius)
- Air emission from industries and energy production.

Atmospheric pollutants can also originate from solid waste dump sites and burning of waste. Rotting processes cause odour problems and methane gas emissions, while burning of wastes generates smoke which is aesthetically unpleasant and contains pollutants such as particulate matter and gases from burning plastics.

Data on atmospheric emissions (e.g. suspended solids, nitrogen, trace metals and hydrocarbons) that specifically contribute to marine pollution are lacking for the entire WIO region. In Mauritius, South Africa and Tanzania, atmospheric emissions are monitored in some of the coastal centres (UNEP et al. 2009c), but this fails to provide insights into the actual loads being deposited in the marine environment.

Based on the rapid increase in urbanisation and tourism development, particularly within the main urban centres of the WIO region, it can be expected that pollutant loads from atmospheric emissions (e.g. nitrogen, trace metals and hydrocarbons) have increased markedly over the past years. This requires further quantification and assessment.

6.3 Pollution Sources (Activities)

6.3.1 Mapping of pollution sources

Important in C&MWQM is not to address potential pollution sources in isolation, but to consider these collectively in specific areas to ensure that any cumulative and/or synergistic effects are considered. Demarcation of activities contribution to coastal and marine pollution for example, can be informed by land-use and marine spatial planning strategies and outcomes. An example of a map illustrating the concept of demarcating pollution sources which the waste inputs can potentially have a negative impact on the coastal and marine environment in a specific area is provided in Figure 6.6.

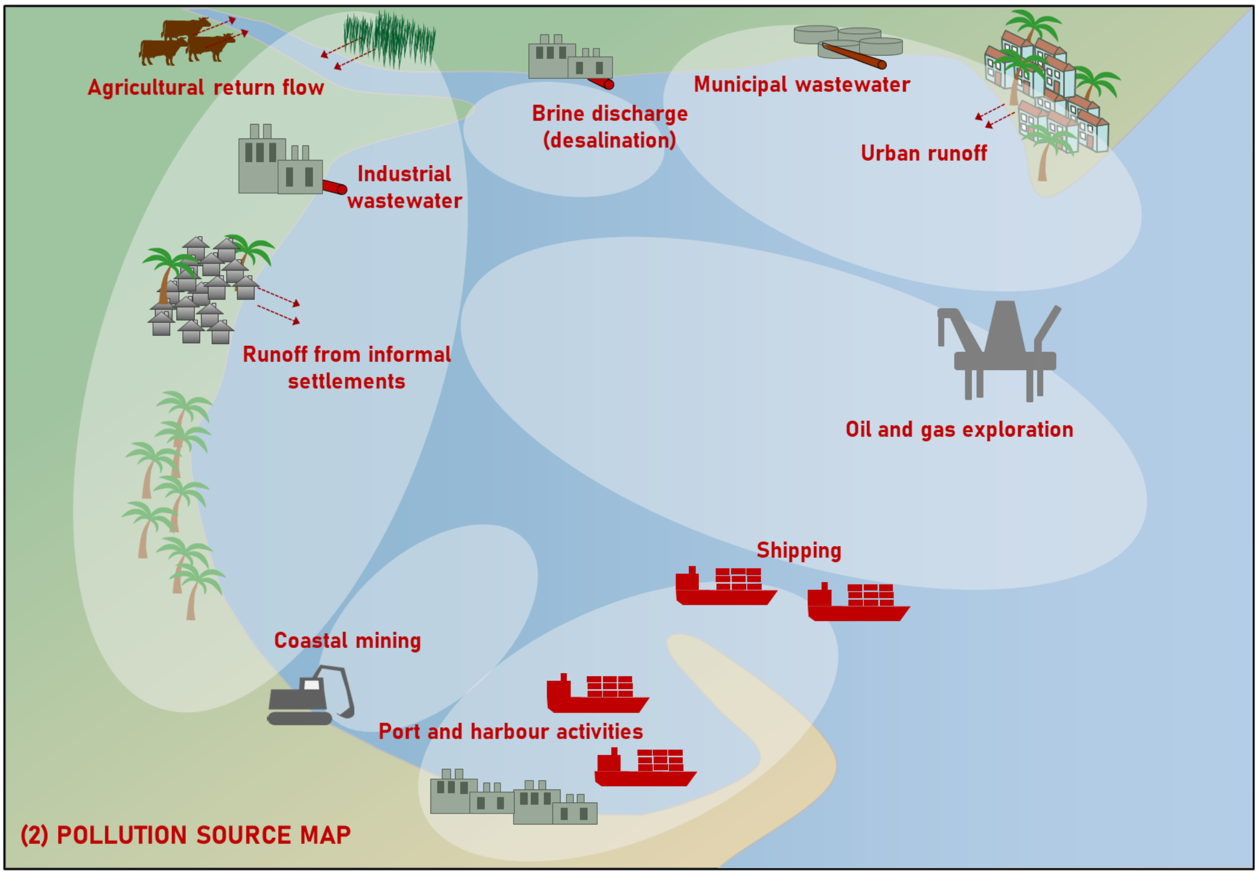


Figure 6.6 Illustration of demarcating potential marine pollution sources (overlapping with important ecosystems and beneficial uses – highlighted in grey - warrant possible management intervention)

Information that is typically required to properly characterise potential pollution sources includes (CSIR 2006):

- Understanding of treatment processes
- Volumes and flow rates of waste and waste streams
- Physical, chemical and microbiological composition of waste and wastewater - in terms of relevant constituents.

From a C&MWQM perspective, the volume and composition of waste and wastewater streams are of particular importance. Volumes and flow rates are obviously site-specific, but it is possible to derive broad characterisation of the composition of waste and waste streams from typical pollution sources from the literature as is provided in the following sections.

6.3.2 Characterisation of typical pollution sources

Nel and Kotze (2009) rightly noted that in environmental (or coastal and marine water quality) management the environment is not managed, but rather that activities within the environment are managed to prevent undesired change to the affected environment.

Activities potentially contributing to marine pollution typically arise from the following sectors (UNEP et al. 2009a):

- Urbanisation and tourism
- Agriculture, aquaculture and forestry
- Industry and mining
- Marine transportation
- Energy production.

This section provides an overview (focusing on the WIO region) of the typical pollution sources encountered within each of the listed sectors, including key pollutant constituents that these sources may introduce to coastal and marine environments. Table 6.5 provides a summary of the key activities within the most prevalent sectors, as well as typical pollutants associated with such activities.

Table 6.5: Major sectors and key activities found to contribute to coastal and marine pollution in the WIO region, and pollutants typically associated with these activities

MAJOR SECTOR & KEY ACTIVITIES SOURCE	TYPICAL POLLUTANTS																
	Thermal pollution	Brine (high salinity)	Discolouration	Solid waste (e.g. litter)	pH	Biodegradable organic matter (affecting O^2)	Suspended/settable solids	Inorganic nutrients	Microbiological contaminants	Toxic inorganics (e.g. S, Cl, CN^-;	Metals	Petrochemicals	Agrochemicals	Pharmaceuticals	Other persistent organic pollutants	Radioactive matter	Harmful organisms
URBANISATION & TOURISM																	
Municipal wastewater (incl. faecal sludge)						●	●	●	●	●	●			●			
Solid waste disposal				●							●			●			
Diffuse urban runoff				●	●	●	●	●	●	●	●	●	●	●			
AGRICULTURE & FORESTRY																	
Return flows							●	●	●				●				
FISHERIES AND AQUACULTURE																	
Fishing fleet waste				●													
Aquaculture farming				●		●	●	●									●
INDUSTRY & MINING																	
Desalination	●	●								●					●		
Paper & Textile	●		●	●		●	●			●							
Chemical					●	●	●			●	●				●		
Food & Beverages	●		●		●	●	●										
Coastal mining							●									●	
TRANSPORTATION (SHIPPING, PORTS AND HARBOURS)																	

MAJOR SECTOR & KEY ACTIVITIES SOURCE	TYPICAL POLLUTANTS																
	Thermal pollution	Brine (high salinity)	Discolouration	Solid waste (e.g. litter)	pH	Biodegradable organic matter (affecting O^2)	Suspended/settable solids	Inorganic nutrients	Microbiological contaminants	Toxic inorganics (e.g. S, Cl, CN^-;	Metals	Petrochemicals	Agrochemicals	Pharmaceuticals	Other persistent organic pollutants	Radioactive matter	Harmful organisms
Oils spills							●					●					
Ballast water discharge																	●
Harbour activities				●	●	●	●	●	●		●	●					
Dredge dumping						●	●				●	●			●		
ENERGY PRODUCTION																	
Offshore oil & gas							●			●	●	●					
Oil refineries	●				●	●						●					

6.3.2.1 Urbanisation and Tourism

Municipal waste and wastewater

Municipal waste and wastewater refers to domestic, or a mixture of domestic and industrial waste and wastewater. The domestic component of municipal waste and wastewater mainly comprise of wastewater (>99%) and solid waste (e.g. faecal sludge), primarily of biodegradable organic material which will eventually decay or decompose. The sludge and wastewater may also contain inorganic matter and heavy metals as well as grit/sand and debris such as cellophane, wood, plastic etc. Municipal sludge and wastewater also contain many microbiological contaminants of which some may be pathogenic or disease-causing. The non-pathogenic bacteria are important for the decomposition of the organic waste load in the wastewater and sludge and form the basis of the biological treatment processes. A group of microorganisms, known as faecal coliforms, is present in large numbers and serves as a convenient indicator for the presence of pathogens harmful to humans and, ultimately, in the environment. A typical composition of raw sewage under dry weather conditions, according to WRc (1990), is provided in Table 6.6. Data shows that sewage not only include high biodegradable organic matter, nutrients and microbiological contaminants, but possible also toxicants such as metals. A growing concern is the presence of pharmaceuticals in municipal waste and wastewater (Fabbri and Franzellitti 2016; Ojemaye and Petrik 2018).

Table 6.6: Typical composition of raw sewage under dry weather conditions (WRc 1990)

CONSTITUENT	ESTIMATED CONCENTRATION
Suspended solids	250 – 400 mg/ℓ
Biological oxygen demand (BOD)	300 – 500 mg/ℓ
Ammonia-nitrogen	20 – 50 mg/ℓ
Total phosphorus	15 – 25 mg/ℓ
Fats	100 – 200 mg/ℓ
Chromium	0,1 – 0,5 mg/ℓ
Copper	0,2 – 0,5 mg/ℓ
Lead	0,08 – 0,4 mg/ℓ
Zinc	0,4 – 0,7 mg/ℓ
Faecal coliform (indicator of microbiological contaminants)	2 – 30 x 10^6 per 100 ml

Within the WIO region non-centralized sewer systems, such as French drains, pit latrines and septic tanks, are widely used to dispose of domestic sewage, producing significant quantities of fecal sludge. Wastewater treatment works (WWTWs) are found in some parts of the region (e.g. South Africa), centralizing collection and treatment of domestic sewage and industrial trade discharges so as mitigate possible detrimentally effects on the environment. The need and design of WWTWs largely depends on the quantity and quality of the domestic sewage generated which, in turn, depends on the service population (including industrial trade effluents to be accommodated). Flow rates of municipal wastewater typically vary during the day with peaks in the morning, noon and late afternoon. However, each area will have a characteristic flow pattern, depending on socio-economic factors as well as the physical layout of the sewerage system(s) with regard to retention times. It is important for municipal waste and wastewater discharges to take seasonal variation in the flow patterns into account, particularly for small coastal resorts where such variation can be very large because of seasonal tourism. Treatment levels are typically categorized into preliminary, primary, secondary and tertiary treatment (DEA RSA 2014a; Morris et al. 2017). Local climate might be important. For example, infiltration (due to damaged pipes) during the wet season or during a rainstorm will increase the flow.

Internationally, it has become common practice to provide some form of central collecting system to communities with a service population greater than about 2 000 (DEA RSA 2014a). Where densely populated coastal settlements are not serviced by reticulated sewage systems, untreated sewage may enter stormwater runoff. However, even in coastal areas where centralized WWTWs exist the rapid growth of populations is increasing effluent volumes that require treatment. Resources are often not available for such infrastructure maintenance or upgrades, either as a result of lack in (municipal) political will or some smaller coastal authorities simply not having the requisite skills for operational management of treatment works. Treatment facilities are therefore often overloaded or malfunctioning, resulting in spillages from pump stations and substandard effluents (Adams et al. 2020).

Diffuse urban runoff

Diffuse urban (stormwater) runoff is a major source of pollution to coastal and marine environments (Müller et al. 2020). However, it is very difficult to characterise urban run-off because of widely varying contaminant concentrations (Wanielista et al. 1977). This, together with large fluctuations in run-off volume and the large number of discharge points, limits the potential to treat such wastewater, which often contains toxic and refractory compounds (Meyer 1985, Ma et al. 2017, Müller et al. 2020).

Along coasts contaminated stormwater runoff from urbanised areas, includes an array of contaminants including biodegradable organic matter (plant material and debris), solid waste (e.g. plastics) suspended solids, nutrients, metals, microbial contaminants and toxic organic compounds (e.g. petroleum hydrocarbons) (Wigington et al. 1983; Brown et al. 1985; Green et al. 1986; Schmidt and Spencer 1986, Ma et al. 2017, Müller et al. 2020). The quality and quantity of storm water run-off is determined to a large extent by catchment characteristics, rainfall characteristics and antecedent moisture conditions. The first flush effect, which is evident as a peak of highest pollutant concentrations at the beginning of a storm event, is the result of accumulated materials being washed from the catchment surface. This effect increases in frequency and intensity as the degree of urbanisation increases (Simpson 1986). In general, highly urbanised catchments produce the greatest concentration of pollutants in stormwater run-off while rural catchments produce the least (Green et al. 1986). The levels of these compounds increase with an increasing volume of vehicle traffic (Hoffman, 1986; Moore et al. 1988). In most of these areas, a low level of sanitary services is provided with the result that pollution in stormwater run-off, which usually drains directly into the surf zone, is more serious than in formally developed areas (Miles 1984).

Solid waste disposal (marine litter)

Solid waste disposal to the marine environment (contributing to marine litter) refers to any type of man-made solid waste which deliberately or accidentally pollutes the environment, which can float on the sea surface, sink on the seafloor or wash up long shores. The increasing use of plastics, together with their low biodegradability, has substantially influenced the spread of marine litter posing a major threat to marine organisms (including micro-plastics). Solid waste washing into storm drains, as well as wind-blown solid waste (paper, plastic, etc.) from urban areas and waste landfills contributes to marine litter loads (Valavanidis and Vlachogianni 2012).

6.3.2.2 Agriculture and Forestry

Pollution from agriculture (and forestry) is regarded as a non-point source of marine pollution and included numerous crop production (e.g. sugar cane) and livestock farming. It derives primarily from diffuse return flows draining agricultural areas. Major pollutants include nutrients (from excessive fertilisation) and toxic organic pollutants (from pesticides and herbicides) (Parris 2011). Runoff from poorly managed agricultural and forestry areas can also contribute to high suspended and settleable solids load to coastal and marine systems (Table 6.5).

6.3.2.3 Fisheries and Aquaculture

Waste from fishing fleets

Waste disposal from fishing fleets is a major ocean-based source of coastal and marine pollution despite efforts under the International Convention for the Prevention of Pollution from Ships (MARPOL) to minimise such waste. Pollutants being dumped included plastics, metals (e.g. empty drums, engine parts), oil (e.g. waste oils and fuel oils), general food garbage (degradable organic matter), and toxic chemicals (e.g. contained in paints, detergents, batteries and brine salts) (Richardson et al. 2017).

Marine aquaculture farming

Marine aquaculture (mariculture) is an emerging sector in the WIO region. Activities that are currently undertaken include the farming of crustaceans (e.g. shrimp, prawns and crabs), seaweed and finfish farming (WIOMSA 2007; ASCLME 2012b; ASCLME 2012d). Major waste products associated with aquaculture include suspended and settleable solids (e.g. uneaten feed and faeces), dissolved waste high in nutrients (N and P), chemicals used for hemotherapeutic purposes (e.g. antibiotics) and pathogens (e.g. diseases in cultured organisms affecting organism in nature (Duada et al. 2019).

6.3.2.4 Industry and Mining

Numerous land-based industries dispose of effluent to coastal and marine environments, where associated pollutants largely depend on the industry type. However, the list of potential waste from various industries elaborated on below is not exhaustive and mainly serves as a guide. Site-specific analysis of industry waste streams should ideally be undertaken to identify any other potentially harmful pollutants.

Desalination plants

With water scarcity being one of the most serious global challenges, demand for alternative sources of potable water, such as desalination of seawater, is increasing (e.g. in South Africa – Swartz et al. 2006). In terms of marine pollution, the disposal of brine (wastewater with elevated salinity) and the chemicals used in pre-treatment and membrane-cleaning, such as antiscalants, coagulants, and cleaning chemicals (e.g. surfactants, alkaline and acid solutions and metal-chelating agents) (Elimelech and Phillip 2011, Cooley et al. 2013).

Paper & Textile productions

The wastewater composition of pulp and paper mills depends on the process that is used to produce the pulp or paper. In most processes mixtures of sodium salts (hydroxide, sulphate and sulphide) are used to digest the wood. Spent liquid (known as 'black liquor') and biodegradable organic matter are major sources of pollution in waste from paper production. One of the major waste products is lignin, which is present as lignosulphonic acid or calcium salts (Billings & Dehaas 1971; Murray 1987; Rudolfs 1953).

Fibres used in the textile industry can be divided into natural fibres (e.g. wool, hair, silk, cotton, flax, sisal, etc.) and synthetic fibres (e.g. rayon, nylon, etc.). Processing mainly involves removing the impurities and, subsequently, imparting various qualities such as dyeing and printing (Rudolfs 1953, Murray 1987; Schlesinger et al. 1971). As a result, pollutants from textile industry waste streams are diverse and vary greatly depending on the chemicals and treatment processes used (as is illustrated in Table 6.5).

Chemicals production

There are numerous types of chemical industries disposing of wastewater to the WIO region, including fertiliser factories and factories producing explosives. Wastewater produced by such industries is consequently very diverse and the composition is largely dependent on the chemicals that are produced. Potential pollutants typically encountered in waste streams from these industries are listed in Table 6.5.

Food and beverage production

Major food and beverage industries relevant to the WIO region include food canning (e.g. fruit, vegetables and meat) and fish processing plants. Pollutants typically include high suspended solids and biodegradable organic matter, while wastewater from cooling systems can result in thermal pollution (Table 6.5). In food canning plants high alkalinity (e.g. from peeling processes where caustic soda is used) and possible discolouration can also be of concern (UNEP 1982; Rudolfs 1953; Thatcher and Clark 1968).

Coastal mining (return flows)

Wastewater or return flows from coastal mining activities (e.g. mineral mining and sand mining) mainly contribute to high levels of suspended and settleable matter in coastal waters. Acid mine drainage (AMD), a waste stream produced when sulphide-containing rocks are exposed to water and oxygen and then leading to acid-induced mobilisation of toxic metals, is also a significant source of pollution at mining sites near the coast (Chalkley et al. 2019).

6.3.2.5 Transportation

Oil spills

Major sources of oil pollution originating from shipping activities include operational discharges associated with day-to-day shipping activities at sea, accidental spillages during transfer of oil in ports or at offshore moorings, continuous diffuse spillages (owing to illegal dumping, bad operational practices, etc.) and large oil spills as a result of a collision or severe structural damage to oil tankers or other vessels while at sea (Taljaard and Rossouw, 1999). The input from operational and accidental spillages is typically diffuse and sporadic, which makes realistic quantification extremely difficult. Major oil spills, in contrast, occur on a different scale, being massive instantaneous events of which the impact is largely dependent on the magnitude and location of the spill and the type of oil spilled.

Chemical constituents associated with oil pollution consist mainly of petroleum hydrocarbons (including poly-aromatic hydrocarbons) and trace metals (Neff, 1979; Swann et al. 1984). The type and concentration of trace metals and hydrocarbons in oils depend on the fuel product and crude oil source. In crude oils, vanadium, nickel and lead are typically the most common metals. In addition to the harmful chemicals released into the sea during an oil spill, the oil slick also causes physical damage by creating aesthetically unpleasant conditions, clogging water intake systems and smothering benthic marine fauna and flora (Taljaard and Rossouw, 1999).

Ballast water

Ships take on ballast water at sea to increase their stability. The risk associated with ballast water discharges from ships is mainly the introduction of exotic organisms, which occurs when ballast water taken from one part of the ocean is discharged into another. In this way the natural ecological balance is upset, resulting in a variety of secondary problems. There is increasing concern, both nationally and internationally, that a wide variety of marine plants and animals (including pathogens) has been transported in the ballast water of ships and introduced into foreign countries.

Port & harbour activities

Activities in harbours that could result in marine pollution are numerous, including:

- Dry dock activities
- Cleaning and maintenance of vessels within harbours (e.g. dust from sand blasting), as well as emptying of toilets into harbour areas
- Dumping of blood water into harbours, as well as off-cuts and offal from fish cleaning operations being washed down into stormwater drains and eventually ending up in the harbours
- Poor waste disposal practices during the scraping and cleaning of ships, which eventually results in chemical pollution of harbour waters, e.g. by antifouling paints
- Litter which ends up in harbour basins as a result of wind, stormwater discharges or by being directly discarded from ship, and oil originating from an accidental spill from a vessel in harbour.

Harbour water is particularly prone to pollution because harbours are sheltered basins, often with poor water circulation. Pollutants entering harbours, therefore, tend to accumulate. Because the sources of pollution entering harbours are diffuse and often intermittent, it is very difficult to quantify such contaminant loading, in contrast to sewage or industrial point discharges. Pollutants associated with sources in harbours are diverse, depending on the source.

Dumping of dredge spoil

Sediment removed during regular maintenance dredging to maintain the depth of shipping channels in harbours is often dumped at sea. Contaminants associated with the dredged material results from the activities associated with the dredged area. Based on its inherent character, common pollutants associated with all dredged spoil are suspended and settleable solids. Harbour sediments are often contaminated with toxic chemicals such as metals and hydrocarbons (Kleinbloesem and Van der Weijde 1983, Stronkhorst and van Hattum 2003, Renzi et al. 2009). When spoil is dumped at sea these chemicals may be released, under suitable conditions, to the receiving marine environment. In contrast, dredged material from ecologically productive areas such as estuaries may contain high concentrations of biodegradable organic matter (Badenhorst 1986). Deep dredging in harbours can also yield sediments that are naturally high in metals of geological origin.

6.3.2.6 Energy production

Offshore oil and gas exploration

Offshore oil and gas exploration is primarily an ocean-based source of pollution. Drilling processes associated with such exploration produce waste streams that include drill cuttings, excess cements, drilling mud fluids, produced water (containing oil) as well as other chemicals. The spatial extent of these discharges varies with the volume of discharge, depth of discharge, local hydrography, particle size distribution, rates of settlement and floc formation, and time since discharge (Cordes et al. 2016).

Oil refineries

A large variety of pollutants may be present in waste streams from refineries including (Rudolfs 1953; UNEP 1982) (Table 6.5):

- Oils (e.g. petroleum hydrocarbons, volatile organic compounds, poly-aromatic hydrocarbons) which could be present as free oil floating on the surface or as an emulsion suspended in water.
- Condensate waters, originating from distillation processes and which can contain high organic loads and reducing chemicals, as well as inorganic and organic toxic substances (e.g. ammonia, cyanides, metals and phenols).
- Acid wastes, which originate from processes in which sulphuric acid is used as a treating agent.
- Caustic wastes originating from washing acidic materials from certain crude oils, resulting in very alkaline (high pH) wastewater, which also has high organic content and toxins such as mercaptans, sulphides and phenols.
- Cooling water (thermal pollution).

In accordance with the *Principle 4: Polluter Pays principle*, owners or designated managers of activities identified as potential pollution sources should take accountability for achieving legislative requirements, providing both the human and financial resources to do so. Key aspects pertaining to such activity-based management are addressed in next chapter.

6.4 Activity-based Management Programmes

Nel and Kotze (2009) aptly noted that in environmental management *'the environment is not managed, but that activities, products and services are managed to prevent undesired change to the affected environment'*. This also applies to C&MWQM, where the collective aim of activity-based management programmes is to control or prevent pollution and to achieve the overarching environmental quality objectives and targets as agreed upon for the study area (Taljaard et al. 1012). While the objective setting phase (see Figure 6.1) is usually a cross-sectoral consultative process, activity-based management, involving the technical planning and operations of specific activities, often maintain a stronger sectoral focus. This is acknowledged in the Implementation Framework where activity-based management, even though largely sector-based, is embedded in a broader, ecosystem-based approach (Taljaard et al. 2013).

The identification of specific sectors and activities for which management programmes need to be developed and implemented should cover both existing as well as planned activities. In the case of C&MWQM, some of the key sectors and activities that could potentially contribute to pollution, are listed in Table 6.5. The expertise to develop and implement activity-based management programmes typically resides with the responsible sector authorities, their service providers, and the related developers and managers. For example, the management of wastewater requires technical and engineering expertise on the technologies available to prevent, minimise, treat and dispose of wastewater. Such skills usually reside in the waste and wastewater (technical) sector and are not located, for instance, in the environmental sector although the latter may fulfil the function as custodian of the marine environment (Taljaard et al. 2012). Provided that various sectors aim to adhere to common environmental objectives and targets, their focus can remain on the (technical) management activities within the sector.

Experience in integrated coastal management (e.g. Taljaard et al. 2012) has shown that effective activity-based management, within a broader ecosystem-based approach, largely dependent on:

- Formal (activity-based) legislation (providing a legal avenue to enforce compliance, although this should not exclude incentives for implementing pollution control measures);
- Standards, Guidelines and Best Practice Guides to assist decision-makers and managers with the practical execution of pollution control or preventative measures, as well as to enforce sustainable environmental best practice;
- Resource Planning, ensuring that identified activity-based interventions and actions are through sufficiently skilled and motivated personnel, equipped with the appropriate material and financial resources throughout planning, construction, operations, and even decommissioning; and
- Contingency Planning, pre-emptive planning to mitigate and control potentially detrimental impacts on the coastal and marine environment during unexpected mal-functioning or accidents.

6.4.1 Formal (activity-based) legislation

Most countries in the WIO region have some form of formal legislation in place towards protecting the marine environment, mostly in accordance with obligations in terms of an array of international conventions and/or agreements (UNEP et al. 201a). These include overarching pieces legislation, typically referred to as 'Environmental Management Act', 'Environmental Protection Act', or 'Environmental Law' that set out broad requirements pertaining to environmental management. However, such broad-scale legislation is not necessarily translated into sector-based implications. In some countries, sector-based legislation has been promulgated which also addresses environmental requirements (e.g. marine pollution from shipping), but this is not necessarily the case throughout all sectors. Although overarching environmental legislation remains critically important to determine a country's intent towards environmental protection, the enforcement of sound environmental practice from within a specific sector is often easier if such environmental requirements are also embedded in sector-specific legislation. In accordance with the *Principle 4: Polluter Pays principle*, those owners or designated managers should take accountability for achieving legislative requirements.

6.4.2 Standards, guidelines and best practice guides

Formal legislation (e.g. Acts) typically provide the 'do's and don'ts' pertaining to the issues at hand, seldom expands on specifications or guidance on the achievement thereof in practice. In this regard standards, guidelines and best practice guides become useful mechanisms whereby to translate legislation into (sector- or activity specific) best practice. These may include:

- Effluent emission standards

- Water quality standards (e.g. the *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine Areas*)
- Best practice for municipal waste and wastewater treatment
- Guidance on green technologies for industries.

In some cases, regional support on standards, guidelines or best practice guides can be provided in order to encourage a harmonised approach across countries in the region (e.g. see Chapter 4). However, it still remains the responsibility of individual countries to adopt these as official national policies.

Historically, limits for pollution sources (e.g. effluent discharges) are set in terms of Uniform Effluent Standards, where the constituent limits are set uniformly for specific effluent types, not necessarily considering the volume of the waste streams nor the assimilative capacity of the receiving environment. In contrast, the 'Receiving Water Quality Objective (RWQO) Approach' principle requires that the limits be set for pollution sources take into account the environmental quality objectives associated with site-specific coastal and marine ecosystems, as well as the beneficial uses of such ecosystems. Therefore, to apply the RWQO approach in setting limits for pollution sources it necessary to perform environmental assessments, taking into account the character of related pollution (or potential pollution) sources, site-specific environmental processes (physical, chemical and biological), as well as the receiving environmental quality objectives (or targets) for designated (or future) beneficial uses.

Difference between Effluent Standards and Water Quality Targets (or Water Quality Standards)

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

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

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

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

Important environmental processes that need to be considered in the environmental assessment for setting limits for pollution sources in coastal and marine systems include (Bartram and Balance 1996):

- Transport, flow, turbulence, flushing, mixing and stratification
- Biogeochemical processes
- Biological characteristics

- Contaminant behaviour (e.g. sedimentation, burial, resuspension and diffusion).

6.4.3 Resource planning

Ultimately, activity-based management entails the execution of identified pollution prevention or control measures interventions or actions that stem from an assessment of important ecosystems and uses versus potential pollution sources in the hotspot. The effective implementation of such interventions and actions, however, relies heavily sufficient human, material and financial resources, which in turn, needs to be planned and budgeted for by those responsible for the execution of such interventions or actions. Of course, such resources planning needs to be informed by the specific requirements pertaining to each of the identified interventions and action (a proposed template for the design and planning of activity-specific objectives and actions, to inform resource planning, is provided in Appendix B). Owners and designated managers of various activities need to make provision in their organisational budgets to appoint appropriately skilled staff, as well as allocate dedicated budgets to address environmental requirements and pollution issues that may emerge as a result of their operations. Also, in line with *Principle 4: Polluter pay principle*, owners or designated managers of activities posing pollution risks should be held accountable for supplying resources for the implementation of pollution prevention or control measures.

The Deming cycle is a popular management model widely applied in organisations as environmental management system (Nel and Kotze 2009). It applies an iterative problem-solving process which includes four elements, namely planning-doing-checking-acting (PDCA) (Walton 1986). ISO14001, a standard for environmental management systems issued by the International Organization for Standardization, is based on this model (ISO 2020). Similarly, responsible government departments need to plan for and appoint skilled officials to perform control and enforcement roles, also ensuring that necessary material and financial resources are made available to perform such roles.

6.4.4 Contingency planning

Contingency planning aims to pre-emptively plan for mitigating and controlling detrimental impacts on the coastal and marine environment during unexpected malfunctions or accidents. Oil spill contingency plans are an example. However, such plans can also be prepared for other activities potentially impacting on the marine environment, such as wastewater and industrial treatment systems. A contingency plan needs to address aspects related to the malfunctioning or breakdown of operations, and prevent of pollution of the marine environment. A plan primarily consists of four sub-components (a template for a contingency plan is provided in Appendix C – UNEP & OCHA Environment Unit 1996):

- Mechanisms for detection of problems - monitoring of operations and systems to timeously detect problems pertaining to a malfunctioning or breakdown ('early warning signal')
- Stipulated procedures and responsibilities - provision of schedules is crucial for rapid and effective implementation of contingency plans
- Action plans - a clear action plan that sets out mitigating measures to protect ecosystems and beneficial uses of the affected marine environment. These include, for example, site notice boards or media releases (newspapers, radio or television) informing users (public) of the potential risks, demarcation of polluted areas, notification of industrial users of seawater and marine aquaculture farms, as well as procedures to be followed in assisting with protection of such facilities against pollution
- Reporting – stipulating procedures and protocols for reporting events of malfunctioning/ breakdown of operations and systems, including internal procedures, as well as reporting to responsible authorities on local, regional, and national levels.

6.5 Environmental Quality Monitoring & Evaluation

The design and implementation of environmental quality monitoring and evaluation programmes forms an integral and critical element of the operational phase in the Implementation Framework. However, in C&MWQM monitoring and evaluation is a means to an end, providing data and information to test for compliance and, most importantly, inform activity-based management intervention. This is illustrated in Figure 3 by the feed-back loop to activity-based management programme in the Implementation Framework. In line with *Principle 4: Polluter pay principle* owners or designated managers of activities posing pollution risks could be held accountable for the execution of monitoring programmes, or contribute towards such programmes. Environmental quality monitoring is dealt with in greater detail in Chapter 7. However, some of the most prevalent monitoring programmes encountered in C&MWQM include:

- Compliance monitoring (usually associated with specific pollution sources)
- Beach water quality programmes (aimed at assessing suitability for recreational use)
- Mussel watch programmes (aimed at tracking long-term trends in pollutant loading along coastal areas using filter-feeding organisms, e.g. mussels)
- Marine litter monitoring
- Dredge monitoring (linked to disposal of material dredged from ports and harbours).

6.5.1 Compliance monitoring (specific pollution sources)

Compliance monitoring, usually associated with specific pollution sources (e.g. municipal or industrial wastewater discharges), typically requires:

- Source monitoring (i.e. monitoring volume and composition of pollution source)
- System performance monitoring (i.e. monitoring the status of infrastructure and treatment processes)
- Environmental monitoring (i.e. monitoring the receiving marine environment).

Source monitoring programmes primarily focus on determining whether potential pollution sources are compliant with emission targets (or critical limits). Source monitoring of point source discharges such as municipal or industrial effluents is often regulated though permitting (i.e. it is a stipulated requirement of permission to discharge) and is relatively easy to achieve as inputs are via a point source (i.e. single pipe). However, source monitoring of diffuse sources such as urban runoff, agricultural return flows or solid waste sources, is much more difficult. For C&MWQM, it is important to monitor both the volume, as well as the physico-chemical properties of waste streams. The list of physico-chemical parameters to be included in monitoring programmes depends on the type of pollution sources, and associated pollutants (e.g. Table 6.5).

Systems performance monitoring refers to regular monitoring of the infrastructure and treatment facilities (e.g. wastewater treatment plants, artificial wetlands constructed to improve the quality of urban runoff, or agricultural practices to improve quality of return flows). Such monitoring typically includes regular physical inspections of the system to identify malfunctioning or system failures, and monitoring of the performance of technical processes.

Monitoring of the receiving marine environment, as part of compliance monitoring programmes, is primarily aimed at testing compliance with predefined environmental quality objectives and targets in important aquatic ecosystems and at designated use areas. Also, such programmes are used to assess whether anticipated behaviour and impacts of a treatment facility (e.g. predicted as part of impact assessment studies) match actual environmental responses. This type of information is necessary in order to respond in good time to unanticipated negative impacts.

6.5.2 Beach water quality monitoring

Beach water quality monitoring often is undertaken at recreational areas to assess suitability of use, especially during peak holiday and tourist seasons (DEA RSA 2012b). These monitoring programmes typically focus on the collection of microbiological data to measure compliance with water quality objectives and targets for recreational use (UNEP et al. 2021b).

6.5.2.1 Sampling design

For beach water quality monitoring, sampling locations are primarily determined by the locality of recreational beaches and the specific sites along the beach should be representative of the water quality throughout the whole contact recreation area.

Microbiological samples should be collected during periods when coastal waters are used for contact recreation. A systematic random-sampling regime is recommended which implies that samples should be collected at a minimum every two weeks during daylight hours, regardless of the weather (although there may be exceptions if conditions present a health and safety hazard, in which case samples should be collected as soon as possible after the programmed time). A monitoring calendar should be drawn up for each year.

6.5.2.2 Sampling procedures and analytical methods

Samples for the analyses of both intestinal enterococci and *E. coli* must be collected. Although enterococci are recommended as the most appropriate indicator for coastal and marine waters, there may be instances where *E. coli* may be more appropriate. In subtropical areas, it may also be necessary to collect samples for the analysis of *C. perfringens* to assist with interpretation of microbiological indicator results.

Water samples are typically collected at a depth of about 15 to 30 cm below the surface where the depth of the water is approximately 0.5 metres. Samples should be collected on the seaward side of a recently broken wave, taking care not to collect backwashing water.

To ensure that all related information is captured at the time of sampling (e.g. information to assist in interpretation of microbiological data, observations on aesthetic conditions and potential presence of toxic substances) a sampling log sheet should be completed at each sampling point on every sampling occasion. Information to be captured should include (see Appendix E for example):

- Sampling location
- Date and time
- Climatic conditions (rainy, sunny, cloud cover)
- Water temperature (e.g. using an in situ probe)
- Salinity (e.g. using an in situ probe)
- Presence of objectionable matter
- Presence of potentially harmful algal blooms
- Indication of potential presence of toxic chemical substances (including chlorine)

- Comments: Any other observations that may be of relevance for interpretation of the data.

Samples collected for *E. coli* analyses should be analysed on the day of sampling - preferably within 6-8 hours after sampling - due to the rapid die-off of this microbiological indictor in marine waters (Guardabassi et al. 2002). Samples collected for intestinal enterococci and *C. perfringens* analyses should be analysed within 24 hours of sampling.

6.5.2.3 Data analysis

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

Commercially available substrate-based methods for microbiological determinations

New substrate-based methods are commercially available for the detection and enumeration of intestinal enterococci and *E. coli* in water are available on the market. For example, Enterolert (IDEXX Laboratories Inc., Westbrook, Maine) is a miniaturised, most probable number method for the determination of intestinal enterococci (Budnick et al. 1996). This method allows for easy, rapid, and accurate detection of enterococci in water. More specifically, Enterolert-E (www.idexx.com/view/xhtml/en_us/water/enterolert-e.jsf) was developed for the European market and correlates with the EU Bathing Water Directive standard method for enterococci (ISO 7899-1). A similar product, Colilert (IDEXX Laboratories Inc., Westbrook, Maine) is available for the determination *E. coli* in water (www.idexx.com/view/xhtml/en_us/water/colilert.jsf). Colilert is approved by the US-EPA and is included in Standard Methods for Examination of Water and Wastewater. Care should be taken when using Colilert technique for analyses in seawater as it can produce false positive results (e.g. Pisciotta et al. 2002). Incubation at 44.5°C was found to prevent most false positives caused by marine bacteria.

Where microbiological assessments are rated against a percentile target value (e.g. 95 percentile $\leq$100 counts per 100 mℓ) it is important to ensure an appropriate sample size. For example, in rating beach water quality using microbiological data collected weekly or bi-weekly, it is recommended that a 12 month running period is applied (in contrast to the typical 5-year period recommended internationally). This is considered most appropriate for situations where the microbiological quality of recreational waters can change markedly over short period. This approach allows for a closer to real-time classification process (e.g. monthly rather than yearly), recognising such variability (DEA RSA 2012a).

Calculation of percentile values for microbiological parameters

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

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

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

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

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

- For n data, X_i, such that i = 1, 2, …, n, rank the n data from lowest to highest where ranked data is Y_i: i = 1, 2, …, n
- Compute the percentile fraction (i.e., proportion) as $p = P/100$ (P is e.g. 95percentile)
- Check if there are enough data to make the calculation, i.e., if $n >= 1/[2(1-p)]$ and $n >= 1/(2p)$ [first limit applies for an upper percentile ($p > 1/2$), and vice versa]
- If there are enough data then calculate the Hazen rank (usually non-integer) $r_{Hazen} = 1/2 + pn$
- Interpolate between integer ranks (i.e., ranked data) adjacent to the Hazen rank using Hazen *P*th percentile = $(1-rf)Y_{ri} + rfY_{ri+1,}$ where *ri* = the integer part of r_{Hazen} and *rf* = fractional part of r_{Hazen} [note that the formula still works if there is just enough data, i.e., for equalities, instead of inequalities, in the equations in item 3 above].

6.5.3 'Mussel watch' programmes

The 'Mussel watch' concept was originally coined by Goldberg (1975) as a bivalve sentinel organism approach to assess geographic status and temporal trends of various chemicals of environmental concern in the coastal environmental (Farrington et al. 2016). The concept is based on the rationale that bivalves (e.g. mussels and oysters) are widely distributed along coasts and because they are sessile they can reflect comparative spatial, but especially temporal trends. These organisms are also good indicators for monitoring environmental quality because pollutant levels in their tissue respond to changes in ambient levels in the environment and accumulate with little metabolic transformation (Kimbrough et al. 2008).

6.5.3.1 Sample design

Because one single species of mussel or oyster is not common to all coastal regions, different target species may have to be used, e.g. mussels (e.g. *Mytilus* species or *Dreissena* species) and oysters (*Crassostrea virginica*). However, caution should be taken when comparing results across species as different species may have different bio-concentration rates for different chemicals (Farrington et al. 2016).

Sampling design for mussel watch programme can be done at various scales from regional, national to local (e.g. pollution hotspots) levels, depending on the purpose (e.g. track compliance or determine long-term trends). To obtain reliable data it is important that selected locations supporting stable populations of bivalves. Also, the concentrations of chemicals in bivalves versus surrounding waters can be influenced by several factors, including life stage of organisms, reproductive status, nutrition, temperature, salinity, interactive effects among chemicals, and particulate matter concentrations in the water column. For these reasons, spatial or temporal comparison should be made with caution where these factors differ among location or sampling periods (Farrington et al. 2016).

6.5.3.2 Sampling procedures and analytical methods

A detailed description of sampling and analytical procedure applicable to 'Mussel watch' monitoring programmes is available from the National Oceanic and Atmospheric Administration (NOAA) and is based on their extensive programme running across the US Apeti et al. (2012). It is recommended that countries in the WIO region intending to undertake 'Mussel watch' programmes consult with this NOAA methodology. The manual provides details from preparation for field sampling through to sample transporting.

An array of chemicals is analysed for in mussel watch programmes, including metals, petrochemical (e.g. poly-aromatic hydrocarbons), persistent organic pollutants such as (e.g. pesticides, polychlorinated biphenyls and butyl tin). Critically important in the analyses of these chemical is proper performance based quality assurance (QA) processes to ensure data quality performed by competent analytical laboratories (Kimbrough et al. 2008).

6.5.3.3 Data analysis

Kimbrough et al. (2008) provide guidance on data analyses for ‘Mussel watch’ programmes. Where the aim is to assess trends over time, Spearman’s rank correlation can be used to evaluate whether concentrations co-vary predictably over time. The Spearman’s rank correlation procedure is a nonparametric technique that is free of assumptions about concentrations being normally distributed with a common variance about locations.

6.5.4 Marine litter monitoring

To develop uniform ways of measuring marine litter the Sustainable Seas Trust and WIOMSA published the *African Marine Litter Monitoring Manual* in 2020 (Barnardo and Ribbink 2020). This stemmed from the lack of data on marine litter in the African region for strategic evidence-based management decisions. It is imperative that data are comparable across regions and countries and this requires a standardization of data collection methods.

6.5.4.1 Sample design

In the design of a litter monitoring programme (i.e. location of sampling sites and frequency of sampling), it is important to consider for example (Barnardo and Ribbink 2020):

- Location of potential sources of marine litter
- Type of litter to be expected (based on the sources)
- Transport and dispersion processes of litter in a receiving marine environment (e.g. influenced by tides, currents and winds).

A good practice is to develop a litter baseline against which to compare follow-up monitoring surveys.

6.5.4.2 Sampling procedures and analytical methods

Litter monitoring can take place in different habitats and this requires different sampling methods. The *African Marine Litter Monitoring Manual* (Barnardo and Ribbink 2020) provides monitoring protocols for five different habitat types (i.e. shorelines, mangroves, water column and surface of river/estuaries, street surveys and non-linear terrestrial habitats such as parks). Consideration and of specific size classes of litter (macro-litter (>25 mm), meso-litter (5–25 mm), and micro-litter (<5 mm, in their longest dimension)) is important as sampling techniques differ based on the size class. Good practice is to incorporate quality control measures in sampling procedures and analytical methods (Barnardo and Ribbink 2020). Specific guidance on plastics monitoring is provided in GESAMP’s *Guidelines on the monitoring and assessment of plastic litter and microplastics in the ocean* (GESAMP 2019).

6.5.4.3 Data analysis

The *African Marine Litter Monitoring Manual* (Barnardo and Ribbink 2020) also provides guidance on data analyses which differ across different types of surveys and habitats. For example, estimates of marine litter abundance may be expressed as number or mass (kg) per unit distance (km), area (km^2) or volume (m^3). Accumulation rates require a temporal unit, which may differ depending on oceanic processes governing litter dynamics, for example the amount of litter may be influenced by tidal cycles or seasonal winds (GESAMP 2019).

6.5.5 Dredge monitoring (ports and harbours)

Dredging is essential to maintain navigation channels in ports and harbours. Dredged material is typically disposed at sea, although increasing standard practise is to investigate beneficial uses of dredged material as an alternative to disposal. Dredging activities can include capital dredging (e.g. expansion or building of new port channels and basins), maintenance dredging (e.g. maintaining existing channels and basins) or clean-up dredging (e.g. removal of contaminated material health and environmental protection purposes) (IMO 1996).

A number of countries within the WIO region are signatories to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) (1972) and London Protocol (1996) that deals with the dumping of waste to the marine environment. Under the London Protocol, all dumping of waste and other matter at sea is prohibited, except for possibly acceptable wastes on the so-called ‘reverse list' of which dredge material is one (DEA RSA 2012a). Whether these wastes are permitted for dumping needs to be assessed using a procedure written into the London Protocol as set out in Annex II of the Protocol.

To assist countries the International Maritime Organisation (IMO) has published a Dredge material assessment framework (Figure 6.7) providing procedures to follow in the assessment of dredge disposal and monitoring of potential effects on the environment (IMO 1996).

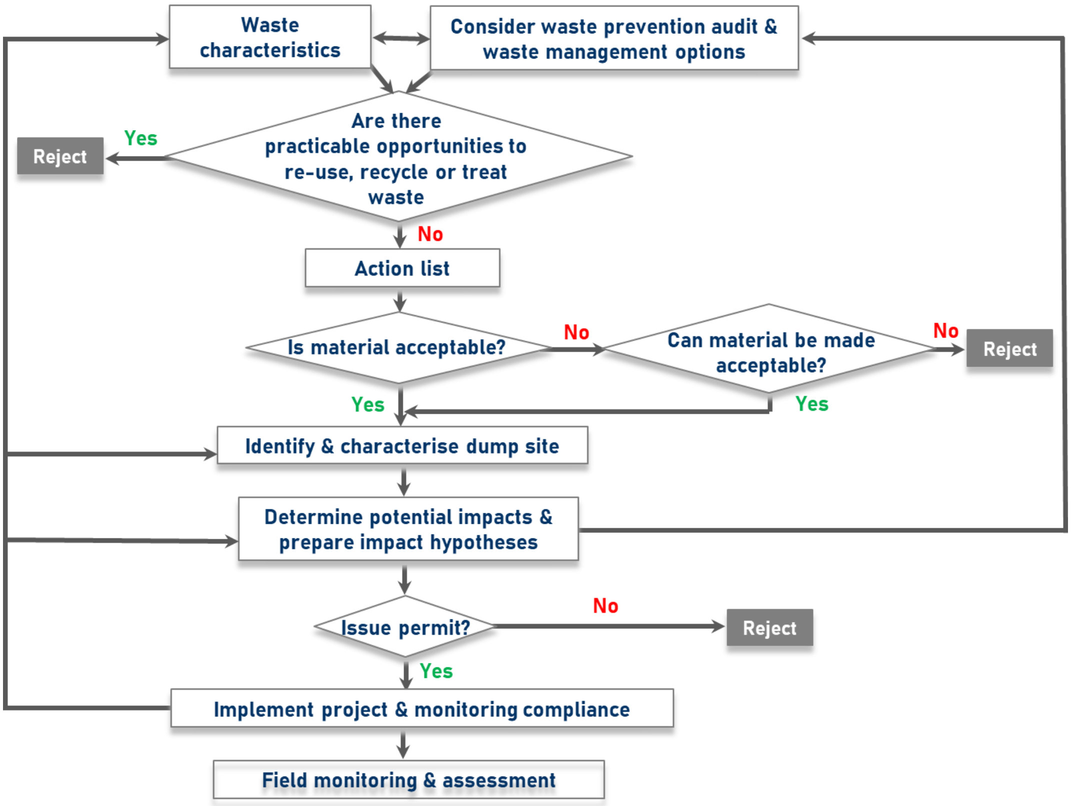


Figure 6.7 London Convention & Protocol: Dredge material assessment framework (IMO 2018)

As per the Protocol member states are required to develop national Action List to provide a mechanism for screening constituent concentrations in sediment earmarked for dredging and disposal thereof at sea (e.g. DEA RSA 2012a). An Action List specifies the upper level and possibly also levels for constituent concentrations in sediments that would have acute or chronic effects on human health or sensitive marine ecosystems – known as Action Levels.

The Action Levels, therefore, provide the decision criteria for determining whether dredged material (i) is suitable for unconfined, sea disposal without further testing, (ii) must undergo detailed testing before a decision can be made, or (iii) is unacceptable for unconfined, disposal at sea and thus requires special management.

6.6 Environmental Quality Status Reporting

Status reporting refers to the reflective, high level evaluation on the environmental and social conditions, trends and pressures performed in specific regions, countries, or even local embayments. These reports can be produced at local (hotspot) and national levels, feeding into regional status reporting (Figure 6.1) contributing to global commitments and agreements.

Status reporting usually takes the form of State of Environment (SoE) Reports (e.g. UNEP et al. 2015), which cover different themes, such as ‘Coastal and Marine’, ‘Atmosphere and Climate’, ‘Land’, ‘Water’, ‘Biodiversity’ and ‘Culture and Heritage’. Reporting on coastal and marine quality matters makes up an important sub-section under the ‘Coastal and Marine’ theme. The driver-pressure-state-impact-response (DPSIR) model is a global standard often adopted for SoE reporting, linking environmental status with related social, economic and political landscapes (Australian Government 2016; SPREP 2020) (Figure 6.8).

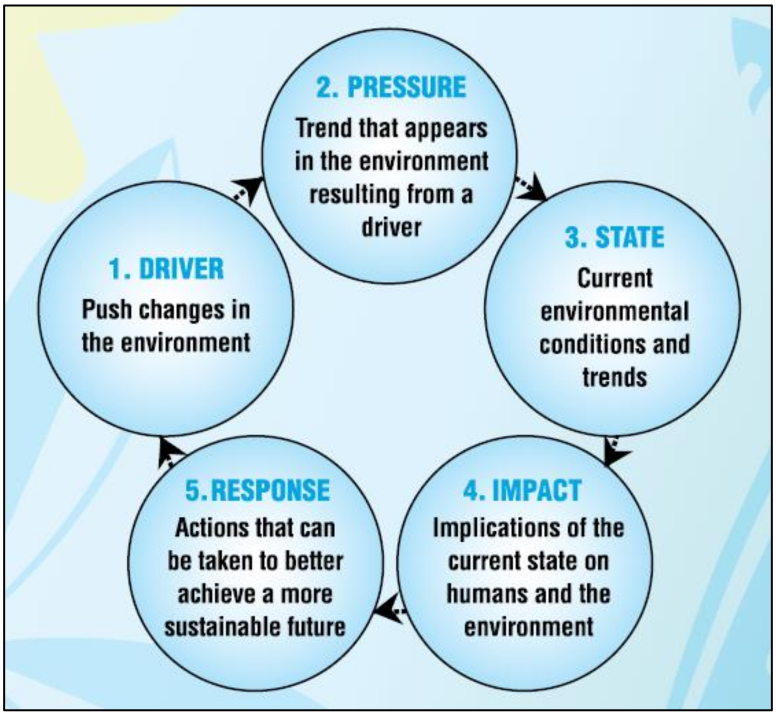


Figure 6.8 Schematic of DPSIR model typically adopted for SoE reporting (Source: SPREP 2020)

Ideally, data and information for SoE reporting should not be generated independently, but rather flow from monitoring programmes that are already undertaken within the Implementation Framework of C&MWQM (Figure 6.1). Therefore, SoE reporting should draw on marine water quality monitoring programmes for its information (a template for status reporting is provided in Appendix F).

SoE reporting provides an avenue through which to mainstream the importance and status of coastal and marine water quality within a region, country or local area because these reports often are used to inform (SPREP 2020):

- Regional, national and local environment planning (based on gaps and priorities identified)

- Project identification (e.g. based on gaps identified in datasets, monitoring, and implementation)
- Cross-sector collaboration (e.g. based on opportunities for interagency collaboration identified)
- Sustainable Development Goals reporting (e.g. tailoring indicators to meet SDG reporting requirements) (e.g. linking to Ecosystem Monitoring Framework – see Figure 6.2).

7. DESIGN OF ENVIRONMENTAL QUALITY MONITORING PROGRAMMES

Ecosystem-based monitoring and evaluation programmes in support of C&MWQM typically comprise (UNEP et al. 2009c):

- Baseline measurement programmes, referring to (usually) short-term, intensive investigations on a wide range of parameters to obtain a better understanding of ecosystem functioning (although long-term baseline programmes can also be conducted for selected parameters to track larger-scale environmental variability).
- Long-term monitoring programmes, referring to ongoing data collection programmes that are primarily targeted at continuously evaluating effectiveness of management strategies and actions designed to maintain a desired environmental objectives and targets.

This chapter provides guidance on the design and implementation of baseline measurement and long-term monitoring and evaluation programmes related to C&MWQM.

7.1 Baseline Measurement Programmes

The main purpose of baseline measurement programmes is to develop an understanding on the physical, biogeochemical and biological characteristics and processes, as well as their site-specific interrelationships, to gain an understanding on ecosystem functioning. Although the focus might be on site-specific coastal and marine ecosystems, it might also be important to gain understanding of the influence of adjacent ecosystems, e.g. inputs from upstream river catchments or exchanges across oceanic boundary. Together with data and information on pollution sources, baseline measurement programmes are crucial for quantitatively assessing or predicting the impact of human activities within a particular study area, and subsequently for deciding on appropriate management actions that will ensure sustainable utilisation of the resource. Baseline monitoring programmes are also important in setting environmental water quality targets, where these are based on a reference data approach (i.e. reference data from a specific site are used in deriving targets for system variables).

7.1.1 Physical data

Data on physical parameters are required to quantify hydrodynamic (or water circulation) processes and sediment dynamics (i.e. the transport, deposition and re-suspension of sediment particles) that are key determinants of the transport and fate of pollutants in the coastal and marine environment. Typical data and information required includes:

- Bathymetry
- Winds
- Currents
- Tides
- Waves
- Water column stratification
- Geomorphology.

7.1.1.1 Bathymetry

The bottom topography or bathymetry of a particular area strongly influences its hydrodynamic and sediment dynamic processes (Figure 7.1). Bathymetric surveys are usually once-off unless there is evidence that the bathymetry of an area has been markedly modified, e.g. after a large flood that may have altered the configuration of the sea bottom.

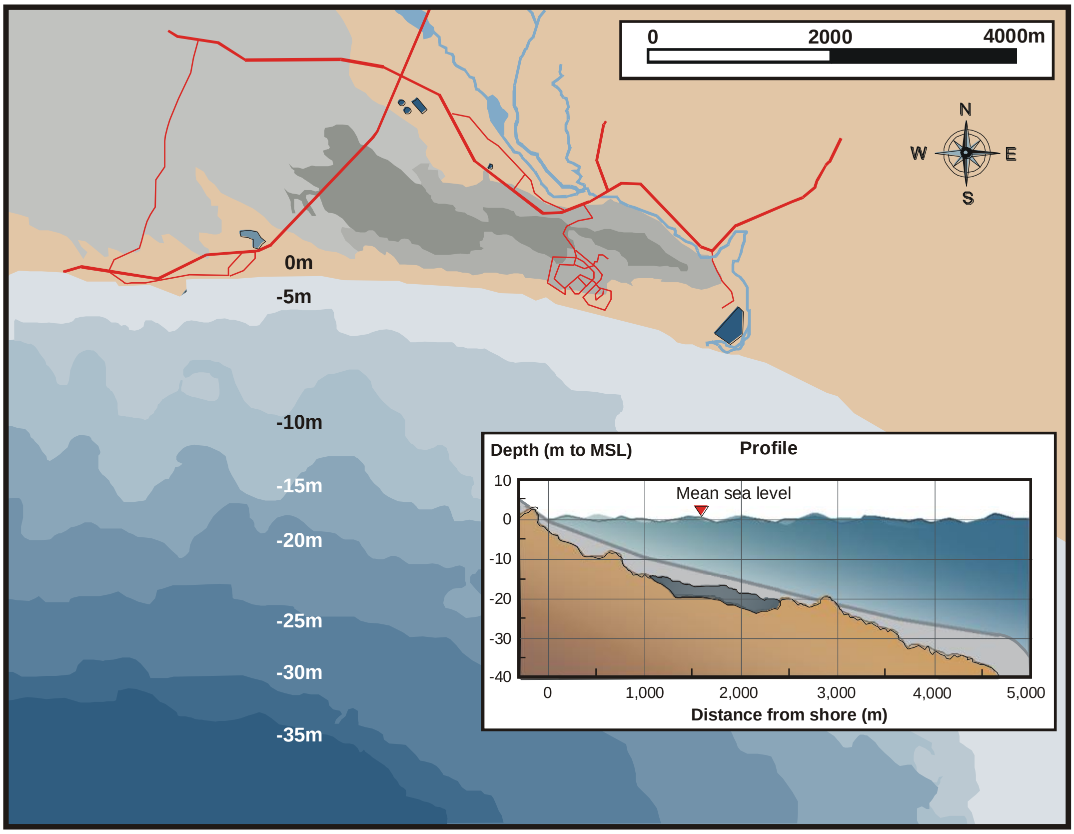


Figure 7.1 Example of bathymetric contour map and typical profile (Source: DWAF RSA 2004)

A bathymetric survey measures the depth at a large number of sites using an echo-sounder operated from a survey vessel. Integrative survey software packages are available that provide accurate position fixing, capturing of bathymetric data and corrections for tides and swells (DWAF RSA 2004).

7.1.1.2 Wind

Wind plays an important role in the behaviour of surface currents, and consequently influences the transport and fate of pollutants. In the absence of strong ocean currents, wind-driven currents usually dominate. Wind data are collected by automatic weather stations that are deployed for a specific period considered best representative of wind fields over a specific marine system. This ‘smaller’ data set can then be correlated with long-term wind data from a nearby weather station to predict long-term wind patterns in the area. Usually wind patterns show strong seasonal variability, influenced by remote climatological conditions, but they can also be influenced by local phenomenon such as changes in the temperature differences between land and sea resulting in a strong diurnal variability (Figure 7.2) (DWAF RSA 2004). This figure illustrates the diurnal and seasonal variability that often is encountered in wind patterns along the coast.

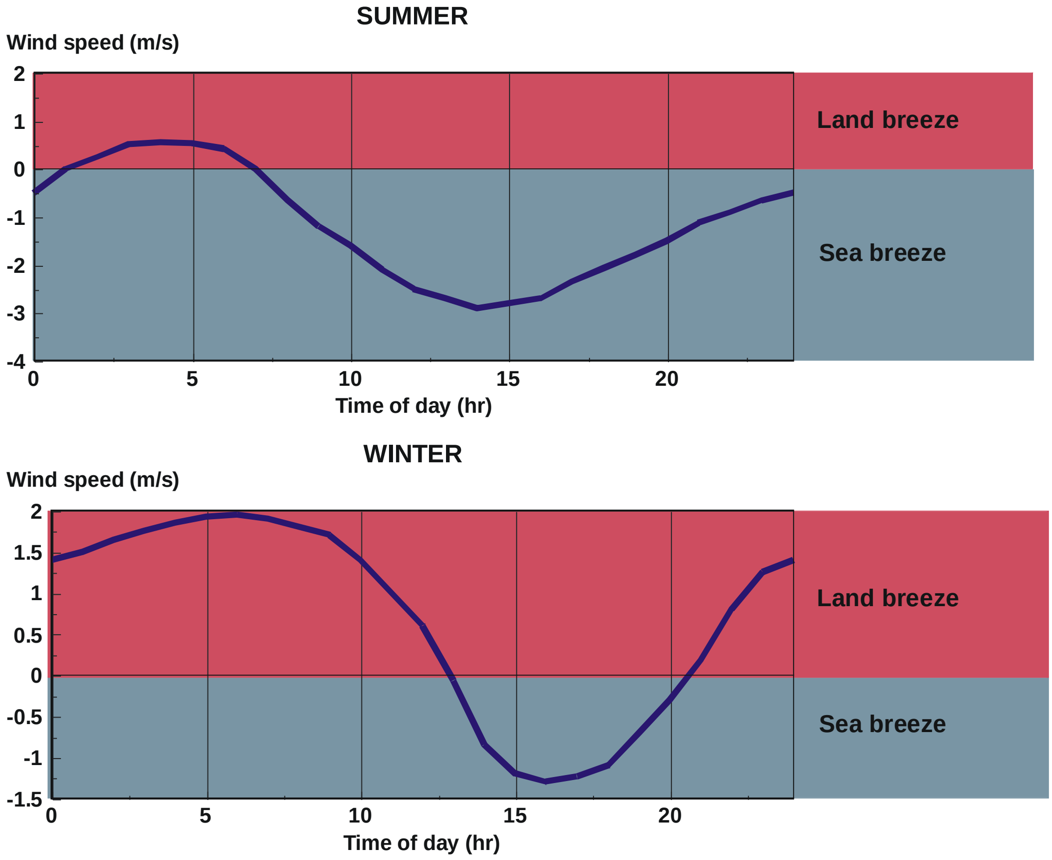


Figure 7.2 Typical diurnal land-sea breeze variations (Source: DWAF RSA 2004)

7.1.1.3 Waves

Waves are particularly important to understand deposition and redistribution of solid phase particles (e.g. sediment). Waves exert a primary influence on marine sediment dynamics especially in shallow water and along the shoreline. In the surf zone, the mixing, transport and dispersion of pollutants is primarily controlled by breaking waves, as well as currents generated by waves as they approach the shore (DWAF RSA 2004).

Wave buoys are used to record data at particular sites, usually over a one-year period. Such data can then be correlated with a nearby long-term recording station to predict long-term wave patterns. Wave data typically need to include time-series plots of wave height and period, occurrences and exceedances for wave height and period and persistence of calms and storms.

7.1.1.4 Currents

Currents (speed and direction) are the main oceanographic processes that influence the transport and fate of pollutants in the marine environment. In the offshore environment, the net current is generated by numerous driving forces including local wind forcing, ambient continental currents (e.g. the Somalia and Agulhas currents), long-shore and rip currents generated by waves, tidal currents and density differences. Closer inshore, just beyond the surf zone currents, water flow is strongly influenced by the seabed topography and the coastline's configuration. Surf zone currents are usually wave-dominated. Long-shore transport is driven by the momentum flux of shoaling waves approaching the shoreline at an angle, cross-shelf transport is driven by the shoaling waves, while water is transported out of the surf zone by rip currents. In estuaries, currents are primarily influenced by the tide, the size (cross-sectional area) of the estuary mouth and the volume and timing of river inflow (DWAF RSA 2004).

Moored current meters at fixed locations are used to collect continuous recordings (Eulerian measurements) at pre-determined time intervals in a chosen study area. Eulerian data provide the basis for statistical estimates of occurrence and persistence of current speed and direction. Lagrangian measurements are collected using drogues, drifters or dye, and determine the spatial distribution of (path and velocity) of particles within a specific area. Vertical current profiles are collected using Acoustic Doppler Current Profilers. A baseline measurement programme should adequately reflect seasonal and other cyclical current patterns, typically requiring deployments over 12 to 18 months (Figure 7.3). This figure illustrates changes in current velocity and directions, as well as a vector plot visualising direction change over time.

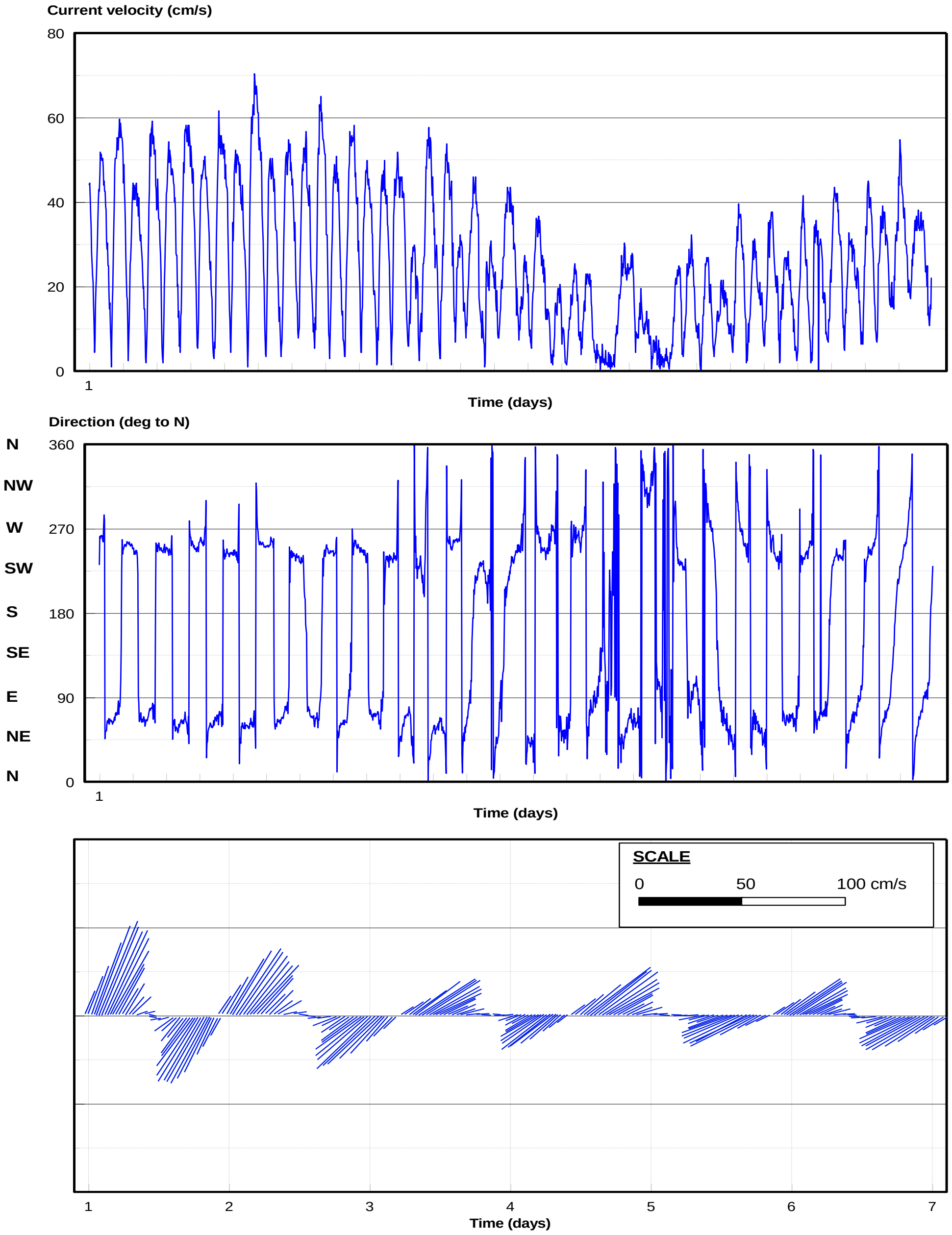


Figure 7.3 Time series data showing current velocities, directions and vectors (Source: DWAF RSA 2004)

7.1.1.5 Stratification

In the marine environment, vertical density gradients in the water column occur as a result of differences in water temperature and salinity. Vertical stratification can result in decoupling of surface and bottom water (e.g. preventing bottom water re-aeration). This can influence the dispersion of waste plumes (e.g. trapping of sub-surface buoyant effluent), thus affecting transport and fate of associated pollutants in coastal and marine waters.

Conductivity-Temperature-Depth (CTD) profilers are used to detect stratification recording both temperature and salinity profiles in the water column. Measurements should ideally be taken simultaneously with current profiling, for example, attaching CTD probes to current profilers.

7.1.1.6 Geomorphology

Geomorphological data (e.g. particle size distribution and organic content of sediments) together with data on hydrodynamic processes, informs sediment characteristics and processes (i.e. transport deposition and re-suspension). Such data are typically generated by grab sampling (essentially providing data on surface sediment characteristics) or sediment coring (providing a ‘history’ of geomorphology over time). Traditionally, samples are collected along uniform sampling grids across specific areas, although an understanding of hydrodynamic processes can be used to optimise the sampling design (e.g. identifying depositional areas using numerical modelling) (DWAF RSA 2004). Figure 7.4 illustrates a contour plot of the percentage mud fraction in an embayment, showing potential pollutant depositional areas associated with highest mud fractions.

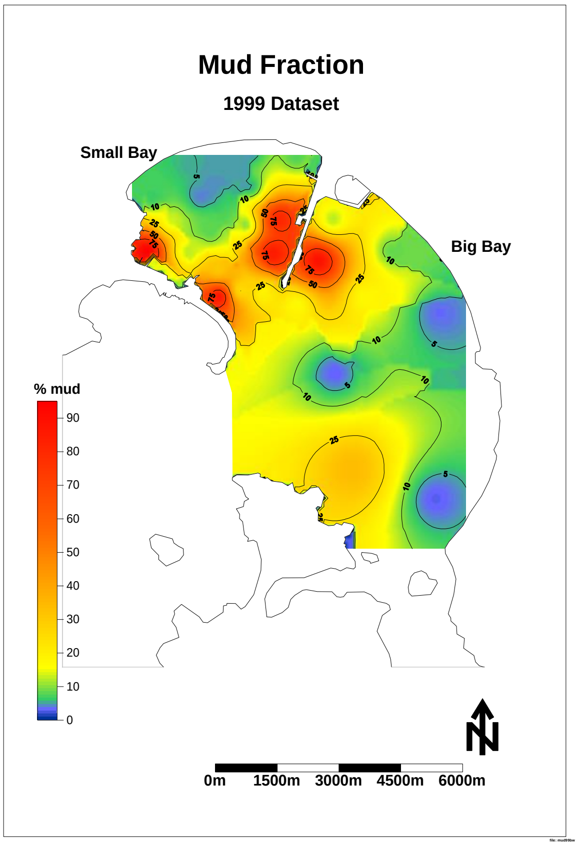


Figure 7.4 Example of spatial distribution of particle size distribution in a coastal area (Source: Monteiro 1999)

For detailed engineering studies (e.g. design of marine outfalls) more detailed, site-specific geomorphological studies are required, including:

- Seismic surveys, which are conducted to obtain information from beneath the sea-floor, using a sound source or transducer towed behind the survey vessel either on a surface float or below the surface.
- Detailed geotechnical reports to support the seismic interpretation (soil classification, cohesive and shear strength of soils, internal angle of friction, soil density characteristics, rock classification and hardness, seismic activities).

7.1.2 Biogeochemical data

Biogeochemical characterisation of the marine environment requires data on the spatial and temporal variability of biogeochemical parameters in the water column and in the sediments, as well as an understanding of the key processes that govern such variability. Biogeochemical data is also required for the calibration and validation of numerical modelling platforms (where applicable), as well as to provide a benchmark (baseline) for future long-term monitoring programmes. It is important that the manner in which biogeochemical data are collected is appropriate for different purposes. For example, numerical model calibration and validation usually requires time-series data.

It is important that data used in the characterisation reflect the present status of the receiving marine environment, i.e. any modifications to the biogeochemical characteristics and processes as a result of existing human activities need to be taken into account. This is particularly relevant when assessing the suitability of historical data sets. Information from physical measurement programmes can be used to assist in the design of the biogeochemical data collection programme, particularly in terms of setting the critical time and space scales.

Data on system variables and nutrients (e.g. temperature, salinity, pH, dissolved oxygen, turbidity, particulate organic carbon and nitrogen, dissolved nutrients) that can be measured in the water column and/or the sediments and their interstitial waters are usually standard requirements in baseline measurements programmes.

Depending on the nature of the investigation, sediment data should be collected from sub-tidal and/or inter-tidal sediments. An understanding of the physico-chemical characteristics of the inter-tidal area is particularly relevant where a wastewater discharge to the surf zone is under investigation.

The selection of metals and other toxic organic contaminants to be studied in a receiving environment is site-specific. A key determining factor in the selection of such parameters is the composition of pollution sources as well as the anticipated effects on the biogeochemical characteristics of, and processes in, the receiving environment. Therefore, the preparation of a preliminary conceptual model of the key biogeochemical processes governing the 'cause-and-effect' linkages between the likely pollution sources and the receiving marine environment is essential to the design of biogeochemical measurement programmes.

The spatial scales at which data are collected may also vary. For example, time series data collected from the water column may require only one or two pre-selected locations, whereas data on spatial distribution patterns require more intensive sampling. A guiding principle is that the initial sampling should cover the near- and far-field scales (e.g. an entire bay), making no assumptions on the locations of, for example depositional areas. This typically requires a high resolution, unbiased grid. The temporal scale of sampling should at least resolve the main source of natural variability of the constituent under investigation. Scales of temporal variability are very different in the water column (minutes - days) compared with sediments (days - seasons - decades). Non-periodic events, such as storms, can also have a dramatic influence that needs to be taken into account where appropriate. Therefore, a sampling frequency that is too low relative to the underlying natural variability will result in biased data that will make it difficult to separate anthropogenic impact from natural water quality anomalies. This is illustrated in dissolved oxygen concentrations measured in a coastal area (Saldanha Bay, South Africa, Figure 7.5). With an hourly data record (automated) it was possible to show that variability in oxygen concentrations was linked to upwelling, and that the low oxygen concentrations were brought into the system by upwelled waters rather than by any localised anthropogenic effects (Monteiro 1999). Weekly sampling would have resulted in an apparently random variability of high and low concentrations. This illustrates the importance of characterising natural variability prior to interpreting the impacts of pollutant sources on the biogeochemistry of a receiving water body.

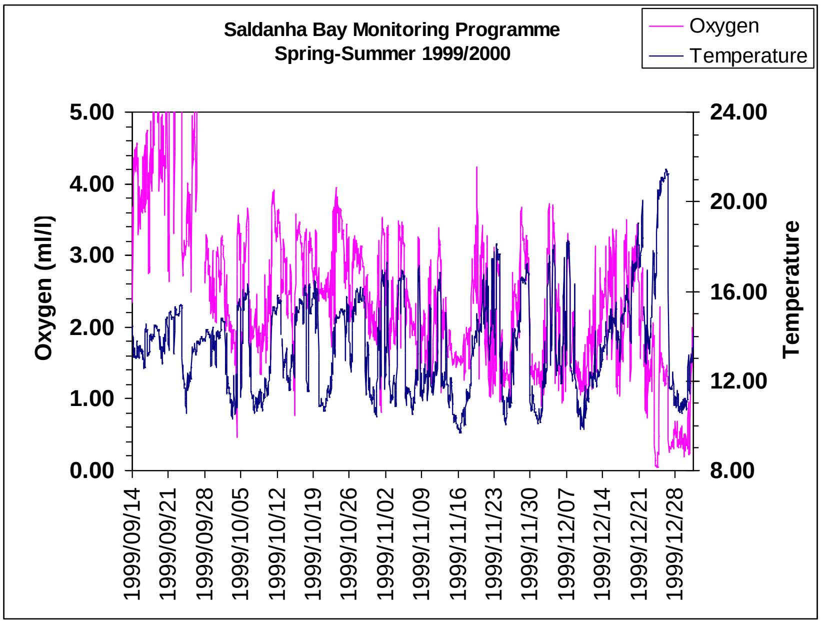


Figure 7.5 Dissolved oxygen variability in bottom water layer in a coastal area (Source: Monteiro 1999)

To interpret biogeochemical data, an understanding of chemicals behaviours immediately after entering the marine environment is required. Therefore, a description of the expected interaction of contaminants with biogeochemical processes in the receiving marine environment is important. On entering the marine environment, contaminants can either (WHO 1982):

- Remain in solution (i.e. remain in the 'free' or dissolved phase). Contaminants in the dissolved phase can either behave conservatively (i.e. their behaviour reflects only the advective and dispersive characteristics of the water body) or non-conservatively (i.e. they are rapidly transformed on entering the marine environment as a result of system variables, such as pH, salinity and temperature, being different from those in a wastewater).
- Adsorb onto solid phase particles. On entering the marine environment many contaminants, such as trace metals, poly-aromatic hydrocarbons and pesticides, adsorb onto particulate matter. Solid phase particles comprise cohesive (non-biological) particles and organic particles. Cohesive (non-biological) particles represent very fine sediment particles (<60 µm) on which adsorption phases such as aluminium hydroxides, manganese hydroxides and iron hydroxides are common. The origin of the organic particles can be natural (e.g. phytoplankton) or introduced through anthropogenic activities (e.g. sewage disposal). Adsorption to solid phase particles is typically described by means of equilibrium partitioning, on the basis of partition coefficients that are different for each solid phase particle. The transport and fate of chemical constituents associated with the solid phase is largely determined by the flux and sedimentation/re-suspension behaviour of solid phase particles.

The sedimentation/re-suspension behaviour of solid phase particles is a sensitive indicator of the potential fate of toxic compounds in the receiving marine environment (Monteiro 1999).

- Precipitate from the water column. A rise in pH and oxygen concentration of water promotes the formation of metal hydroxides, carbonates and other metal precipitates. Under such conditions, if the concentration of a trace metal is higher than the solubility of the least soluble compounds that can be formed between the metal and available anions in the receiving water, precipitation will occur. Where appropriate, solubility products and stability constants, which describe precipitation processes specific to the metal/anion complex, need to be sourced from the literature to quantify such transformations (Stumm and Morgan 1970; Faust and Aly 1981). However, most metals, with the exception of iron (Fe) and manganese (Mn) that readily precipitate their hydroxides, will usually remain in solution in seawater at concentrations that are much higher than those occurring naturally (Solomons and Förstner 1984; WHO 1982).

Another form of transformation is that which occurs in the case of certain poly-aromatic hydrocarbons, in particular volatile organics (e.g. benzene, toluene and xylene). On entering coastal and marine waters, these compounds do not follow the conventional 'dilution' behaviour. It is thought that these compounds are actually extracted out of the aqueous phase and into the buoyant hydrophobic fraction that results in their concentration in a film at the water's surface (referred to as the surface micro-layer) which subsequently evaporates to the atmosphere, rather than diluting. It is extremely difficult to predict the transport and fate of such volatile compounds in the receiving environment.

7.1.3 Biological data

Characterisation of the biology of a specific area, for the purposes of C&MWQM typically requires (DWAF RSA 2004):

- Identification of important and sensitive ecosystem or habitat types, e.g. reefs, kelp beds, sandy and rocky bottoms
- Knowledge of biota (species abundance and community composition) associated with the different ecosystem or habitat types, focusing on dominant species, species of particular conservation importance and species targeted for exploitation.

The high mobility of pelagic and planktonic organisms in the water column makes representative sampling nearly impossible and particular care should be taken when interpreting data on such organisms. In addition, the distribution and abundance of marine organisms often show strong diurnal and/or seasonal variability, depending on numerous climatic, physical and biogeochemical factors. Therefore, it is important to ensure such information is collected simultaneously and is taken into account when interpreting the ecological data. Biological data should be suitable for statistical and community analyses as proposed below. In summary, data required to characterise biological processes include:

- A geo-referenced map showing the distribution of the various ecosystem or habitat types (also to refine beneficial use map in terms of the aquatic ecosystems), highlighting areas with:
  - Biological resources of conservation importance
  - Biological resources targeted for exploitation
  - Biological resources that have been lost or are stressed as a result of anthropogenic influence.
- For each ecosystem or habitat types, a listing of the key species and their abundance and community composition, as well as expected temporal and spatial variability. This may be expensive to obtain and it may therefore be more realistic to focus on selected indicator species and community structure.

- Data on biological resources that are potentially sensitive to anthropogenic influences (existing or proposed) and information on cause-and-effect relationships.

7.2 Key Elements of Long-term Monitoring Programmes

Long-term monitoring programmes are ongoing data collection programmes that are usually less intensive than baseline measurement programmes. These programmes form an integral part of C&MWQM and are designed to evaluate:

- Effectiveness of management actions in achieving compliance with Environmental Quality Objectives, critical limits (e.g. wastewater emission targets) and the implementation of mitigating actions
- Status and trends in the environment in terms of the health of important ecosystem components and designated beneficial uses in order to respond, where appropriate, in good time, to potentially negative impacts, including cumulative effects
- Whether the predicted environmental responses, identified during the scientific assessment process, match the actual responses
- Whether the initial assumptions remain valid (for example, the geographical boundary conditions).

Important considerations for long-term monitoring programmes

- Competent skills: A range of skills and competencies are required to successfully develop and implement a long-term monitoring programme. The team therefore should include scientists with experience and expertise in various physical, chemical and biological disciplines the various fields of the programme that need to be addressed (as are identifiable at this early stage). Statistical skills are also important. While many natural scientists have a basic knowledge of statistics, most do not have a sufficiently strong grounding for the design of statistically defensible programmes. Therefore, involving a statistician from the outset can avoid numerous problems.
- Budget constraints: Environmental monitoring can be expensive, especially for programmes that cover large spatial and temporal scales. There are very few occasions when the budget is tailored to fit a long-term monitoring programme. Rather, water quality monitoring programmes are usually tailored to fit budgets. Therefore, it is important from a practical point to understand budget realities. If an available budget is insufficient to meet the requirements of a detailed monitoring programme, prioritisation of key components will be required, planning for an incremental roll out of the programmes. Reducing the scope of a monitoring programme to suit a budget also necessitates an assessment of whether the statistical validity of the programme can be maintained.
- Stakeholder communication: When designing long-term monitoring programmes, it is important to engage with key role players or affected parties pertaining to coastal and marine water quality through dedicated institutional platforms. This is important to ensure alignment with the needs and concerns of the stakeholders, and to get buy-in. Scientists must resist the urge to plan long-term monitoring programmes to align with their research expertise and interests, and rather focus on the requirements for C&MWQM within the context of the strategic framework.

Figure 7.6 illustrates the key components of a long-term monitoring and evaluation programme (e.g. (ANZECC 2000; US-EPA 2003) in alignment with the implementation framework for C&MWQM's monitoring objectives which are typically distilled from the water and sediment QTs negotiated for important aquatic ecosystems and designated beneficial uses (Chapter 6.2). Monitoring objectives can also be specified in terms of biological parameters (e.g. species diversity, abundance and community composition) that incorporate some degree of 'acceptable change' from a baseline data set and/or an appropriate control site.

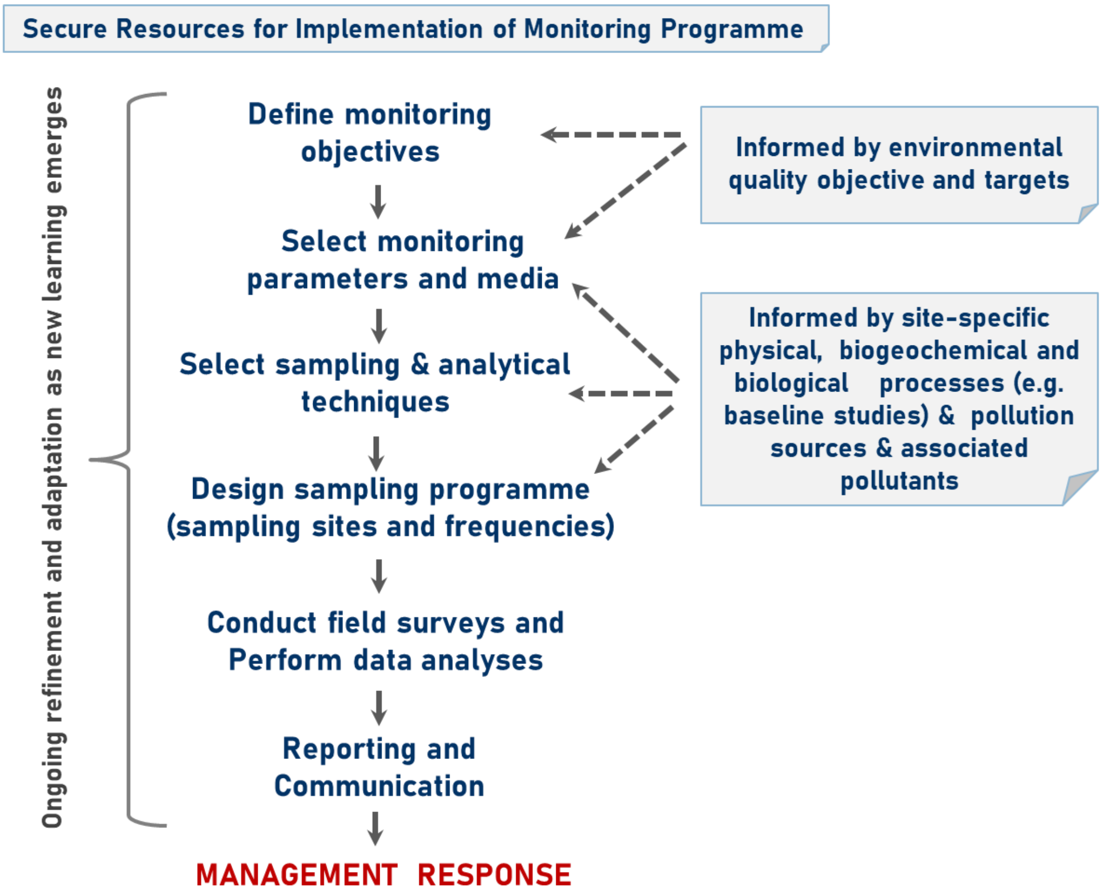


Figure 7.6 Key components of a long-term monitoring programme

Even though a structured approach is recommended for designing and implementing long-term monitoring programmes, such processes should remain dynamic and iterative, continuously adjusting efforts to incorporate new knowledge, aligned with *Principle 3: Integrated, adaptive management approach*. Guidance on each of the components is provided in the following sections.

7.2.1 Secure resources for implementation of programme

Environmental quality monitoring programmes can be costly, in terms of human, material and financial resources. It is therefore critical that before undertaking such a programme such resources are secured. Resource s for monitoring, as for the other activity-based management interventions and actions, needs to be planned and budgeted for by the authorities or organisations that are held responsible for such monitoring (usually defined in national-level legislation), or alternatively sourced from national or international environmental funding organisation. In line with *Principle 4: Polluter pay principle* owners or designated managers of activities posing pollution risks could be held accountable for the execution of monitoring programmes, or contribute towards such programmes.

7.2.2 Monitoring objectives

Measurable site-specific objectives are a key component of a sound long-term monitoring programme. Without clear monitoring objectives the danger exists that a long-term monitoring programme will become ‘monitoring-for-the-sake-of-monitoring’ rather than fulfilling the crucial role of informing and subsequently providing a means of adapting and improving C&MWQM efforts. Clear monitoring objectives are fundamental to the design of a focused and cost-effective monitoring programme.

7.2.3 Monitoring parameters and media

The selection of measurement parameters (or indicators) is site-specific and should be suitable to quantify whether monitoring objectives (as defined above) are being complied with, as well as the defined pollution sources and associated pollutants (Chapter 5). Key determining factors in the selection of monitoring parameters include (UNEP et al. 2009c):

- Range of natural variability for the indicator since this will influence its ability to detect change (very often, however, this natural variability will be unknown until the monitoring programme has generated data)
- Characteristics of existing or anticipated pollution sources
- Anticipated impacts on water and sediment quality that may affect the required environmental quality targets of aquatic ecosystems and other beneficial uses
- Collection, measurement and analysis costs involved.

Useful criteria to apply in the identification of suitability of indicators are provided in Table 7.1

Table 7.1: Useful criteria for identification of indicator suitability (ANZECC 2000)

Relevance	Does the measurement parameter reflect directly on the issue of concern?
Validity	Does the measurement parameter respond to changes in the environment and have some explanatory power?
Diagnostic value	The measurement parameter must be able to detect changes and trends in conditions for the specified period. Can the amount of change be assessed quantitatively or qualitatively?
Responsiveness	Does the measurement parameter detect changes early enough to permit a management response, and will it reflect changes due to the manipulation by management?
Reliability	The measurement parameter should be measurable in a reliable, reproducible and cost-effective way.
Appropriateness	Is the measurement parameter appropriate for the time and spatial scales that need to be resolved?

Three media can be used for aquatic monitoring, namely water column, sediment and living organisms. A major consideration in the choice of media is the environmental time spans that they reflect (Chapman 1996).

The water column is typically a highly variable environment, due to factors such as turbulence, tidal action, and often strong diurnal influences. Thus, data collected from the water column provides only a snapshot of conditions at the time of sampling, or at most about an hour prior to sampling. For this reason, the collection of numerous samples is usually required to characterise adequately conditions in the water column. This has obvious cost implications. Therefore, it is usually more appropriate (and cost effective) to focus on those environmental components that tend to integrate impacts or change over time, such as sediments and organisms. However, in some cases the choice of indicator, or need for real time data, dictates sampling media choice. For example, sampling of the water column is essential in monitoring microbiological indicators (e.g. Enterococci or *E. coli*) at recreational or marine aquaculture areas. Management of such areas requires near real time data to ensure that potential risks to human health are mitigated timeously. As a result, data need to be collected at weekly or two-weekly intervals (and even daily during high usage periods, such as vacations).

Sediment integrates environmental conditions for at least several weeks, but it can take months or even a year to observe changes in the quality of deposited sediments. Thus, fewer samples are required to characterise the quality of sediment compared to the water column. Such pragmatic considerations also play a role in the selection of the media, for example concentrations of most contaminants are much higher in sediments than in the water column which makes detection and measurement in the laboratory far easier.

Living organism media (biota) are used in various ways in long-term monitoring programmes, for example surveys of living organisms (e.g. benthic invertebrate community composition), toxicity tests, histological and enzymatic studies, and the chemical analysis of body tissues.

Filter feeding bivalves (such as mussels and oysters) are internationally recognised as suitable indicators for bio-accumulation studies in the marine environment (Cantillo 1998). The basis for biomonitoring with bivalves is their ability to bio-accumulate contaminants to a degree that is proportional to the contaminants bioavailability. Such bioaccumulation results in relatively high concentrations which makes detection and measurement easier. These organisms are also sessile, making them useful indicators for site-specific change, and when collected regularly over a wide area they provide useful insight into temporal and spatial contaminant trends. Further bivalves are consumed by humans (and indeed other organisms) and thus provide a measure of potential health implications associated with consumption.

Since it is expensive to perform detailed biological monitoring programmes it is important that scientifically sound reasons are provided for the selection of specific biotic indicator species. Rather than measuring entire biotic communities, indicator species are often identified as proxies for evaluating ecosystem health. In studies throughout the world, macroinvertebrate communities are used successfully in monitoring programmes (ANZECC 2000). In conjunction with related biogeochemical parameters, meiofauna distribution patterns have also been used successfully in this regard (e.g. in intertidal areas along sandy beaches (Skibbe 1991)). Macrophytes have also been used as long-term indicators of ecosystem health in estuaries (CSIR 2003). Fish have also been successfully used (ANZECC 2000), particularly in areas that support resident populations, such as estuaries, shoals, reefs and settlements on moored substrates. Biotic indices based on biological communities usually integrate conditions over the time required for the organisms' life cycles or development. This can range from a few weeks to several months (meiofauna, macroinvertebrates), years (fish, macrophytes) and to decades and longer (coral reefs). Where the marine environment supports biotic species of economic importance (e.g. fisheries species such as prawns) the distribution and abundance of these species are also effective monitoring parameters.

Other practical considerations in the selection of parameters and media, are the availability of appropriate technical expertise and analytical facilities to accurately measure selected parameters and logistical challenges in transferring samples from the field to the laboratory within specified holding times and conditions for analysis. Although samples of most media can be preserved in the field and frozen in the laboratory until analysis, the analysis of many water column parameters must proceed within relatively short timeframes after sample collection (a few hours in the case of bacteria, for example). Finally, a tiered approach in the selection of media and parameters is recommended, especially where resource constraints are encountered. For example, in monitoring sediment quality, the first tier may focus only on the measurement of contaminant concentrations in sediment, the second tier on sediment toxicity testing, and the third tier on analysis of benthic invertebrate community composition and structure. The logic behind a tiered approach is that it is pointless to proceed to the next tier if the first tier results do not point to a significant problem, only advancing to the next tier if a high probability for adverse environmental effects is expected.

Suggested reading:

- Scheltinga DM, Counihan R, Moss A, Cox M and Bennett J (2004) Users' guide for Estuarine, Coastal and Marine indicators for regional NRM monitoring. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management.
  http://nlwra.gov.au/files/products/national-land-and-water-resources-audit/pn21280/pn21280.pdf
- USEPA. Estuarine and coastal and marine waters: Bioassessment and biocriteria technical guidance.
  http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries.pdf.
- USEPA. Evaluation guidelines for ecological indicators.
  http://www.epa.gov/emap/html/pubs/docs/resdocs/ecol_ind.pdf.
- Environmental Protection Agency (Ireland) (2001) Parameters of water quality: Interpretation and standards.
  http://www.epa.ie/rivermap/docs/Parameters.pdf
- European Union (2014) Technical guidance on monitoring for the Marine Strategy Framework Directive.
  https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/technical-guidance-monitoring-marine-stategy-framework-directive
- British Columbia, Canada (2019) Marine monitoring guidance (aimed mainly at marine outfall monitoring).
  https://www2.gov.bc.ca/[...]/guides/forms/2021-01-05-marine_monitoring_guidance.pdf

7.2.4 Sampling and analytical techniques

Once monitoring parameters and media have been selected, appropriate sampling and analytical techniques have to be identified. A wide range of field and laboratory methods can be applied and these are far too numerous to discuss in this document. It is strongly recommended that an accredited analytical laboratory perform chemical analyses of marine biogeochemical parameters. Below are suggested literature sources that can give insight on the sampling and analytical technique for water, sediments and biological activity.

Suggested reading:

General

- USEPA guidance on field sampling.
  http://www.epa.gov/region4/sesd/fbqstp/

Water

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7.2.5 Design of sampling programmes

The spatial boundaries of a long-term monitoring programme are informed by the demarcation of important ecosystems and beneficial uses (Chapter 6.2), the location of pollutions sources (Chapter 6.3), as well as the anticipated footprint of pollutant transport, dispersion and impact, based on the understanding gained of site-specific physical, biogeochemical and biological characteristics during the baseline measurement programmes (ANZECC 2000).

Placement of sampling stations is one of the most challenging aspects of designing long-term (or impact) monitoring programmes. For example, to assess change in environmental condition relative to a (spatial) reference condition some monitoring stations (so-called 'impact stations') must be situated in the immediate vicinity of the disturbance, while others ('reference or control stations') must be located in areas that are beyond the influence of the disturbance. Ideally, physical and chemical conditions at reference stations should be identical in all ways to the impact stations with the exception of the influence of the disturbance. There are situations when locating sampling stations is much easier as they are fixed by the presence of the disturbance being monitoring and/or the location of designated beneficial use areas. For example, marine aquaculture facilities are logical sampling locations if located in areas where marine pollution sources pose potential risks to human health or the quality of farmed finfish and shellfish. Practical considerations, accessibility and safety concerns also play a role in the locations of sampling stations. It is pointless identifying a sampling station location that cannot be accessed under normal conditions. Preliminarily identified locations for sampling stations should be marked on a map or an aerial photograph, but the final locations should be decided upon only after a field reconnaissance. This reconnaissance may reveal important issues that the design team was not aware of from the map or photograph, such as the inability to access a station or safety concerns posed by sampling at the station. Should such issues arise, then the stations should be re-located. Google Earth™ (http://earth.google.com/) is a handy tool for the preliminarily identifying the locations of sampling stations.

7.2.5.1 Sampling strategy

There are two main categories of sampling strategy, namely probability-based and authoritative. Probability-based sampling strategies apply sampling theory and involve the random selection of sampling units. An essential feature of a probability-based sample is that each member of the population from which the sample was selected has a known probability of inclusion. When a probability-based design is used, statistical inferences may be made about the sampled population from the data obtained from the sampling units. Authoritative sampling strategies involve the selection of sampling units on the basis of expert knowledge or professional judgment. Authoritative sampling is not equi-probable, meaning that each member of the population from which the sample was selected does not have an equal or known probability of inclusion. Therefore, it is not possible to draw inferences about the sampled population because an authoritative bias is introduced. Thus, the validity of the data gathered is dependent on the knowledge of the sampler, and if new knowledge comes to light or previous knowledge is discredited then the validity of the data is called into question.

Methods of Probability based sampling:

- *Simple random sampling* – selecting particular sampling units (e.g. locations and/or times) using random numbers resulting in all possible selections of a given number of units being equally likely. Simple random sampling is most useful when the population of interest is relatively homogeneous (i.e. no major patterns of contamination or hotspots are expected). The main advantages of this design are that it provides a statistically unbiased estimate of the mean, proportions, and variability, it is easy to understand and easy to implement, and sample size calculations and data analysis are straightforward. Despite its simplicity, simple random sampling is rarely used in environmental monitoring programmes, because aquatic ecosystems are rarely homogenous, either spatially or temporally. Because every portion of the site has an equal opportunity to be selected, if contaminant hotspots constitute only a small portion of the total study area, random sampling will likely fail to detect them. Under these circumstances, random sampling will give undue weight to the less contaminated portions of the site. Random sampling may also be less efficient and, as a result, more expensive than other sampling strategies because it requires more samples to obtain the same result. It is most viable when the target population or study area is small.
- *Stratified random sampling* – separating target population into non-overlapping strata or subpopulations known (or thought to be) more homogeneous (relative to the environmental medium or the contaminant). This approach allows focusing on areas of greatest concern while retaining the benefits of a random sampling plan. One of the principal reasons for using a stratified design is to ensure a more representative sample by distributing the sample throughout the population's spatial and/or temporal dimensions. Advantages of this sampling design are that it has potential for achieving greater precision in estimates of the mean and variance, and that it allows computation of reliable estimates for population subgroups of special interest. The main disadvantage of this design is that the design team needs to have prior knowledge of the population in order to effectively define the strata and allocate the sample sizes. This type of knowledge is often not available in aquatic ecosystems.
- *Systematic sampling* – collecting samples at regular intervals over space or time. An initial location or time is chosen at random, and then the remaining sampling locations are defined so that all locations are at regular intervals over an area (grid) or time (systematic). Systematic designs are good for uniform coverage, ease of use, and the intuitive notion that important features of the population being sampled will not be missed. Also, samples taken at regular intervals, such as at every node of an area defined by a grid, are useful when estimating spatial or temporal correlations or identifying a pattern. Examples of systematic grids include square, rectangular, triangular, or radial grids. In random systematic sampling, an initial sampling location (or time) is chosen at random and the remaining sampling sites are specified so that they are located according to a regular pattern. Systematic and grid sampling is used to search for hot spots and to infer means, percentiles, or other parameters and estimate spatial patterns or trends over time. This design provides a practical and easy method for designating sample locations and ensures uniform coverage of a site, unit, or process.
- *Composite sampling* - involves physically combining and homogenizing environmental samples or subsamples to form a new sample (i.e. a composite sample). The chemical or biological analyses of interest are then performed on (aliquots of) the composite sample. Because compositing physically averages the individual samples, averaging few composites' analytical results can produce an estimated mean that is as precise as one based on many more individual sample results. Compositing can be very cost effective because it reduces the number of chemical analyses needed. It is most cost effective when analysis costs are large relative to sampling costs. However, it demands that there are no safety hazards or potential biases (for example, loss of volatile organic components) associated with the compositing process. Compositing is often used in conjunction with other sampling designs when the goal is to estimate the population mean and when information on spatial or temporal variability is not needed. Perhaps the most well-known form of composite sampling in the marine environment is that used for Mussel Watch programmes. In these programmes, numerous mussels are collected

from a sampling site, and the tissue is then composited and homogenised before laboratory analysis for targeted chemicals.

- *Cluster sampling* - identifying pre-defined sites and collecting several replicate samples within the site. This type of sampling is commonly used for impact monitoring programmes, especially for sampling benthic invertebrate communities since these often display considerable small-scale spatial variability. Therefore, the collection of a single sample is considered insufficient to provide an adequate understanding of the community composition and structure. Furthermore, the collection of replicate samples at each site permits the statistical comparison of data through such procedures as Analysis of Variance.

Methods of Authoritative sampling

- *Haphazard sampling* - Samples are taken in a haphazard (not random) manner, usually at the convenience of the sampler when time permits. This is only possible with a very homogeneous condition over time and space; otherwise biases are introduced in the measured population parameters. It is not recommended because of the difficulty in verifying the homogeneous assumption.
- *Judgmental sampling* - In this sampling, the selection of sampling units (i.e. the number and location and/or timing of collecting samples) is based on the investigators knowledge of the system or condition under investigation and on professional judgment. Judgmental sampling is distinguished from probability-based sampling in that inferences are based on professional judgment, not statistical theory. Therefore, conclusions about the target population are limited and depend entirely on professional judgment's validity and accuracy. Probabilistic statements about parameters are not possible. This type of sampling is commonly used in screening surveys, to document whether there is, or is not a problem with regard to a specific issue. For example, investigators may have a good understanding of the most probable sources of a contaminant in a specific area and, based on this knowledge, may focus attention on these sources only.

7.2.5.2 Sampling frequency and timing

Sampling frequency (number of samples collected over a set period) largely depends on the:

- Variability in the load of contaminants from marine pollution sources
- Variability in processes driving transport and fate in the receiving environment
- Temporal sensitivity of the ecosystem to pollutant loading, i.e. exposure time versus negative impact.

Thus, to adequately define the sampling frequency, the design team must understand how the system operates and the issue that is being investigated (scientific assessment studies, baseline monitoring programmes and conceptual models previously mentioned become important once again). Expected methods and requirements of statistical analyses also influence the frequency of sample collection. For example, the objective for the monitoring programme may be to determine the frequency that a parameter exceeds a water quality guideline at a certain level of confidence. In this case the number of sampling periods can be determined using appropriate statistics.

The sampling frequency should at least resolve the main source of natural variability of the constituent under investigation. Scales of change over time differ widely in the water column (minutes - days) compared with sediments (days - seasons - decades), as noted above. Non-periodic events, such as storms, can also have a dramatic influence that needs to be taken into account.

Therefore, a sampling frequency that is too low relative to the underlying natural variability will result in biased data that will make it difficult to separate a human-derived impact from a natural anomaly. In the same way, sampling at a frequency that is too low relative to the variability in waste inputs may result in marked negative impacts being missed. In the water column, high frequency physical processes, such as tides, currents, wind and waves are the primary influences on variability. In order to resolve the problem of the variability in the water column, sampling frequencies generally have to be high (e.g. hourly-daily-weekly). As a result, the use of water column measurement parameters as part of monitoring programmes is often not cost-effective, and sediment parameters are usually more pragmatic.

Sediment sampling frequency is strongly linked to the time-scale within which the sediments act as 'particle traps'. As with sampling of the water column, sediment sampling at a frequency that is lower than the periodic re-suspension events will make trends difficult to interpret and could lead to spurious conclusions. Therefore, where cost constraints necessitate limitations on sampling frequencies, it will be inappropriate to select sampling locations that are situated in areas reflecting short-term variability. In such instances, longer-term depositional areas should rather be targeted. For example, because sediment processes often show strong seasonal trends, sampling is often confined to a particular season. Depositional sites can be designated as short- or long-term. A location on an open coast may be a depositional site for a period of days to weeks whereas an estuary may be a depositional site for a period of months to years. The ecological impact of both does not have to be linearly related to the persistence. Both provide important insights into the sediment and pollutant dynamics of the coastal and estuarine environments and are key to the design of optimal monitoring programmes, particularly in terms of sampling frequency.

Use of numerical modelling

To overcome the inherent uncertainties of inherent spatial and temporal variability of coastal aquatic systems, long-term monitoring programmes have traditionally relied on frequent monitoring of spatially extensive sampling grids. However, with the use of numerical modelling many of the inherent problems of the traditional approach can be overcome. Numerical modelling has proven to be very useful in enhancing the design of long-term monitoring programmes and improving the interpretation of the results of monitoring. Such numerical models provide process links that enhance the ability to diagnose problem areas, as well as anticipating problems through their predictive capacity. The benefits of numerical modelling in the design of long-term monitoring programmes include:

- Definition of the most critical spatial and temporal scales of impact in the system. Important insights are provided by a combination of the synthesis of the existing understanding of the key processes and the model assumptions and inputs
- Improved interpretation and understanding of monitoring results in the context of a dynamic environment that determines the transport and fate of pollutants.

The aim, therefore, is to use the capability of numerical models to reduce uncertainties in relation to system variability, key processes, and how these influence the transport and fate of contaminants. Because this increased understanding provides greater confidence in the predicted outcomes, investment in the monitoring can be limited to only a number of critical parameters measured at critical spatial and temporal scales.

Although long-term monitoring programmes may, initially, still require relatively extensive spatial and intensive temporal scales to address uncertainties in a system's response, over a number of years these can be reduced to only a few selected points through an iterative process, as the predicted responses of the system are verified.

The use of biological media is commonly resorted to as a technique to overcome the problem of high temporal variability, particularly analysis of body tissues of filter feeders (e.g. mussels, oysters). However, it is important to realise that the body mass of these organisms also has a strong seasonal variability related to spawning cycles. Natural variability therefore needs to be separated from potential long-term signals caused by human interference. To address this issue, the following are required as a minimum:

- Samples need to be taken at appropriate intervals determined by ambient variability
- Long-term sampling needs to be performed within a narrow time-window each year to reduce seasonal uncertainty.

Lastly, beneficial uses and patterns of usage of a waterbody may determine sampling frequency. For example, one objective for monitoring bathing waters is to determine potential exposure of humans to sewage derived pathogens. If there is a strong seasonality in bathing, then it makes sense to focus most of the sampling effort during the bathing season. As previously noted, in such cases where there are potential risks to human health, near real time data are needed and peak bathing seasons might require daily sample collection.

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7.2.6 Field sampling and data analyses

The successful execution of the sampling strategy is clearly critical to the success of the monitoring programme. In essence, this requires considerable organisational and logistical skills. The correct calibration of instruments, safe deployment and use of sampling equipment, sample collection, handling and storage, field measurement and metadata collection requires experienced multi-disciplinary field teams. Returning samples to laboratories within prescribed time periods, their analysis and quality control similarly involves a high level of planning and co-ordination. A project leader with suitable project management skills is therefore required.

Although the data analysis step of the monitoring programme design intuitively occurs after implementation of sample collection and availability of results, statistical considerations should inform the entire sampling design process. Therefore, a large proportion of the data analysis procedures should be during the sampling design process. Of course there are instances where this cannot be anticipated. For example, an unknown relationship between two parameters could be found to be strongly correlated, permitting correlation analysis.

There are three basic approaches for data assessment:

- Assessment over long periods of record for the purpose of determining trends and changes over time (e.g. for trend monitoring)
- Analysing the relationships between measured values for variables in the monitoring program to determine differences and the significance of the differences (e.g. for impact monitoring)
- Assessment of the extent to which measured water quality meets published guidelines, criteria or objectives (e.g. for compliance monitoring).

There are numerous ways to represent data graphically. Typical presentation formats include:

- Time series plots, which constitute a simple means to illustrate trends, cyclical variations and outliers
- Plots to illustrate spatial and temporal variability (e.g. contour plots, scatter plots, and bar graphs), for example, to show the spatial or temporal effects of pollution sources in an area
- Statistical summary of variable, for example, using box and whisker plots (e.g. ranges, mean, percentiles)
- Seasonal or periodical variations, illustrated through plots of statistical parameters (e.g. ranges, percentiles, means) of discrete monthly or seasonal data sets collected over a long period
- Correlation plots between two or more variables, illustrating relationships between these different variables.

To be useful from a management perspective, data must be presented in a clear format to provide the appropriate scientific and engineering knowledge for informed and effective decision-making. The most effective manner in which to communicate environmental data and information is through graphical presentation of numerical and statistical data. The advantages of the graphical presentation of data are:

- Large data sets can be illustrated effectively
- Qualitative aspects, such as correlations and trends, as well as quantitative aspects such as outliers, are illustrated effectively
- Provides a user-friendly means of communicating complex numerical and statistical outputs.

Suggested reading:

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- USEPA guidance for the analysis of an extremely wide suite of physical and chemical parameters in all types of media can be found at http://www.epa.gov/epawaste/hazard/testmethods/sw846/online/ index.htm

Data management is an especially important consideration. Environmental quality monitoring programmes lead to the generation of large amounts of data. These data are expensive to collect and require substantial investments of both human and financial resources. A data management system must be developed to store these data for both immediate and future use. The data management system must include a detailed description of data identifiers. Data should be stored in a manner that facilitates its usage for purposes other than simple archiving, including statistical analysis or import into Geographical Information System software. Software packages have specific data format requirements and it is imperative that these requirements are understood prior to designing the data management system. This will avoid unnecessary and time consuming data conversion.

A good data management system should have (ANZECC 2000):

- Reliable procedures for the recording of analytical and field observations
- Procedures for systematic screening and validation of data (quality control)
- Secure storage of information
- Simple retrieval system
- Simple means of analysing data
- Flexibility to accommodate additional information.

Ultimately, it would be desirable to develop a regional marine monitoring data repository (or data base) accessible to contracting parties and other interested stakeholders through, for example the Nairobi Conventions Clearing House Mechanism platform.

7.2.7 Reporting and communication

There is little logic in conducting environmental monitoring if the information is not disseminated. The findings of monitoring programmes are usually of interest to a wide range of stakeholders, including the scientific community, policymakers, non-governmental organisations, and the general public. Reporting and dissemination is therefore a key part of environmental programmes. Given the usually strong differences in the level of understanding of technical details by different target audiences, an information dissemination strategy to account for different needs must be developed as the monitoring programme matures.

The most common form of information dissemination is through the preparation of technical reports. Further information dissemination occurs through the publication of findings in peer-reviewed scientific journals, although this is targeted at the scientific community. The vast majority of stakeholders interested in monitoring programme findings do not have a scientific background. Technical reports are usually difficult for these stakeholders to understand. It is important that the needs of these stakeholders be accommodated through the preparation of non-technical (summary) reports. Another useful way of communicating with non-technical audiences is by summarising data in graphical plots and the presentation of data summaries in maps wherever possible. All of these tools can also be used in public presentations, which are useful for disseminating programme findings. While printed reports were historically the dominant form of disseminating data, the internet is increasingly being used for this purpose. Various other communication routes can be utilised to communicate findings to wider stakeholder groups, such as pamphlets and media reporting.

The frequency of reporting is important. Source monitoring (referring to monitoring of composition and volumes of marine pollution sources) requires near real-time reporting (i.e. as close as possible to the time of sampling) to ensure that mitigating measures can be implemented timeously. Environmental monitoring programmes require less frequent reporting, e.g. usually six-monthly or annually. In general monitoring reports should include (see example template for report in Appendix D):

- A list of monitoring objectives (or hypotheses) and how these relate to the overall Environmental Quality Objectives specified for the study area
- Details of the design and implementation of the monitoring programme (also indicating the relationship between selected measurement parameters and monitoring objectives)
- An evaluation of the monitoring data in relation to the monitoring objectives (or hypotheses). This evaluation should make use of data summaries and graphical presentations in order to enhance readability
- A statement on whether the monitoring objectives have been met
- In the event of non-compliance, possible reasons for the non-compliance
- Management strategies and actions required to address non-compliance
- Recommendations on refinements to the monitoring programme
- Appendices containing cruise and laboratory reports, raw data tables and other relevant background information.

8. KEY RECOMMENDATIONS

This initiative is in response to the Contracting Parties to the Nairobi Convention that urged the Secretariat to establish a Strategic Framework for C&MWQM in the WIO region, led by the Regional Task Force (RTF) on Water Quality under WIOSAP.

Towards initiating the effective operationalisation of C&MWQM in WIO region, the following policy recommendations are proposed for consideration by the Contracting Parties:

- Contracting Parties adopt the Strategic Framework for C&MWQM for the WIO region, including the *Guidelines for Setting Environmental Quality Objectives & Targets for Coastal and Marine areas*.
- Contracting Parties formally establish a Regional Task Force (RTF) for C&MWQM (which is currently a project-level task force under the WIOSAP – RTF for Water, Sediment and Biota Quality)
- Contracting Parties establish national C&MWQM Task Forces to facilitate and coordinate C&MWQM at national-level, feeding into the RTF through national focal points.
- Contracting Parties adopt, as appropriate, the Strategic Framework for C&MWQM at national-level, including *the Guidelines for Setting Environmental Quality Objectives & Targets for Coastal and Marine areas.*
- Established national C&MWQM Task Forces coordinate the identification of national-level hotspots, as well as the establishment of local C&MWQM committees to oversee the execution of 'hotspot' implementation programme.
- Established national C&MWQM Task Forces coordinate the compilation of national-level status reports that would feed into overarching regional status reports - coordinated by the RTF - to inform various regional processes (e.g. WIO State-of-Coast reporting, Ecosystem Monitoring Strategies).

The following technical recommendation is proposed for consideration by the Contracting Parties in support of effective operationalisation of the Strategic Framework:

- The Nairobi Secretariat work with partners to support capacity building programmes in support of the effective implementation of the Strategic Framework for C&MWQM, including the *Guidelines for the development of Environmental Quality Objectives and Targets.*

Ultimately, the achievement of the Strategic Objectives set for coastal and marine water quality in the WIO region - *Water quality in the WIO region meets international standards by year 2035* – will rely on countries embracing this Strategic Framework for C&MWQM and adopting the proposed implementation into national policy and best practice, as appropriate. It will also will require political commitment to assist in securing dedicated financial resources and the skilled personnel required in the execution of C&MWQM programmes.

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APPENDIX A: Template for C&MWQM Plans (Hotspots)

Chapter 1: Introduction
- 1.1 Background
- 1.2 Purpose of C&MWQM programme

Chapter 2: Situation Assessment (Pollution Hotspot) (see Chapter 6.1 in document)
- 2.1 Geographical boundaries of pollution hotspot
- 2.2 Brief description of coastal and marine environment
- 2.3 Socio-economic context (demographics, economic profiles, important social considerations)
- 2.4 Legal framework applicable to C&MWQM
- 2.5 Institutional Arrangements for C&MWQM

Chapter 3: Zonation of Important Ecosystems and Uses (Current & Planned) (see Chapter 6.2 in document)
- 3.1 Location map of Important Ecosystems, as well as required EQTs (as per *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas*)
- 3.2 Location map of social and economic uses (ecosystem services), as well as required EQTs (as per *Guidelines for Setting Water and Sediment Quality Targets for Coastal and Marine areas*)

Chapter 4: Identification of Pollution Sources (Activities) (see Chapter 6.3 in document)
- 4.1 Location map of pollution sources (activities)
- 4.2 Description and quantification of each of the identified pollution sources (activities)

Chapter 5: Identification of Problem Areas (informed by learning from above chapters)
- 5.1 Identify specific pollution sources (activities) impacting on C&MWQ (i.e. affecting important ecosystems and beneficial uses)

Chapter 6: Activity-based Management Programmes (see Chapter 6.4 in document)
- 6.1 Activity x (e.g. Municipal waste and wastewater, Industrial Waste disposal, Solid waste (litter & plastics), Urban runoff (stormwater), Shipping, etc.).
  - 6.1.1 Related legislation, guidelines or best practice applicable
  - 6.1.2 Related government authorities and/or owners & managers
  - 6.1.3 Activity-specific objectives and actions for C&MWQM (see Appendix B)
  - 6.1.4 Detailed Action Plans (see Appendix B)

Chapter 7: Monitoring Programme (see Chapters 7 in document)

APPENDIX B: Template for Action & Resource Planning

Activity-specific Objectives with Comprehensive Action Lists and Priorities, e.g.:

OBJECTIVE 1: List specific environmental quality objective to be achieved linked to activity	
ACTION 1: List Action…	
Relevant legislation	
Responsible agent/authority	
Existing risk to biodiversity	
Existing risk to socio-economics	
Overview of resource requirements	
Estimated budget	
PRIORITY	LOW/MEDIUM/HIGH
ACTION x: List Action…	
Relevant legislation	
Responsible agent/authority	
Existing risk to biodiversity	
Existing risk to socio-economics	
Overview of resource requirements	
Estimated budget	
PRIORITY	LOW/MEDIUM/HIGH

Detailed Planning for Selected Priority Actions, e.g.:

<table>
<tr><td>ACTION</td><td>Describe action to be undertaken</td></tr>
<tr><td>Completion date</td><td>Provide date of expected completion</td></tr>
<tr><td>Performance indicator</td><td>When will we know action has been completed successfully?</td></tr>
<tr><td>Applicable standards or Quality Targets</td><td></td></tr>
<tr><td>Available methods or best practice-guides</td><td></td></tr>
<tr><td>Detailed work plan</td><td>Task 1:
Task 2:
Task 3:</td></tr>
<tr><td>Scheduling</td><td>
<table>
<tr><th rowspan="2">TASK</th><th colspan="9">TIME (months)</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th></tr>
<tr><td>1</td><td>■</td><td>■</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td>■</td><td>■</td><td>■</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td>■</td><td>■</td><td>■</td><td>■</td></tr>
</table>
</td></tr>
<tr><td>Milestone/interim performance indicator</td><td>
<table>
<tr><th>MILESTONE</th><th>INTERIM PERFORMANCE INDICATOR</th><th>DUE DATE</th></tr>
<tr><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Responsibilities for different tasks</td><td>Identify specific departments, personnel and/or service providers responsible for execution of this action</td></tr>
<tr><td>Monitoring and reporting plan</td><td>• Define data and information to measure in order to monitor performance indicator/s
• Specify frequency at which data/information should be collected/monitored
• Where and when to report on progress</td></tr>
<tr><td>Human resource plan</td><td>
<table>
<tr><th rowspan="2">HUMAN RESOURCE</th><th colspan="3">WEEKS PER TASK</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Staff member 1</td><td></td><td></td><td></td></tr>
<tr><td>Staff Member 2</td><td></td><td></td><td></td></tr>
<tr><td>Service provider</td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Financial resource plan</td><td>
<table>
<tr><th>TASK</th><th>COST</th></tr>
<tr><td>1</td><td></td></tr>
<tr><td>2</td><td></td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>TOTAL</td><td></td></tr>
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APPENDIX C: Template for Contingency Plans

- Chapter 1: Introduction
  - 1.1 Purpose
  - 1.2 Scope
- Chapter 2: Legal and Other Requirements
  - 2.1 International/regional
  - 2.2 National
  - 2.3 Local
- Chapter 3: Roles and Responsibilities
  - 3.1 Responsible government authorities
  - 3.2 Owners or designated managers of related activities
- Chapter 4: Relationship with Other Contingency Plans
  - 4.1 International/regional plans
  - 4.2 National Disaster plan
  - 4.3 Local plans
- Chapter 5: Emergency Preparedness Framework
  - 5.1 Emergency organisation structure
  - 5.2 Emergency response plans and procedures
- Chapter 6: Emergency Response Actions
  - 6.1 General Response to Emergency Environmental Incidents
  - 6.2 Resources for Response Action
  - 6.3 Key contact lists
  - 6.4 Response and management teams
  - 6.5 Emergency preparedness plans
  - 6.6 Emergency equipment
  - 6.7 Training
- Chapter 7: Environmental Monitoring
- Chapter 8: Communication
  - 8.1 Internal notification
  - 8.2 Regulatory notifications and reporting
  - 8.3 Stakeholder and community notification
- Chapter 9: Environmental Recovery
  - **9.1** Site assessment
  - 9.2 Remediation and rehabilitation
  - 9.3 Cost recovery
- Chapter 10: Evaluation and Review

APPENDIX D: Template for Monitoring Reports

Chapter 1: Introduction

1.1 Background

1.2 Reason for Monitoring Programme

Chapter 2: Study Area and Specific Environmental Quality Objectives

2.1 Brief description of coastal and marine environment (map)

2.2 Specific environmental quality objective and targets applicable to study area

2.3 Specific pollution sources (activities) under investigation in study area

2.4 Standards applicable to pollutions sources (activities)

Chapter 3: Design of Monitoring Programme

3.1 Selection monitoring parameters (motivation and frequency of sampling)

3.2 Location of sampling stations

3.3 Frequency of sampling

Chapter 4: Description of Sampling, Analytical and Data Analysis Procedures

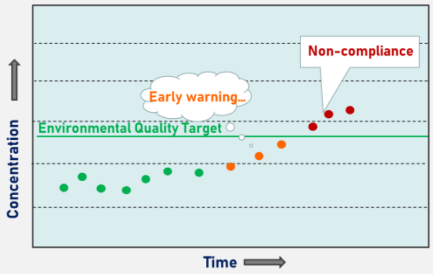
4.1 Sampling and *in situ measurements*

4.2 Laboratory analysis procedures

4.3 Data analysis methodology

Chapter 5: Results and Discussion

Present results from monitoring programme and interpret in relation to required environmental quality targets/objectives/standards, e.g.:



Chapter 6: Key Findings

Summarise key findings from results and discussion, e.g. compliance/non-compliance, trends, etc.

Chapter 7: Recommendations

7.1 Identify management strategies and actions to address non-compliance

7.2 Identify refinement to monitoring programme (if relevant)

Appendices: Cruise, field and laboratory reports, raw data tables and other relevant background information considered relevant

APPENDIX E: Beach Water Quality Sampling Log Sheet

SITE NAME			
SAMPLING LOCATION			
MAP POSITION	Latitude	Longitude	
PERSON COLLECTING SAMPLE			
DATE & TIME	Date	Time	
RELATED INFORMATION COLLECTED AT SAMPLING LOCATION			
Climatic conditions (e.g. rainy, sunny, cloudy)			
Wind direction			
Surface current direction			
Water temperature (°C)			
Salinity			
		Yes	No
Presence of objectionable matter?			
	If yes, contact responsible authority for further action (Contact & Tel: ……………….)		
Presence of potentially harmful algal blooms?			
	If yes, contact responsible authority for further action (Contact & Tel: ……………….)		
Indication of potential presence of toxic chemical substances (including chlorine)?			
	If yes, contact responsible authority for further action (Contact & Tel: ……………….)		
COMMENTS:			

APPENDIX F: Template for Status Reporting (DIPSR)

Chapter 1: Introduction

- 1.1 Background
- 1.2 Approach (i.e. DPSIR framework)

Chapter 2: Brief overview of Coastal and Marine Environment

- 2.1 Brief description of important coastal and marine ecosystems, including important ecosystems services and beneficial uses
- 2.2 Socio-economic context (demographics, economic profiles, important social considerations)

Chapter 3: Drivers of Coastal and Marine Pollution

Identify and describe underlying (or root causes) of water and sediment quality deterioration, e.g. population growth, poverty and inequality, inappropriate governance, inadequate knowledge and awareness, inadequate financial resources)

Chapter 4: Pressures contributing to Coastal and Marine Pollution

Identify and describe activities contributing to pollution (e.g. see Table 6.5)

Chapter 5: State, Trends and Impacts on Coastal and Marine Environment

Describe current state, trends observed in coastal and marine environment quality and discuss impacts as a result of pressures (as identified above). This information in typically sourced from ongoing C&MWQM monitoring and evaluation programmes

Chapter 6: Management Responses

- 6.1 Described successes in management responses in preventing/mitigating coastal and marine pollution in recent past
- 6.2 Identify specific risks (as reflected in state/trends/impacts) requiring urgent management intervention in near future (if numerous prioritise based on relative resilience of affected environments)