A structured ecosystem-scale approach to marine water quality management

S Taljaard[1]*, PMS Monteiro[1,2] and WAM Botes[3]
[1]*CSIR, P O Box 320, Stellenbosch, 7599, South Africa*
[2]*Department of Oceanography, University of Cape Town, Rondebosch, 7700, South Africa*
[3]*WAMTechnology cc P O Box 195, Stellenbosch, 7599, South Africa*

Abstract

Activities and developments in the coastal zone, and in adjacent catchments, pose an increasing threat to the sustainability of the natural and socio-economic goods and services supplied by marine ecosystems. Governing authorities have had to develop new policies to promote environmentally responsible and sustainable development practices, either through legislation and/or incentive mechanisms. These, in turn, created the need for holistic and integrated frameworks within which to design and implement environmental management programmes.

A structured ecosystem-scale approach for the design and implementation of marine water quality management programmes developed by the CSIR (South Africa) in response to recent advances in policies and legislation pertaining to sustainable utilisation of Southern Africa's marine environment is discussed. The framework provides an integrated scientific base within which to set, for example, wastewater emission targets, taking into account ecosystem process complexity. It also aims to support and stimulate local stakeholder empowerment and involvement.

Keywords: marine water quality, integrated management, ecosystem scale

Introduction

Agriculture, industrial and residential developments in the coastal zone and in adjacent catchments pose an increasing threat to the sustainability of the natural and socio-economic goods and services supplied by marine ecosystems, even where such developments may create other socio-economic benefits.

Historically marine water quality was managed on an individual or case-by-case basis, which did not necessarily take into account possible cumulative or synergistic effects as a result of multiple activities or developments within a specific area. To account for cumulative or synergistic effects, a more holistic approach was required – rather focusing on the ecosystem than on individual activities or developments. Recent developments in numerical modelling, in particular its ability to integrate over different spatial and temporal scales, have permitted the development of such ecosystem-scale approaches.

In order to manage potential conflict, governing authorities had to develop new policies to promote sustainable development practices, either through legislation and/or incentive mechanisms. These, in turn, also created the need for holistic and integrated frameworks within which to design and implement environmental management programmes.

Internationally, different approaches to marine water quality management have been proposed. For example, in 1990 the Water Research Centre (United Kingdom) prepared a guide, particularly aimed at providing guidance in the design, operation and maintenance of environmentally acceptable marine outfall schemes for sewage (WRc, 1990). One of the principle objectives of this guide was to 'provide a common framework for both engineers and scientists to take account of the inter-relationship between the environment and engineering aspects of marine treatment'. The framework addressed issues such as:

- Legal framework
- Environmental quality issues
- Planning of data collection studies
- Aspects of the engineering design and construction of marine outfall schemes
- Operation and maintenance (including monitoring).

In this context the United Nations Environmental Programme (UNEP) also prepared *Guidelines on Municipal Wastewater Management* (UNEP, 2002), providing practical guidance for implementing the *Global Programme of Action for the Protection of the Marine Environment from Land-based Activities* (GPA) on sewage. The need for '…a comprehensive, integrated and stepwise approach to urban wastewater management to improve human health and maintain environmental integrity…' is explicitly stated with a strong emphasis on strategies for ensuring effective institutional arrangements and social participation.

As part of the series on *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* Environment Australia provided a management framework particularly aimed at the effective application of water quality guidelines in the arena of marine water quality management (ANZECC, 2000a). The framework recognises, amongst others, the need to:

- Define primary management aims, including environmental values
- Determine appropriate water and sediment quality guidelines
- Establish monitoring and assessment programmes, focused on water quality objectives

* To whom all correspondence should be addressed.
☎ +27 21 8882494; fax: +27 21 882693;
e-mail: staljaar@csir.co.za
Received 24 November 2005; accepted in revised form 15 March 2006.

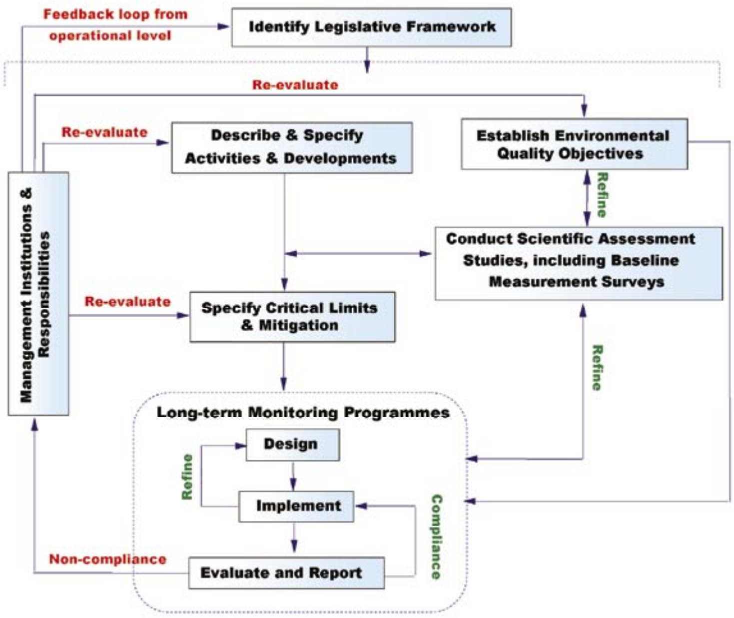

Figure 1
A framework for the design and implementation of marine water quality management programmes

- Initiate appropriate management responses, based on maintaining water quality objectives.

In South Africa, policies and legislation pertaining to the protection of the country's natural resources, including the marine environment, have improved markedly over the past 10 years. Although recognising the need for development, legislation such as the National Water Policy (April 1997), the Environmental Management Policy (July 1997), the Policy on Integrated Pollution and Waste Management for South Africa (March 2000), the Policy on Sustainable Coastal Development in South Africa (April 2000), the National Water Act (Act 36 of 1998), the National Environmental Management Act (Act 107 of 1998) and the Marine Living Resources Act (Act 18 of 1998), now requires that such development occur in an environmentally responsible and sustainable manner. With particular reference to the marine water quality, the Policy on Sustainable Coastal Development in South Africa has the following as two of its goals:

- To implement pollution control and waste management measures in order to prevent, minimise and strictly control harmful discharges into coastal ecosystems
- To manage polluting activities to ensure that they have minimal adverse impact on the health of coastal communities, and on coastal ecosystems and their ability to support beneficial human uses.

In response to these new legislative requirements, and taking into account international trends and advances in ecosystem-scale complexity and processes and science and technology (e.g. the application of numerical models), the CSIR (South Africa) developed a generic framework within which to design and implement marine water quality management programmes. The framework had to ensure that marine water quality-related issues were addressed in a holistic, structured and cost-effective manner, through focused procedures and clear identification of data and information requirements. A holistic, integrated framework for the design and implementation of marine water quality management programmes developed by the CSIR in response to recent advances in policies and legislation pertaining to the sustainable utilisation of South Africa's marine environment is discussed here. The framework provides an integrated scientific base within which to set, for example wastewater emission targets (WET), taking into account ecosystem process complexity.

Although the participatory approach was not widely used in the management of marine water quality in the past, processes such as Integrated Environmental Management and Environmental Impact Assessment have called for much wider stakeholder engagement in environmental management. The framework therefore also aims to support and stimulate local stakeholder empowerment and involvement.

A similar framework was put forward by the CSIR in 1995, mainly to facilitate the effective management and control of marine outfalls along the South African coast (Taljaard and Botes, 1995). However, as a result of advances in marine water quality science and technology this framework has had to be refined.

Framework for Marine Water Quality Management Programme

Based on a review of international practices and the authors' own experience in the South African context, it was decided that key components to be included in marine water quality management programmes comprise:

- Identification of the legislative framework
- Establishment of management institutions and responsibilities
- Determination of environmental quality objectives
- Specification of activities/developments affecting marine water quality
- Scientific assessments
- Design and implementation of monitoring programmes.

A schematic illustration of the linkages between these components is provided in Fig. 1. Each of the components is discussed in more detail in the following section.

Legislative framework

A marine water quality management programme needs to be designed and implemented within the statutory framework governing marine water quality and related issues in a particular country while taking into account international treaties and

Available on website http://www.wrc.org.za
ISSN 0378-4738 = Water SA Vol. 32 No. 4 October 2006
ISSN 1816-7950 = Water SA (on-line)

legislation. Although legislation is likely to differ from one country to another, key international programmes, treaties and conventions that may have to be taken into account, include:

- **Agenda 21:** The internationally accepted strategy for sustainable development adopted at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. Agenda 21 is a plan for use by governments, local authorities and individuals to implement the principle of sustainable development contained in the Rio Declaration. This document has significant status as a consensus document adopted by about 180 countries. Agenda 21 is, however, not legally binding on states, and merely acts as a guideline for implementation (www.un.org/esa/sustdev/agenda21text.htm).
- **World Summit on Sustainable Development (WSSD)** (generally known as the Johannesburg Summit) **(2002):** Formulated two new principles which are central to the philosophy of managing marine water quality at the systems scale (www.gpa.unep.org/news/gpanew.htm):
  - The call for a move away from the management of individual resources towards an ecosystem-based management of coastal systems
  - Setting of wastewater emission targets (WET) which limit the upper boundary of land-based discharge fluxes into coastal systems to a level in which ecosystem impacts are not measurable.
- **United Nations Environmental Programme (UNEP)** which was initiated in 1972 and contains several programmes pertaining to marine pollution, e.g. the Ocean and Coastal Areas Programmes and the Regional Sea Programmes (www.unep.org/).
- **Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)**: Adopted in November 1995, designed to assist states in taking action individually or jointly within their respective policies, priorities and resources that will lead to the prevention, reduction, control or elimination of the degradation of the marine environment, as well as to its recovery from the impacts of land-based activities. The GPA builds on the principles of Agenda 21. The Regional Seas Programme of UNEP has been identified as an appropriate framework for the delivery of the GPA at the regional level (www.gpa.unep.org/).
- **London Convention for the Prevention of Marine Pollution by Dumping of Wastes and other Matter (1972, amended 1978, 1980, 1989):** In November 1996 the contracting parties to the London Convention of 1972 adopted the 1996 Protocol, which, when entered into force, replaces the London Convention (www.londonconvention.org/London_Convention.htm).
- **International Convention for the Prevention of Pollution from Ships** (**MARPOL convention**) (1973/1978) is the main international convention covering prevention of pollution of the marine environment by ships as a result of operational or accidental causes and includes regulations aimed at preventing and minimizing pollution from ships (www.imo.org/home.asp).
- **United Nations Convention on the Law of the Sea (UNCLOS) (1982),** which lays down the fundamental obligation of all States to protect and preserve the marine environment. Further, it urges all States to cooperate on a global and regional basis in formulating rules and standards and otherwise take measures for the same purpose. It addresses six main sources of ocean pollution: land-based and coastal activities, continental-shelf drilling, potential seabed mining, ocean dumping, vessel-source pollution and pollution from or through the atmosphere (www.un.org/Depts/los/index.htm).
- **United Nations Convention on Biological diversity (1992)** which came into force in December 1993, has three main objectives, namely the conservation of biological diversity; the sustainable use of biological resources; and the fair and equitable sharing of benefits arising from the use of genetic resources (www.biodiv.org).

Effective legislation (together with practical operational policies and protocols) is a key requirement for the successful management of marine water quality. A sound legislative framework, for example, empowers responsible authorities to legally challenge offenders, provided that such legislation is supported by sufficient resources (both human and financial).

Management institutions and responsibilities

A key driving factor in the successful implementation of any management programme is the establishment of the appropriate management institutions as well as identifying their roles and responsibilities. Typically, the legislative framework within a particular country should provide specifications and guidance in this regard.

Traditionally the responsibility for the management and control of marine water quality issues resided with the responsible government authorities as well as the potential impactors (e.g. municipalities, industry and developers). Although these traditional management structures are still important, the value of also involving other local interested and affected parties, through stakeholder forums or local management institutions, has proved to be of great value to the overall management process (Henocque, 2001; Van Wyk, 2001; Taljaard and Monteiro, 2002; Cape Metropolitan Coastal Water Quality Committee, 2003). Not only do these local management institutions provide an ideal means by which interested and affected parties can be consulted on designated uses and environmental quality objectives for a specific area, they also fulfil the important role of local watchdogs or custodians. Although such institutions usually do not have executive powers they have been shown to be very successful mechanisms that can be used to pressurise responsible authorities to respond appropriately, for example, in instances of non-compliance.

Key to the success of local management institutions is a sound and easily accessible scientific information base, to empower local stakeholders to participate in the decision making process. It is also essential that local management institutions include all relevant interested and affected parties in order to facilitate a participatory approach in decision-making. These should include representatives from:

- National and regional government departments
- Nature conservation authorities
- Local authorities
- Industries
- Tourism boards and recreation clubs
- Local residents, e.g. through ratepayers associations
- Non-government organisations.

It is usually extremely difficult and financially uneconomical to manage marine environmental issues in isolation because of potential cumulative or synergistic effects on the receiving environment. Such collaboration is best facilitated and achieved through a joint local management institution. A local management institution being actively involved in the management of marine water quality matters at local level is also ideally positioned to test the effectiveness and applicability of legislation and policies, which are normally developed at state or provincial levels. It is also important, therefore, that these institutions be utilised by higher tiers of government as a mechanism for improving legislation related to the management of marine water quality, supporting the principle of adaptive management.

The Saldanha Bay Water Quality Forum Trust (SBWQFT) is an example of an existing local management institution that functions very well (Van Wyk, 2001). The forum was established in June 1996 through the efforts of individuals with an interest in Saldanha Bay (South Africa) who created an awareness of the need to address the deteriorating water quality in the Bay. The SBWQFT is a voluntary organization comprising officials from local (municipality, Nature conservation), regional (regional office of the Department of Water Affairs and Forestry) and national authorities (Department of Environmental Affairs and Tourism), representatives from all major industries in the area (e.g. National Ports Authority, seafood-processing industries, marine aquaculture farmers) and other groups who have a common interest in the area (e.g. tourism).

Environmental quality objectives

The ultimate goal in marine water quality management is to keep the marine environment fit for all designated uses. To achieve this goal, the quality objectives set for a particular marine environment should be aimed at protecting important marine ecosystems as well as the designated uses of the marine environment (also referred to as beneficial uses). Environmental quality objectives must be set as part of the management framework to provide a basis from which to assess and evaluate management strategies and actions.

The setting of objectives may be achieved through a four-step approach:

- Define the geographical boundaries of the study area
- Define important aquatic ecosystems and designated uses within the specified area
- Define management goals for important aquatic ecosystems and designated use areas
- Determine site-specific (measurable) environmental quality objectives, pertaining to sediment and water quality requirements.

A very important initial step in setting environmental quality objectives is to determine the **geographical boundaries** of the area within which the management framework is to be implemented. The anticipated influence of all major human activities and developments, both in the near and far field, must be taken into account, including the location of and inputs from different waste sources to the marine environment. Important issues that need to addressed, include:

- Proximity of depositional areas where pollutants introduced from one or more pollution source can accumulate – these can be at distant locations for specific sources, particularly where the source discharges into a very dynamic environment but subsequently is transported to an area of lower turbulence.
- Possible synergistic effects in which the negative impacts resulting from a particular source could be aggravated through interaction with pollutants introduced by other waste sources in the area, or even through interaction with natural processes.

The ultimate goal in the management of marine waters is to keep the environment suitable for all designated uses – both for existing and future uses (this includes the 'use' of designated areas for biodiversity protection and ecosystem functioning). The second step, therefore, is to identify and map **important aquatic ecosystems and designated uses** within the study area.

In the case of South Africa, beneficial uses of the coastal marine waters are subdivided into three categories (RSA DWAF, 1995), namely:

- Mariculture use (including collection of seafood for human consumption)
- Recreational use
- Industrial uses (e.g. intake of cooling water and water for fish processing and/or mariculture).

Both existing usage and proposed usage (as captured in strategic and future development plans) should be considered and these should be agreed upon in consultation with local interested and affected parties through the local management institutions.

The identification and mapping of important marine ecosystems and designated uses of the marine environment within a study area provide a good basis for the derivation of site-specific environmental quality objectives. The example of Saldanha Bay is presented in Fig. 2 (adapted from Taljaard and Monteiro, 2002).

Once important marine ecosystems and designated uses have been identified, broad management goals should be defined for each of the above uses. In the case of the protection of the aquatic marine ecosystem, these can be quantified in terms of the level of species diversity that needs to be maintained, while in the case of recreational or marine aquaculture areas, the management goal could be to achieve a certain rating or classification.

Agreement on the designated uses and management goals of a particular area should be obtained in consultation with local interested and affected parties (or stakeholders) through, for example, the local management institutions. Once agreement has been obtained on important aquatic ecosystems and designated uses, their location, as well as the management goals for each particular area (**site-specific environmental quality objectives**) pertaining to water quality requirements, needs to be established – the rationale being that although management goals are the real management end-points, the goals will only be achieved if certain measurable quality targets are maintained (Ward and Jacoby, 1992).

In order that environmental quality objectives are practical and effective management tools, they need to be set in terms of measurable target values or ranges for specific water column and sediment parameters or in terms of the abundance and diversity of biotic components. Environmental quality objectives can be derived from:

- National and international legal requirements (e.g. specification of constituent limits in sediments for dredging purposes under the London Convention)
- Recommended target values for a particular country (such guideline documents include those from South Africa (RSA DWAF, 1995), Australia and New Zealand (ANZECC, 2000a), Canada (Environment Canada, 2002) and the United States (US-EPA, 2002)
- Other scientific data and information sources (e.g. results from bioassay research studies).

Available on website http://www.wrc.org.za
ISSN 0378-4738 = Water SA Vol. 32 No. 4 October 2006
ISSN 1816-7950 = Water SA (on-line)

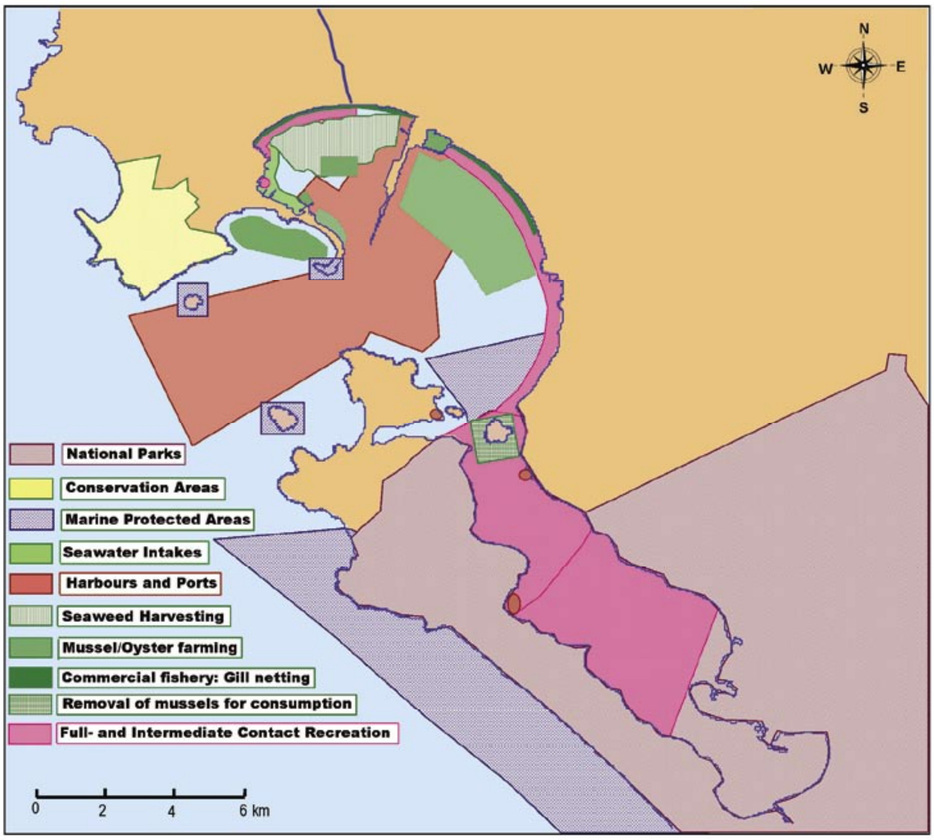

Figure 2
The location of important marine ecosystems and beneficial use areas in Saldanha Bay, South Africa (adapted from Taljaard and Monteiro, 2002)

Developments/activities affecting marine water quality

Effective management of marine pollution in a particular area requires quantitative data on waste inputs, as well as on other activities or developments that directly (or indirectly) affect marine water quality. Although anthropogenic perturbations of marine water quality are usually perceived to be the result of marine pollution sources, it is important to realise that developments that modify circulation dynamics in the marine environment, such as harbour and marina structures, can also modify these quality characteristics.

Sources of waste entering the marine environment can be categorised broadly into the following groups of activities, which either occur at sea or on land:

- Waste originating from land-based sources, including sewage effluent discharges, industrial effluent discharges, storm water run-off, agricultural and mining return flows, contaminated ground water seepage
- Waste entering the marine environment through the atmosphere, e.g. originating from vehicle exhaust fumes and industries
- Maritime transportation (which includes accidental and purposive oil spills and dumping of ship garbage)
- Dumping at sea (e.g. dredge spoil)
- Offshore exploration and production (e.g. oil exploration platforms).

To ensure that possible cumulative and synergistic effects are taken into account during the scientific assessment studies, it is important that both existing and proposed developments and activities in the study area that may potentially affect the quality of the receiving marine environment be mapped. The example of Saldanha Bay is shown in Fig. 3 (adapted from Taljaard and Monteiro, 2002). In the case of waste inputs, waste loads (both in terms of volume and constituent concentrations) need to be described and quantified.

Scientific assessment studies

Scientific assessment studies are required to determine whether the marine environment is able to support important ecosystems and designated beneficial uses (as defined in terms of the environmental quality objectives) in addition to being subject to waste inputs and other modifications associated with activities and developments in the study area. These assessments take into account process complexity and natural variability that require the understanding of, and information on, physical, biogeochemical and biological characteristics and processes.

The level of detail required for scientific assessment studies largely depends on the type of investigation. For example, a preliminary assessment (or 'fatal flaw analysis') is typically conducted as a desktop assessment using available data and information and expert judgement, while a detailed investigation may require extensive field data collection programmes and sophisticated modelling tools. In this respect, numerical modelling techniques have proven to be powerful tools (Monteiro, 1999) in that:

- Models provide a workable platform for incorporating the complexity of spatial and temporal variability in the marine environment
- Model assumptions and inputs provide a means of synthesising an understanding of the key processes and stimulating stakeholder discussion on their relevance to the objectives
- Modelling assists in defining the most critical spatial and time scales of potential negative impacts in the receiving system

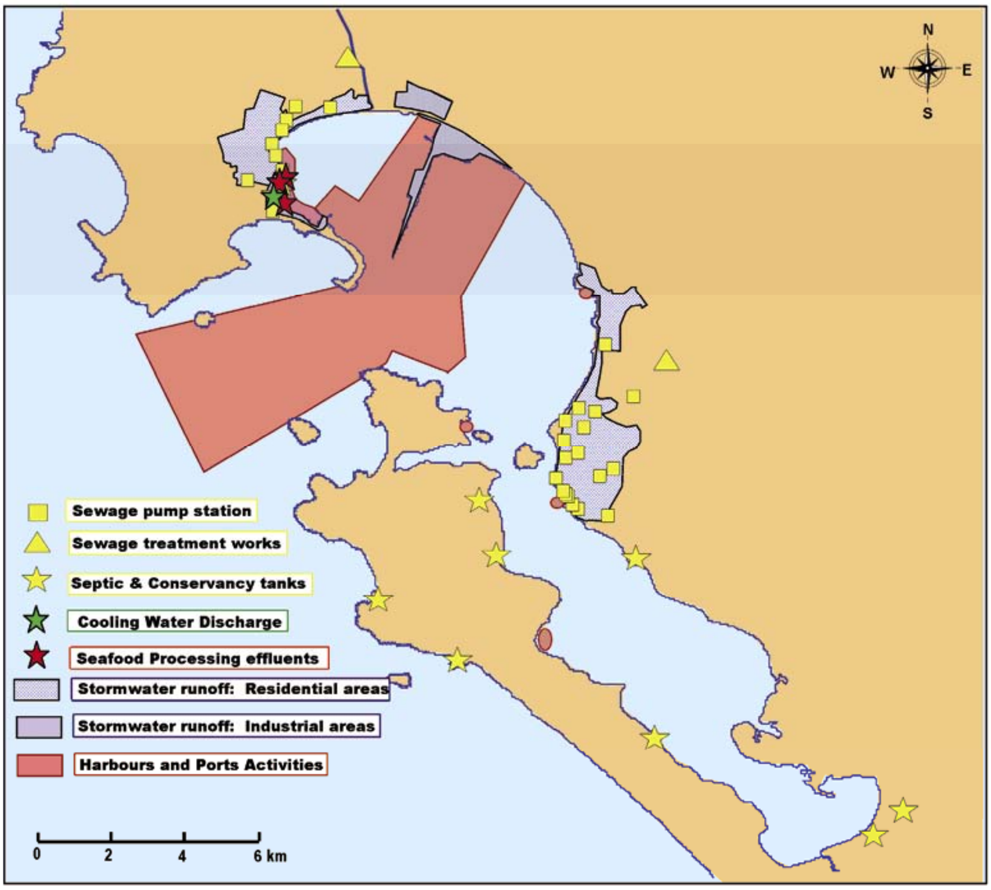

Figure 3
Location of activities and developments potentially affecting marine water quality in Saldanha Bay, South Africa (adapted from Taljaard and Monteiro, 2002)

- Model outputs provide quantitative results which can be used, together with field data, to check the quality of assumptions and insights.

The aim of using numerical modelling is to assess, through sensitivity analyses, the consequences of uncertainty in relation to system variability, key processes and most importantly, how these influence the transport and fate of contaminants. This reduced uncertainty provides greater confidence in the reliability of the predicted outcomes and is used to focus the investment in monitoring to critical parameters at critical time and spatial scales. Quality data on the volumes (in particular flow rates) and contaminant composition are crucial inputs to numerical modelling studies.

In the application of numerical modelling techniques, the following criteria must be met:

- The model must be appropriate to the situation in which it is utilised
- The model must be calibrated and validated against a full field data set adequately describing the site-specific physical and biogeochemical oceanographic conditions ('ground truthing')
- A sensitivity analysis must be conducted to demonstrate the effect of the uncertainties of key parameters based on the variation in input data and controlling assumptions
- The reporting of model outputs must include a clear description of assumptions, a summary of numerical outputs, and confidence limits and sensitivity analyses.

Key outcomes of the scientific assessment component include:

- Refinement of environmental quality objectives based on an improved understanding of site-specific physical, biogeochemical and biological characteristics, processes and scale complexity
- Recommendations on critical limits for activities and developments so as to ensure compliance with environmental quality objectives (e.g. wastewater emission targets [WET])
- Recommendations on modifications to the structural design of developments (e.g. to mitigate modification in circulation patterns) so as to ensure compliance with environmental quality objectives, if and where achievable
- Recommendations on mitigating actions (and/or contingency plans) to be implemented during the construction and/or operations of specific developments and activities to minimise any risks to marine water and sediment quality.

Specification of critical limits and mitigating actions

The outcomes of the scientific assessment studies are typically presented to the responsible management authorities and institutions for final decision making to provide confirmation on specifications regarding:

- Critical limits for developments and activities (critical limits on waste volumes and composition are typically written into licence agreements for waste disposal practices)
- Modifications to the structural design of the development where relevant
- Mitigating actions to be implemented during the construction and/or operation of relevant developments and activities.

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

Long-term monitoring programmes

Long-term monitoring forms an integral part of any management programme. In this context, it is important to note the difference between baseline measurement programmes (or surveys) and monitoring:

- Baseline measurement programmes refer to shorter-term or once-off, intensive investigation of a wide range of parameters to obtain a better understanding of environmental processes (e.g. as part of the **Scientific Assessment** component). The role of baseline measurement programmes is also to identify the key scales of spatial and temporal variability that need to be part of a model set-up or tested as part of the sensitivity analysis phase.
- Long-term monitoring refers to ongoing data collection programmes which are designed and implemented so as to continuously evaluate the:
  - Effectiveness of management strategies and actions in achieving compliance with critical limits and the implementation of mitigating actions, e.g. compliance with the limits on volume and composition of the wastewater discharges (i.e. source or compliance monitoring)
  - Trends and status of changes in the environment in terms of the health of important ecosystem components and designated beneficial uses in order to respond, where appropriate, in good time to potentially negative impacts, including cumulative effects
  - Whether the predicted environmental responses, identified during the assessment process, match the actual responses
  - Whether the initial assumptions remain valid such as for example the boundary conditions and waste loads.

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

Key elements of a successful long-term monitoring programme include (UNESCO/WHO/UNEP, 1992; ANZECC, 2000b; NZWERF, 2002; US-EPA, 2003):

- **Site-specific monitoring objectives**, distilled from the environmental quality objectives and critical limits previously specified.
- **Focused and cost-effective programme design**, based on an understanding of the physical, biogeochemical and biological processes, also taking into account anthropogenic modifications to such processes. Aspects to be addressed include:
  - *Measurement parameters* (or indicator species), depending on factors such as the characteristics of waste inputs and the sensitivity of indicator species to respond to the site-specific anthropogenic interferences
  - *Selection of sampling locations*, depending on factors such as the predicted temporal scale of influence, both in the near and far field, as well as scales of greatest sensitivity in respect of the anthropogenic interferences and ecosystem responses
  - *Sampling frequency,* depending on factors such as variability in volume and composition of waste inputs, the variability in processes driving transport and fate in the receiving environment and the temporal sensitivity of the ecosystem to contaminant loading, i.e. exposure time vs. detrimental impact
  - *Sampling and analytical techniques*, depending on the selection of measurement parameters and the output that is required to evaluate properly whether monitoring objectives are complied with.

  Numerical modelling has proven to be very useful in enhancing the design of monitoring programmes and improving the interpretation of monitoring results (Monteiro, 1999). Such numerical models provide the process links that enhance the ability to diagnose problem areas as well as to anticipate problems through their predictive capacity. The benefits of numerical modelling in the design of long-term monitoring programmes include:
  - Definition of the most critical space- and time-scales of impact in the system in that important insights are provided by the combination of the existing understanding of key processes and the model assumptions and inputs
  - Improve interpretation and understanding of the 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. Traditionally, monitoring programmes to evaluate ecosystem health included intensive sampling grids to overcome the inherent uncertainties of the spatial (and temporal) variability of the system. However, with the use of numerical modelling, many of the inherent problems of the traditional approach can be overcome in that these models assist in defining the most critical space- and time-scales at which monitoring will need to be done in order to obtain the desired output.
- **Data evaluation and reporting**, where monitoring results need to be presented in a clear format, providing the appointed management institution(s) with the scientific information necessary for effective decision making (i.e. facilitating effective adaptive management).

  Non-compliance will require management response, which may include:
  - A request to responsible parties to re-evaluate critical limits and mitigation actions, environmental quality objectives and/or the operations of related activities and developments, taking into account the latest understanding of related issues (i.e. following the principle of adaptive management).
  - Prosecution, in instances where a facility fails to comply with critical limits and mitigation actions to minimise risks to marine water quality (e.g. where these were set as legal requirements as part of a licence agreement or permit).

Conclusions

The management framework presented here has already been successfully applied in several areas. For example, it has been used as a framework for the development of management programmes in heavily utilised urban bay areas such as False Bay and Saldanha Bay, South Africa (Taljaard and Monteiro, 2002;

Taljaard et al., 2000; Monteiro and Kemp, 2004).

It also proved to be a sound basis from which to develop management and long-term monitoring programmes for marine outfalls (Monteiro, 1999). As a result, the framework has recently been incorporated into South Africa's operational policy for the disposal of land-derived wastewater to the marine environment (RSA DWAF, 2004).

The management framework has also been recommended as the preferred approach and method for the management of marine water quality in the broader Southern African context (Taljaard, 2006) through a project undertaken as part of the Benguela Current Large Marine Ecosystem (BCLME) Programme (www.bclme.org). The BCLME region includes the countries of Angola, Namibia and South Africa and the management framework has been well received by key stakeholders in the region, even though it has not as yet been officially incorporated in the national policies and legislation of all the countries.

As is the case with any process, the structured ecosystem-scale approach for the management of marine water quality discussed in this paper is by no means 'caste in stone'. It should be adjusted continuously to incorporate site-specific requirements, as well as new scientific knowledge and technologies, thereby supporting the principle of adaptive management.

Acknowledgements

The authors would like to thank the Saldanha Bay Water Quality Forum Trust, the Department of Water Affairs and Forestry (South Africa) and the Benguela Current Large Marine Ecosystem (BCLME) Programme who provided us with the opportunity to test the application of this framework as part of the development of the Saldanha Water Quality Management Plan, the Operational Policy for the Disposal of Land-derived Wastewater to the Marine Environment of South Africa and the Management of Land-based Marine Pollution in the BCLME Region, respectively. Pat Morant (CSIR) is also thanked for his valuable advice.

References

AUSTRALIA AND NEW ZEALAND ENVIRONMENT AND CONSERVATION COUNCIL (ANZECC) (2000a) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy No 4. Canberra, Australia. ISBN 0 642 19562 5.

AUSTRALIA AND NEW ZEALAND ENVIRONMENT AND CONSERVATION COUNCIL (ANZECC) (2000b) Australian Guidelines for Water Quality Monitoring and Reporting. National Water Quality Management Strategy No 7. Canberra, Australia. ISBN 0 642 19562 5.

CAPE METROPOLITAN COASTAL WATER QUALITY COMMITTEE (2003) Annual Report 2003. Report produced by the Committee, a voluntary association of senior officials from local, provincial and national government and civil society. Catchment Stormwater and River Management, City of Cape Town, South Africa.

HENOCQUE Y (2001) Urban communities and environmental management in France: The example of the Toulon Bay Contract. *Ocean & Coastal Manage.* **44** 371-377.

MONTEIRO PMS (1999) A Modelling-Driven Environmental Baseline Assessment for the Proposed New Hood Point Outfall in East London: Sediment Biogeochemistry Baseline Study. CSIR Report ENV-S-C 99109C. CSIR, Stellenbosch, South Africa.

MONTEIRO PMS and KEMP A (2004) Water Quality Management Plan for Saldanha Bay. Phase III: Setting of Critical Loads Using a Modelling-Based Ecosystem Approach. CSIR Report ENV-C-S 2004-083. CSIR, Stellenbosch, South Africa.

NEW ZEALAND WATER ENVIRONMENT RESEARCH FOUNDATION (NZWERF) (2002) Ray D (ed.) *New Zealand Municipal Wastewater Monitoring Guidelines*. Published by the New Zealand Water Environment Foundation, Wellington. ISBN 1-877134-40-6.

REPUBLIC OF SOUTH AFRICA DEPARTMENT OF WATER AFFAIRS AND FORESTRY (RSA DWAF) (1995) South African Water Quality Guidelines for Coastal Marine Waters. **Volume 1.** Natural Environment. **Volume 2.** Recreation. **Volume 3.** Industrial Use. **Volume 4.** Mariculture. Pretoria.

REPUBLIC OF SOUTH AFRICA, DEPARTMENT OF WATER AFFAIRS AND FORESTRY (RSA DWAF) (2004) Water Quality Management Series Sub-Series No. MS 13.2. Operational Policy for the Disposal of Land-Derived Water Containing Waste to the Marine Environment of South Africa (1st edn.) Pretoria.

TALJAARD S and BOTES WAM (1995) Marine water quality management in South Africa. *Water Sci. Technol.* **32** (2) 281-288.

TALJAARD S, VAN BALLEGOOYEN RC and MORANT PD (2000) False Bay Water Quality Review. **Volume 2**: Specialist Assessments and Inventories of Available Literature and Data. Report to the False Bay Water Quality Advisory Committee. CSIR Report ENV-S-C 2000-086/2. CSIR, Stellenbosch, South Africa.

TALJAARD S and MONTEIRO PMS (2002) Saldanha Bay Marine Water Quality Management Plan. Phase I: Situation Assessment. Report to the Saldanha Bay Water Quality Forum Trust. CSIR Report ENV-S-C 2002-115/1. CSIR, Stellenbosch, South Africa.

TALJAARD S (2006) Baseline Assessment of Sources and Management of Land-Based Pollution in the BCLME Region (Project BEHP/LBMP/03/01) Report submitted to UNOPS as part of the Benguela Current Large Marine Ecosystem Programme. CSIR Report CSIR/NRE/ECO/ER/2006/0010/C. Stellenbosch, South Africa (www.bclme.org). Accessed on 18 Sep 2006.

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION, WORLD HEALTH ORGANISATION & UNITED NATIONS ENVIRONMENTAL PROGRAMME (UNESO/WHO/UNEP) (1992) *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring* (2nd edn.) An Imprint of Chapman & Hall, London, Glasgow, Weinheim, New York, Tokyo, Melbourne, Madras. ISBN 0-419-21600-6.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (US-EPA) (2002) Water Quality Criteria. Office of Water, Office of Science and Technology (4304T), United States Environmental Protection Agency. EPA-822-R-02-047 (www.epa.gov/waterscience/criteria/). Accessed on 18 Sep 2006.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (US-EPA) (2003) Elements of a State Water Monitoring and Assessment Program. Assessment and Watershed Protection Division, Office of Wetlands, Oceans and Watershed, United States Environmental Protection Agency. EPA 841-B-03-003 (www.epa.gov/owow/monitoring/repguid.html)(Accessed on?)

VAN WYK CF (2001) Die Saldanha Baai Water Gehalte Forum Trust: 'n Instrument vir Beplande Geïntegreerde Monitering en Bestuur van Watergehalte. M.Sc. Thesis, University of Stellenbosch, South Africa.

WATER RESEARCH CENTRE (WRc) (1990) Design Guide for Marine Treatment Schemes. **Volume I**: Introduction, **Volume II**: Environmental Design and Data Collection, **Volume III**: Materials, Construction and Structural Design and **Volume IV**: Operations and Maintenance and Cost Functions. Report No. UM 1009. Swindon, UK.