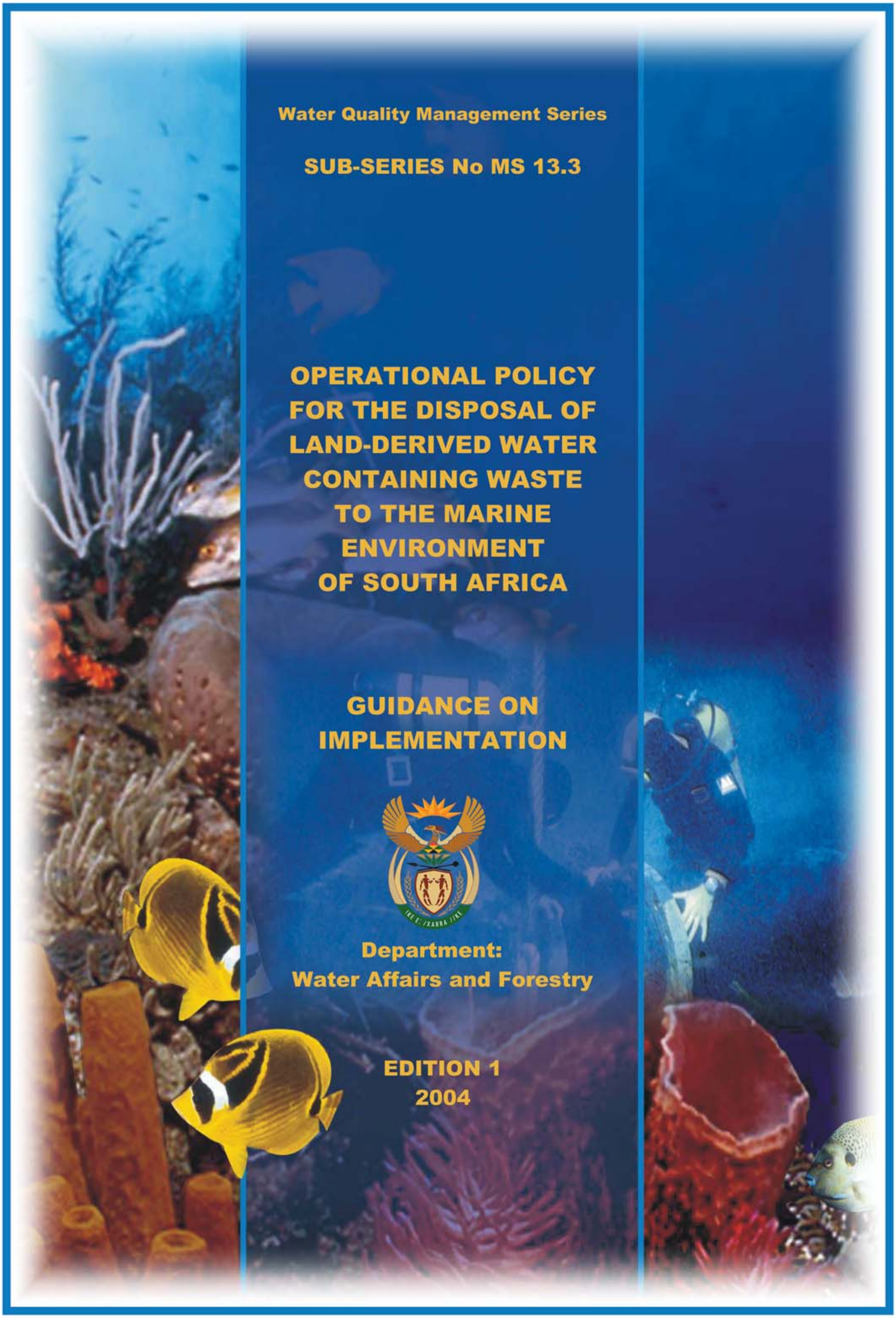

Water Quality Management Series

SUB-SERIES No MS 13.3

OPERATIONAL POLICY FOR THE DISPOSAL OF LAND-DERIVED WATER CONTAINING WASTE TO THE MARINE ENVIRONMENT OF SOUTH AFRICA

GUIDANCE ON IMPLEMENTATION

Department:
Water Affairs and Forestry

EDITION 1
2004

WATER QUALITY MANAGEMENT SERIES

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GUIDANCE ON IMPLEMENTATION

Department of Water Affairs and Forestry

DEPARTMENT : WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

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FOREWORD

This operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa outlines the Department of Water Affairs and Forestry's new thinking in relation to discharges to sea.

In line with international trends and our national objectives of efficient and effective management of the nation's resources, priority is given to a receiving water quality management approach. Previously the focus was on 'end-of-pipe' pollution control with little attention to the receiving environment, whereas this new approach focuses on the capacity of the receiving environment to assimilate waste and hence ensure water that is fit for use by all its other intended users.

In recent years, the discharge of land-derived water containing waste to the marine environment has been receiving increasing attention in many parts of the world due to the environmental sensitivity of the oceans and the cumulative impact of these discharges on the marine environment. In South Africa there are more than forty discharges of water containing waste formalised through authorisations issued in terms the Water Act, 1956 (Act 54 of 1956) and the National Water Act, 1998 (Act 36 of 1998). These discharges vary widely from surf zone and estuarine discharges of municipal sewage or industrial wastewater to discharges through well designed offshore marine outfalls fitted with hydraulically efficient diffusers operating in water depths of more than 20 metre.

The aim of this operational policy is to provide Basic Principles and Ground Rules as framework within which disposal practices for land-derived water containing waste could be evaluated when marine disposal is a possible alternative. It also provides a management framework within which such disposal needs to be conducted.

The Department of Water Affairs and Forestry would like to extend our sincere gratitude to all those who contributed to the development of this Operational policy and supporting documents.

EXECUTIVE SUMMARY

INTRODUCTION

The Department of Water Affairs and Forestry (DWAF) commissioned this project to develop an *operational policy*, specifically focusing on the *disposal of land-derived water containing waste (or wastewater) to the marine environment of South Africa* (including estuaries, the surf zone and offshore marine waters) in order to fulfil its legal obligation in terms of the management and control of land-derived water and water containing waste (to be referred to as 'wastewater' for the purposes of this document).

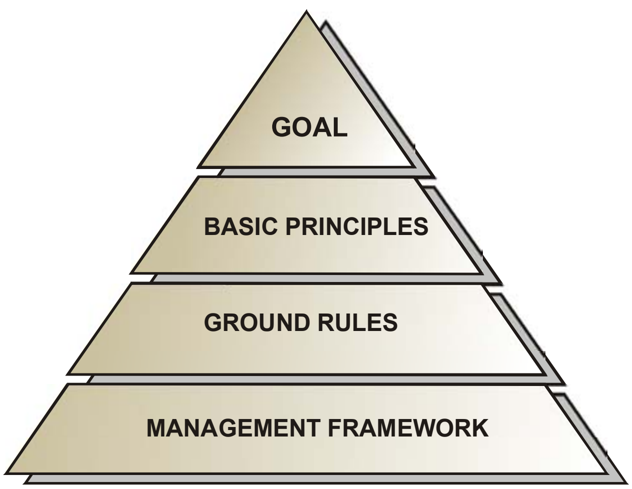
The Department of Water Affairs and Forestry's strategic view of the disposal of land-derived wastewater to the marine environment is as follows:

Taking into account the generally favourable, dynamic physical conditions along the South African coastline, responsible disposal of land-derived water containing waste (referred to as wastewater) to the marine environment is considered an option in South Africa, provided that all reasonable efforts have been made, first of all to prevent waste, and secondly, to minimise waste.

However:

- ***Because South Africa is a water scarce country, the loss of freshwater to the marine environment must be limited in terms of water conservation and demand management strategies.***
- ***According to the White Paper on a National Water Policy for South Africa, 'efforts to introduce source control will be strengthened, through standards and licensing and through changes in technologies and land use, with the final aim of getting as close as possible to a situation in which there is no discharge of pollutants into our water (including the marine environment)'.***

The structure of this operational policy for the disposal of land-derived wastewater to the marine environment of South Africa is illustrated below:



The **Goal** of this operational policy for the disposal of land-derived wastewater to the marine environment of South Africa is as follows:

To achieve water quality that is 'fit for use' and that can maintain aquatic ecosystem health on a sustainable basis by protecting of the country's water resources (including marine waters), in a manner allowing justifiable social and economic development. This will be achieved in accordance with the hierarchy of water quality management goals of the DWAF, namely:

- ***Prevent waste***
- ***Minimise waste***
- ***Dispose responsibly.***

The goal will be achieved through enforcement of the Basic Principles, Ground Rules, and Management Framework stipulated in this operational policy.

Basic Principles provide the broad framework or direction within which to develop ground rules on the disposal practices of land-derived wastewater to the marine environment, as well as the management thereof. The basic principles were distilled from the broader international and national legislative context to give international and national credibility to the policy.

Ground Rules derived within the broader framework of the Basic Principles, provide more specific rules that will be applied by Government when, for example considering new licence applications or review existing licences to dispose of land-derived wastewater to the marine environment.

(The Basic Principles and Ground Rules are discussed in detail in the *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa* [RSA DWAF Water Quality Management Sub-Series 13.2]).

The **Management Framework** provides the generic and structured approach within which the management and control of disposal of land-derived wastewater to the marine environment of South Africa needs to be conducted.

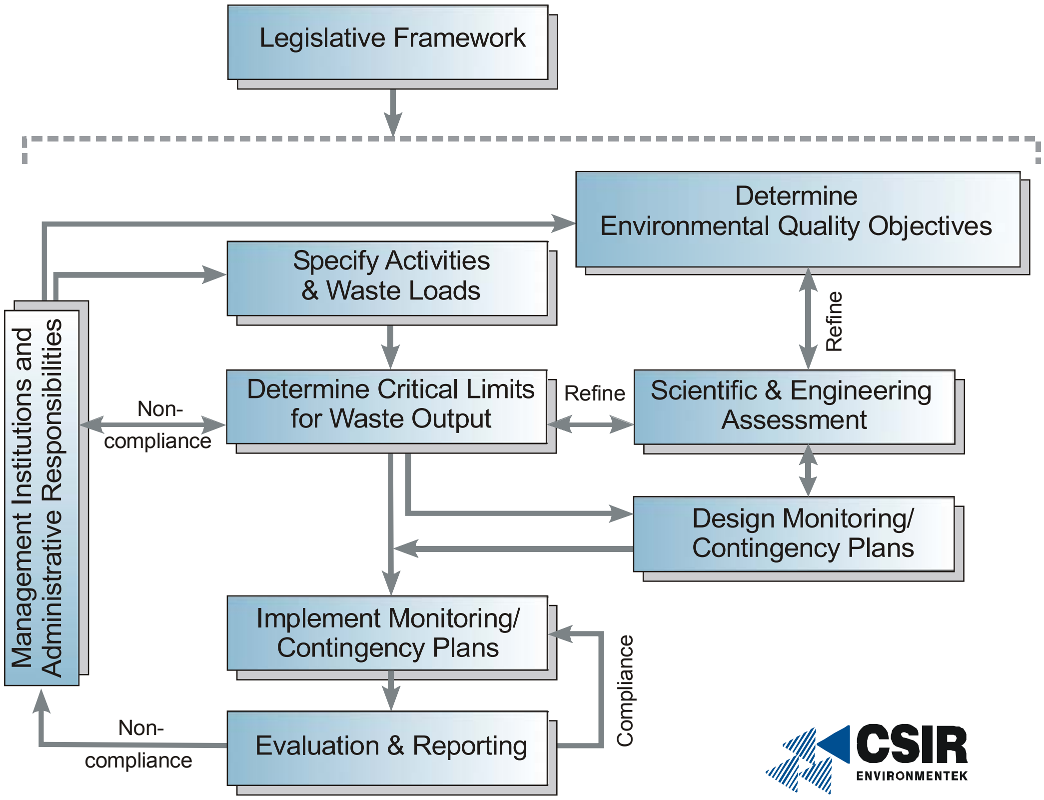
PURPOSE OF THIS DOCUMENT

The purpose of this document is to provide practical guidance to authorities, managers, engineers and scientists on the implementation of the operational policy for the disposal of land-derived wastewater to the marine environment in the context of the management framework (applicable to both existing and proposed discharges). Although an attempt was made to keep this document as user-friendly as possible so as also to provide the less experienced with an overview of the implementation processes, it is primarily aimed at managers, scientists and engineers who are responsible for the technical implementation of the operational policy.

Guidance on the implementation of the operational policy for the disposal of land-derived wastewater to the marine environment, provided in this document, is described within the context of the management framework.

OVERVIEW OF THE MANAGEMENT FRAMEWORK

The Management Framework provides the generic and structured approach within which the management and control of disposal of land-derived wastewater to the marine environment of South Africa needs to be conducted. A flow chart illustrating the logical sequence of the above-mentioned components is schematically illustrated in the figure on the following page.



A brief overview of each of the components is provided below.

Legislative Framework

A management framework should be designed and implemented within the international and national legislative frameworks governing the particular activities and affected environmental domains. In the case of the disposal of land-derived wastewater to the marine environment, these requirements are provided for in the *Basic Principles and Ground Rules* of this operational policy.

Further information on the legislative framework is provided in Section 2 of this Document.

Management Institutions and Administrative Responsibilities

The disposal of land-derived wastewater to the marine environment is currently governed by the DWAF under the National Water Act 36 of 1998. The DWAF works in consultation with other government departments. In the context of this operational policy, water use authorisation, under section 21 of the NWA will be required for:

- New applications to dispose of land-derived wastewater to the marine environment
- Existing discharges of land-derived wastewater to the marine environment that are not considered to be existing lawful water use in terms of Section 32 of the NWA
- Upgrades, extensions of existing WWTW or industries discharging to the marine environment that were not approved in terms of the original authorisation

- Change in effluent volume or composition (a licence is issued based on a specific effluent volume and composition, therefore if these change, the discharger legally must re-apply).

Although the DWAF is responsible for the overarching management and administration of the disposal of land-derived wastewater to the marine environment, a key element in the successful implementation of this operational policy is the establishment of local management institutions, representing all the role-players in a designated area, and which fulfil the role of 'local watchdogs' or 'custodians'.

Further information on management and administrative responsibilities is provided in Section 3 of this Document.

Environmental Quality Objectives

The area within which this management framework is applied must be determined, taking into account the anticipated influence of the proposed discharge, both in the near and far fields (e.g. an entire bay or ecosystem).

Environmental quality objectives must be set in consultation with stakeholders. The identification and mapping of sensitive marine ecosystems and the beneficial uses in the affected areas provide the basis for the derivation of such site-specific environmental quality objectives.

In order for environmental quality objectives to be practical and effective management tools, they need to be set in terms of measurable target values or ranges for specific water column, sediment and biological parameters.

Further guidance on procedures to be followed to determine the area boundaries, important ecosystems, beneficial uses and associated environmental quality objectives is provided in Section 4 of this Document

Activities and associated Waste Loads

To ensure that possible cumulative and synergistic effects are taken into account, the waste loads of the activities under investigation, as well as those of existing waste inputs to the study area (both in terms of quantity and quality), need to be defined.

Further guidance on determining the specification for different types of wastewater is provided in Section 5 of this Document

Scientific and Engineering Assessment

The objective of this component of the management framework is to refine the environmental quality objectives for a particular marine receiving environment and to establish whether a waste disposal practice can be designed that will comply with such environmental quality objectives. The following are required:

- Characterise the physical and biogeochemical processes and the ecological functioning of the receiving marine environment

- Conduct the hydraulic design of (offshore) outfall, based on preliminarily required dilution estimates and taking into account characteristics of waste loads (both in terms of volume and composition)

- Determine achievable near and far field dilution and deposition/re-suspension patterns, taking into account other anthropogenic influences in the study area, as well as possible synergistic or cumulative effects

- Assess for compliance with environmental quality objectives. Where compliance cannot be achieved, for example, through adjustment of the hydraulic design, either the critical limits for the waste load need to be reduced (e.g. through additional pre-treatment prior to discharge) or the environmental quality objectives need to be re-defined (only in extreme situations, e.g. in cases where the economic/social gains justify such environmental sacrifice).

- Define the structural design and construction considerations of a marine outfall to meet requirements as determined by the above.

Further guidance on the procedures to be followed in the scientific and engineering assessment is provided in Section 6 of this Document. Where appropriate, a distinction is made between requirements for a pre-assessment and a detailed investigation as specified within the authorisation process discussed in Section 3 of this document.

Monitoring and Contingency Plans

Long-term monitoring plans need to be designed and implemented to enable the continuous evaluation of:

- The effectiveness of management strategies and actions to comply with the licence conditions and design criteria (Compliance monitoring and System Performance monitoring)

- The trends and status of changes in the environment in terms of the health of important ecosystems and designated beneficial uses in order to respond to and also to assess if the environmental responses that were predicted during the assessment process match the actual responses (Environmental monitoring).

Monitoring programmes typically become part of the licence issued by the DWAF for a particular discharge under section 21 of the NWA. These monitoring programmes are designed and implemented at the cost of the licensee (following the Polluter Pays Principle).

To be useful from a management perspective, monitoring data must be evaluated against pre-determined objectives. Results need to be presented in clear format, providing the appointed management institution/s with the scientific and engineering information needed for effective decision making (i.e. facilitating effective adaptive management).

Contingency plans and mitigating actions are required to minimise the risks to the environment in the event of malfunctioning, both during construction and operation. Decommissioning of a wastewater disposal scheme is also addressed.

Further guidance on procedures to be followed in monitoring and contingency planning is provided is in Section 7 and 8 of this Document, respectively.

RECOMMENDATIONS FOR FUTURE IMPLEMENTATION

The following are recommended for future implementation:

- Operational policies (relating to specific activities) are considered crucial building blocks in achieving an integrated and holistic pollution control and waste management system for South Africa. It is recommended that such policies also be developed for other waste disposal activities to the marine environment. These include activities associated with shipping traffic and dredge spoil dumping, which currently fall within the jurisdiction of the DEAT. To facilitate effective cooperative governance, such policies should eventually be combined in an overarching operational policy for the disposal of waste to the marine environment of South Africa.
- Operational policies need to be developed for the land-based management and control of diffuse wastewater sources (e.g. urban stormwater run-off, agricultural and mining return flows). These need to be dealt with on a catchment level, rather than per individual water resource component. International trends need to be taken into account as well as national initiatives.
- Where multiple developments and activities occur in a study area, it is usually extremely difficult and financially uneconomical to manage marine environmental issues in isolation because of, for example, their potential cumulative or synergistic effect on the receiving environment. Collaboration is often best achieved through a joint local management institution. It is, therefore, recommended that the DWAF and DEAT, jointly investigate an official route whereby local management institutions can be formally constituted to assist in the management and control of the quality of marine water resources in South Africa. Towards enforcing the involvement of local role players, the DWAF already requires the establishment of a local monitoring committee, as a licence condition for the disposal of land-derived wastewater to the marine environment.
- To incorporate new learning, both national and international, it is recommended that a review be undertaken of the *South African Water Quality Guidelines for Coastal Marine Waters* for the protection of the marine environment and other beneficial uses. These guidelines also need to include List I and List II substances (List I substances are regarded as particularly hazardous and need to be *eliminated* from wastewater discharges, while List II substances are regarded as less hazardous but nevertheless need to be *controlled*). List II substances are typically those for which specific target values need to be determined. It is also recommended that future updates of the *South African Water Quality Guidelines for Coastal Marine Waters* include sediment quality guidelines.
- It is recommended that South Africa regularly update the inventory of waste discharges to the marine environment, both in terms of volumes and loads. This information should be accessible to the public through the Internet. This publication has become general practice in many countries and provides a sound base from which to holistically assess effectiveness of an operational policy.
- It is recommended that a *Code of Practice* be developed for specific industries in South Africa, specifically addressing ways in which to eliminate or minimise the production of waste, based on best available techniques. This Code of practice should provide clear guidance to industries with regard to their environmental obligation by specifying environmentally sound technologies. This source directed approach to waste elimination and minimisation is considered to be of great value. Documentation available for use in other countries, such as Canada and New Zealand, could to a large extent be adopted for South Africa.
- In countries in which industries (and their waste loads) are not well-defined, prohibited or controlled, substance lists consist of individual substances, e.g. benzene. However, in countries, like Canada and New Zealand, in which industry types and their waste are well-defined, the prohibited or controlled lists also include certain waste stream types. To accommodate, for example synergistic effects from complex effluent, this is an approach that should be investigated for South Africa, once industry types and their waste are more clearly defined.

APPROVAL

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- Sappi Saiccor
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- WESSA

- KZN Wildlife
- Mhlathuze Water
- Mgeni Water
- Buffalo City (East London)
- Nelson Mandela Metropole (Port Elizabeth)
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- Provincial Departments of Health
- City of Cape Town
- Fishing Industries
- Caltex Refinery, Milnerton
- Petro SA (formerly Mossgas)
- Saldanha Bay & St Helena Bay Water Quality Forum
- Orange River Interim Management Committee
- Alexcor, De Beers and Transhex
- District Municipality (Northern Cape)
- Koeberg Power Station
- Earth Life Africa
- WWF, formerly known as the World Wildlife Fund
- Development Bank of South Africa (DBSA)
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DOCUMENTS IN SERIES

Sub-Series MS13.1	Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Inception Report
Sub-Series MS13.2	Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa
Sub-Series MS13.3	**Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation**
Sub-Series MS13.4	Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices

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ACRONYMS

ANZECC	Australian and New Zealand Environment and Conservation Council
BAT	Best available technology
BOD	Biochemical oxygen demand
CEPA	Canadian Environmental Protection Act
COD	Chemical oxygen demand
CTD	Conductivity-Temperature-Depth
CWA	Clean Water Act (United States)
1-D	One-Dimensional
2-D	Two-Dimensional
3-D	Three-Dimensional
DBSA	Development Bank of South Africa
DEAT	Department of Environmental Affairs and Tourism
Defra	Department of Environment, Food and Rural Affairs (UK)
DPLG	Department of Provincial and Local Government
DWAF	Department of Water Affairs and Forestry
EC	European Community
e.p.	Equivalent population
EPA (Australia)	Environmental Protection Authority (Australia)
EPA	Environmental Protection Agency
GPS	Global Position System
GRP	Glass reinforced plastic
HDPE	High density polyethylene
IEM	Integrated Environmental Management
KZN	Kwazulu-Natal
LC_{50}	Concentration that is lethal to 50% of the test organisms
LPDE	Low density polyethylene
MATD	Minimum acceptable toxicant dilution
MDPE	Medium density polyethylene
MPa	Mega Pascal (unit)
NEMA	National Environmental Management Act 107 of 1998
NOAEC	No-observed-adverse-effect-concentration
NPDES	National Pollutant Discharge Elimination System
NTRPC	Natal Town And Regional Planning Commission
NWA	National Water Act 36 of 1998
NZWERF	New Zealand Water Environment Research Foundation
POTW	Public owned treatment works
PRO	Primary Responsible Officer
PVC	Polyvinal chloride
SADCO	South African Data Centre for Oceanology
SANCOR	South African National Committee for Oceanographic Research
SEPA	Scottish Environment Protection Agency
SS	Suspended solids
SUDS	Sustainable Urban Drainage System

UNEP	United Nations Environmental Programme
uPVC	Unplasticised Polyvinal chloride
US-EPA	United States Environmental Protection Agency
WESSA	Wildlife and Environment Society of South Africa
WHO	World Health Organisation
WMS	Water Management System of DWAF
WRC	Water Research Commission
WRc	Water Research Centre
WWF	WWF - formerly know as the World Wildlife Fund
WWTW	Waste water treatment works
ZID	Zone of initial dilution

GLOSSARY OF TERMS

Advective transport	The transport of dissolved or suspended material in a horizontal plane by a current
Agglomeration	An area where the population and/or economic activities are sufficiently concentrated for urban wastewater to be collected and conducted to an urban wastewater treatment plant or to a final discharge point
Agricultural run-off	Irrigation tail-water, other field drainage, animal yard, feedlot, or dairy run-off, etc.
Anthropogenic	Having to do with man, or caused by humans
Aquifer	Underground layer of permeable rock, sand or gravel that conveys water
Aquaculture	Breeding and rearing of freshwater and marine (mariculture) organisms, such as fish, including the husbandry, management, nutrition, genetics and controlled propagation of all aquatic organisms for use by humans
Assimilative capacity	The ability of an ecosystem to absorb substances such as human waste and pollutants
Bathymetry	Measurement of the depths of water bodies (ocean, estuaries, dams)
Benchmark	Point of reference
Benthic organisms	Organisms living in or on sediments of aquatic habitats
Bioaccumulation	A process whereby chemical substances are accumulated by aquatic organisms, directly from water or through consumption of food containing such chemicals
Bioavailable	Able to be taken up by organisms
Biochemical oxygen demand (BOD)	A measurement of the amount of oxygen taken up by micro-organisms in oxidizing reducing material in the water sample. Normally measured over a 5 day period at 37 degrees C
Biodiversity	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems
Catchment	In relation to a watercourse or watercourses or part of a watercourse, this term means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points
Chemical oxygen demand (COD)	A measure of the amount of potassium dichromate needed to oxidise reducing material in the water sample. It is generally higher than the biochemical oxygen demand.
Coastal area	The part of the land affected by its proximity to the sea, and that part of the sea affected by its proximity to the land as the extent to which man's land-based activities have a measurable influence on water chemistry and marine ecology
Collecting system	A system of conduits that collects and conducts urban wastewater
Community	Assemblage of organisms characterised by a distinctive combination of species that occupy a common environment and interact with one another
Community composition	All taxa present in a community

Cumulative impact (or effect)	Cumulative impact is the impact on the environment which results from the incremental or combined effects of one or more developmental activities in a specified area over a particular time period, which may occur simultaneously, sequentially, or in an interactive manner.
Diffusive transport	When dissolved or suspended material ‘flows’ from one part within a medium with high concentrations to adjacent parts of the medium with low concentrations
Dilution	The reduction in concentration of a substance due to mixing with water
Dissolved oxygen (DO)	Oxygen dissolved in a liquid, the solubility depending upon temperature, partial pressure and salinity, expressed in milligrams/litre or milliliters/litre
Domestic wastewater	Wastewater arising from domestic and commercial activities and premises, which may contain sewage (as per General Authorisations - GG 20526 GN 1191 of 8 October 1999)
Echo-sounder	Device that determines depth by measuring the time taken for a pulse of high-frequency sound to reach the sea bed or a submerged object and for the echo to return.
Ecological integrity	Maintaining a diverse, healthy and productive natural system
Economic incentive	A motivating financial instrument, such as a tax concession or rebate, used to encourage a particular attitude or action
Ecosystem	A community of plants, animals and organisms interacting with each other and with the non-living (physical and chemical) components of their environment
Eddies	The movement of a stream of water in which the current doubles back on itself causing a type of ‘whirlpool’. This is typically caused by promontories along a coastline or due to counteractions from driving forces such as wind shear and an ambient current
Effluent	Liquid fraction after a treatment process (i.e. preliminary, primary, secondary or tertiary) in a wastewater treatment works
Environmental impact	A positive or negative environmental change (biophysical, social and/or economic) caused by human action
Environmental quality objective	A statement of the quality requirement for a body of water to be suitable for a particular use (also referred to as Resource Quality Objective)
Environmental quality standard	The specified concentration of a substance that legally may not be exceeded so as to protect the receiving environment for a particular use
Equity	Treating all people with dignity, fairness and justice.
Equivalent population	The population that comprises the resident population, an allowance for holiday visitors and a conversion of industrial pollution loads to population terms, based on flow or biological load
Estuary	A partially or fully enclosed body of water which is open to the sea permanently or periodically, and within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land. The upstream boundary of an estuary is the extent of tidal influence.
Eulerian (current measurements)	Measuring current by means of a geographically fixed meter that measures the velocity of flow of the passing water
Eutrophication	Enrichment of water with nutrients causing abundant algal or plant growth often leading to subsequent deficiencies in dissolved oxygen

Far field	Within the context of ocean outfalls, the spatial/volumetric extent of the receiving water body in which the waste field is transported and dispersed after the initial dilution process
Habitat	A place, characterised by its physical properties and other life forms, where an organism or community occurs
Head works	The head works receives wastewater from a catchment and treats it to a specified standard prior to discharge.
Industrial wastewater	Wastewater arising from industrial activities and premises. Contaminated stormwater drainage from industrial premises is included in this definition
Initial dilution	The dilution of the wastewater plume generated by jet momentum and the buoyancy effects that occur between the outlet ports of a marine outfall's diffuser and the sea surface
Initial mixing zone	During the initial dilution process, ambient water is entrained by jet and buoyancy-induced turbulence and shear, causing dilution of the rising wastewater plume. When the density of the discharge plume approaches the density of the seawater, the initial dilution process will cease and, depending on stratification in the water column, this process may stop below the surface. The spatial/volumetric extent of the initial dilution process is referred to as the **initial mixing zone**. This process can be manipulated by the hydraulic design of the outfall system (discharge rate and diffuser configuration). Ambient processes will control the further mixing of the wastewater plume. However, these cannot be manipulated and the degree of mixing, when compared with the achievable initial dilutions, is almost insignificant. Only the physical location of the discharge structure can be optimised for achieving required dilutions at distant locations.
Land-based treatment	The treatment of wastewater at an inland site. Inland treatment, for example includes preliminary, primary, secondary or tertiary treatment of the wastewater prior to discharge.
Integrated Development Plan	A plan drawn up by local government to prioritise and co-ordinate development activities and investment, and to promote effective use of budgets
Interstitial water	Water that occurs naturally within the pores or spaces between sediment particles
Inter-tidal	Zone between high and low tide-marks
Lagrangian (current measurements)	Measuring currents by recording the path of a neutrally-buoyant float that follows the flowing water mass
Macroinvertebrates	Animals that have no backbone and are visible without magnification
Macrophytes	Macrophytes are (aquatic) plants that are large enough to be apparent to the unaided eye
Mariculture	Cultivation of marine plants and animals in natural and artificial environments
Marine discharge	Discharging wastewater to the marine environment either to an estuary or the surf zone or through a *marine outfall* (i.e. to the offshore marine environment)
Marine environment	Marine environment includes estuaries, coastal marine and near-shore zones, and open-ocean-deep-sea regions.

Marine outfall	A submarine pipeline originating on shore, which conveys wastewater from a head works to a submerged discharge location on or near the seabed beyond the surf zone (i.e. to the offshore marine environment). Also referred to in the literature as a long sea outfall/pipeline and ocean outfall/pipeline.
Measurement parameter	Within the context of this document, any parameter or variable that is measured to find out something about an ecosystem
Meiofauna	Animals ranging in size from approximately 0.1 mm to 1 mm that live within sediments
Municipal wastewater	Domestic wastewater or the mixture of domestic wastewater with industrial wastewater and/or urban stormwater run-off
Nearfield	Within the context of ocean outfalls this refers to the spatial/volumetric extent of the receiving water body in which the initial dilution process takes place.
Nearshore	Within the context of ocean outfalls, this is the zone in the sea in which wave action has a significant effect on water circulation and shoreline processes (erosion and accretion).
Non-point source pollution	Pollution originating from a number of diffuse sources often associated with run-off from agricultural and urban areas
Offshore	Within the context of ocean outfalls, this is the zone in the sea in which wave action has an insignificant effect on water circulation and shoreline processes (erosion and accretion)
Physiography	Description of the natural features of the seabed (physical geography)
Point-source pollution	Pollution discharged from a specific fixed location, such as a pipe or outfall structure
Pollution	The direct or indirect alteration of the physical, chemical or biological properties of the natural environment, including the marine environment, so as to make it less fit for any beneficial purpose for which it may reasonably be expected to be used, or to make it harmful or potentially harmful to the welfare, health or safety of human beings or to any aquatic or non-aquatic organisms
Precautionary principle	Avoiding risk through a cautious approach to development and environmental management
Preliminary treatment	Involves the removal from wastewater of 'litter' and solids by coarse and/or fine screens as well as the removal of 'grit' (particles sizes > 0.2 mm and with a specific gravity > 2.6) by settling or separation. The effect on the suspended solid concentrations and *BOD* in the sewage is insignificant.
Primary treatment	Involves the removal from wastewater of settleable organic and inorganic solids by sedimentation tanks. The solids, which settle as sludge, have to be disposed of or treated. Fats (oil and grease) are also skimmed from the top of the settling tank. During primary treatment > 40% of suspended solids and 20% of *BOD* are removed.

Reserve	The quantity and quality of water required: • to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be relying upon, taking water from, or being supplied from the relevant water resource, and • to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.
Resource quality objectives	Management Objectives for a resource relating to quality of all the aspects of a water resource including: • the quantity, pattern, timing, water-level and assurance of instream flow; • the water quality, including the physical, chemical and biological characteristics of the water; • the character and condition of the instream and riparian habitat; and • the characteristics, condition and distribution of the aquatic biota. These objectives are set by the Department of Water Affairs and Forestry in terms of Chapter 3 of the NWA
Rhodamine-B dye	A fluorescent red basic xanthene dye used in the marine environment to determine transport and dispersion patterns
Risk-aversion	Active avoidance to possible exposure to loss of human life, or property damage as a result of hazardous events or coastal processes.
Seashore	The water and the land between the high- and low-water marks
Secondary dilution or dispersion	The further dilution that occurs after initial dilution when a wastewater plume is advected away from the discharge area
Secondary treatment	The separation of liquid and solids contained in primary treated wastewater by a stabilizing process, utilizing micro-organisms and oxygen (aerobic biological treatment by biofilters and/or aeration tanks). The liquid and solids are separated through settling and the sludge is disposed of or treated. Normally secondary treatment removes > 70% of suspended solids and BOD.
Side scan sonar	Sonar is the acronym for **so**und **n**avigation **a**nd **r**anging, a technique used for the detection and location of underwater objects by emitting acoustic waves, and by the interception of the reflected acoustic waves from underwater obstacles. A side scan sonar is a sonar system that transmits sound energy and analyses the echo (return signal) which bounces back from irregularities on the sea-floor, providing a black and white ‘trace’ of the sea-floor. Usually the side scan sonar (housed in a towfish) is towed behind a boat at a predetermined depth in deeper water or it can be mounted on the hull of the boat for use in shallow water.
Sludge	Residual sludge, whether treated or untreated, from urban wastewater treatment plants
Subtidal	The zone below the low-tide level, i.e. it is never exposed at low tide
Sustainability	In terms of water quality management (DWAF), this means: ‘Fitness for use by other users and future generations’ and the ability to assimilate waste means the ability to receive and process waste to such an extent that the water remains fit for use by its other intended users.

Surf zone	Also referred to as the 'breaker zone' where water depths are less than half the wavelength of the incoming waves with the result that the orbital pattern of the waves collapses and breakers are formed
Synergistic effect	When the effect of two chemicals acting together has a greater negative impact on an ecosystem than the impact of each chemical individually, or the sum of the individual impacts
Tertiary treatment	Involves the further treatment of secondary treated wastewater to remove nitrogen, phosphorus, ammonia, remaining suspended solids, organic compounds, heavy metals and dissolved solids by special treatment processes
Trade effluent	Term used for industrial wastewater discharged to a WWTW
Urban stormwater run-off	Stormwater run-off from paved areas, including parking lots, streets, residential subdivisions, of buildings, roofs, highways, etc.
Waste	Any solid material or material that is suspended, dissolved or transported in water (including sediment) in such volumes, composition or manner that, if spilled or deposited in the natural environment, will cause, or is reasonably likely to cause, a negative impact
Water containing waste	Water containing solid, suspended or dissolved material (including sediment) in such volumes, composition or manner that, if spilled or deposited in the natural environment, will cause, or is reasonably likely to cause, a negative impact
Wastewater	See *Water containing waste*

SECTION 1: INTRODUCTION

1.1 OVERVIEW OF OPERATIONAL POLICY

The Department of Water Affairs and Forestry (DWAF) commissioned this project to develop an *operational policy*, specifically focusing on the *disposal of land-derived water containing waste (or wastewater) to the marine environment of South Africa* (including estuaries, the surf zone and offshore marine waters) in order to fulfil its legal obligation in terms of the management and control of land-derived water and water containing waste (to be referred to as 'wastewater' for the purposes of this document).

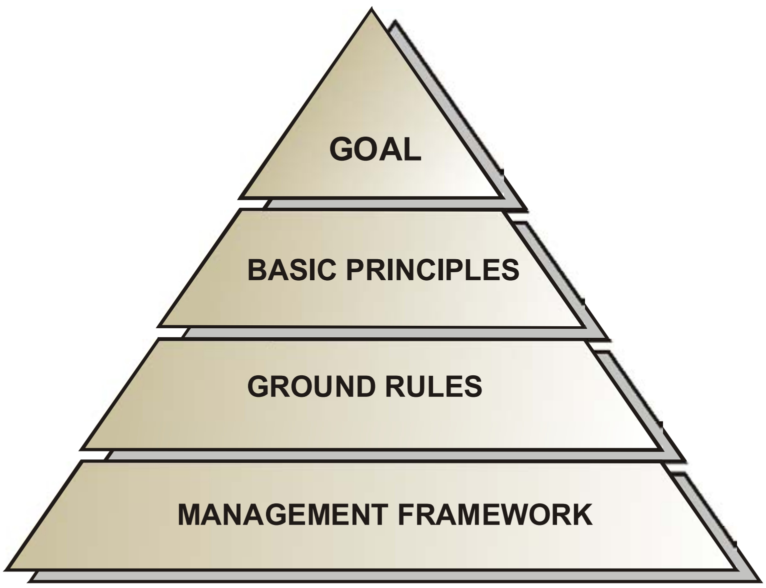
The Department of Water Affairs and Forestry's strategic view of the disposal of land-derived wastewater to the marine environment is as follows:

Taking into account the generally favourable, dynamic physical conditions along the South African coastline, responsible disposal of land-derived water containing waste (referred to as wastewater) to the marine environment is considered an option in South Africa, provided that all reasonable efforts have been made, first of all to prevent waste, and secondly, to minimise waste.

However:

- ***Because South Africa is a water scarce country, the loss of freshwater to the marine environment must be limited in terms of water conservation and demand management strategies.***
- ***According to the White Paper on a National Water Policy for South Africa, 'efforts to introduce source control will be strengthened, through standards and licensing and through changes in technologies and land use, with the final aim of getting as close as possible to a situation in which there is no discharge of pollutants into our water (including the marine environment)'.***

The structure of this operational policy for the disposal of land-derived wastewater to the marine environment of South Africa is illustrated below:



The **Goal** of this operational policy for the disposal of land-derived wastewater to the marine environment of South Africa is as follows:

To achieve water quality that is 'fit for use' and that can maintain aquatic ecosystem health on a sustainable basis by protecting of the country's water resources (including marine waters), in a manner allowing justifiable social and economic development. This will be achieved in accordance with the hierarchy of water quality management goals of the DWAF, namely:

- ***Prevent waste***
- ***Minimise waste***
- ***Dispose responsibly.***

The goal will be achieved through enforcement of the Basic Principles, Ground Rules, and Management Framework stipulated in this operational policy.

Basic Principles provide the broad framework or direction within which to develop ground rules on the disposal practices of land-derived wastewater to the marine environment, as well as the management thereof. The basic principles were distilled from the broader international and national legislative context to give international and national credibility to the policy.

Ground Rules derived within the broader framework of the Basic Principles, provide more specific rules that will be applied by Government when, for example considering new licence applications or review existing licences to dispose of land-derived wastewater to the marine environment.

(The Basic Principles and Ground Rules are discussed in detail in the *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa* [RSA DWAF Water Quality Management Sub-Series 13.2]).

The **Management Framework** provides the generic and structured approach within which the management and control of disposal of land-derived wastewater to the marine environment of South Africa needs to be conducted.

1.2 OVERVIEW OF MANAGEMENT FRAMEWORK

The Management Framework provides the generic and structured approach within which the management and control of disposal of land-derived wastewater to the marine environment of South Africa needs to be conducted. A flow chart illustrating the logical sequence of the above-mentioned components is schematically illustrated in Figure 1.1. A brief overview of each of the components is provided below.

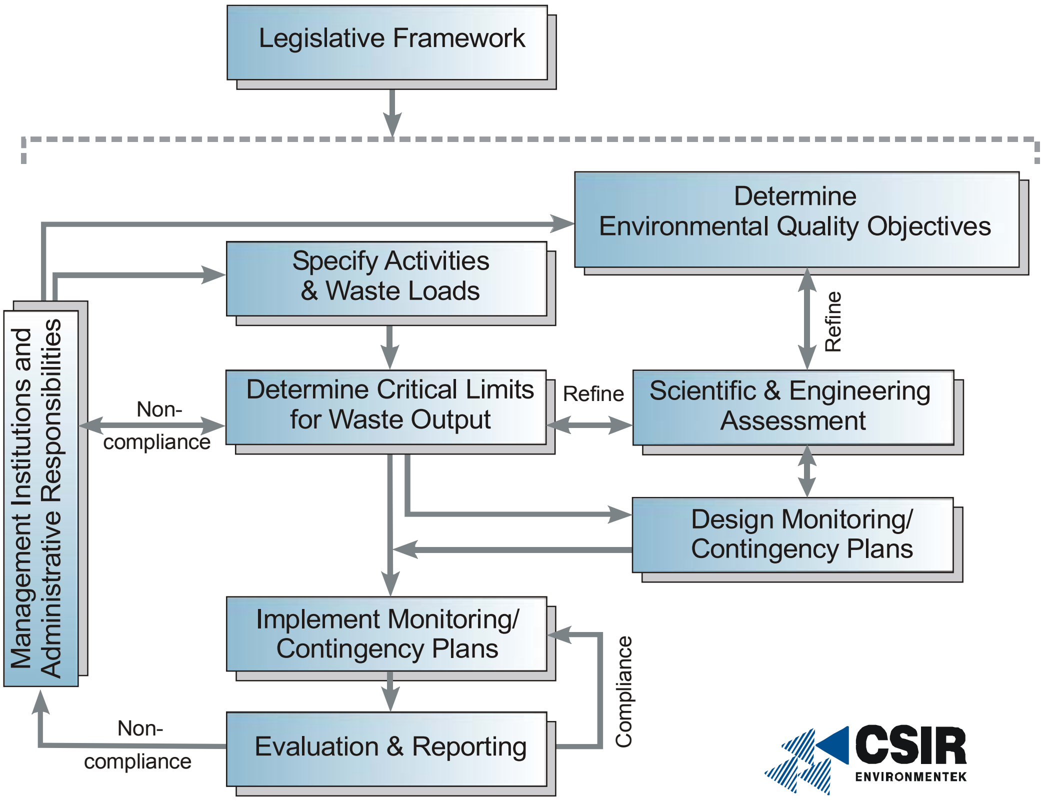


FIGURE 1.1: ***A management framework for the implementation of the Operational policy for the disposal of land-derived wastewater to the marine environment of South Africa***

1.2.1 Legislative Framework

A management framework should be designed and implemented within the international and national legislative frameworks governing the particular activities and affected environmental domains. In the case of the disposal of land-derived wastewater to the marine environment, these requirements are provided for in the *Basic Principles and Ground Rules* of this operational policy.

Further information on the legislative framework is provided in Section 2 of this Document.

1.2.2 Management Institutions and Administrative Responsibilities

The disposal of land-derived wastewater to the marine environment is currently governed by the DWAF under the National Water Act 36 of 1998. The DWAF works in consultation with other government departments. In the context of this operational policy, water use authorisation, under section 21 of the NWA will be required for:

- New applications to dispose of land-derived wastewater to the marine environment
- Existing discharges of land-derived wastewater to the marine environment that are not considered to be existing lawful water use in terms of Section 32 of the NWA
- Upgrades, extensions of existing WWTW or industries discharging to the marine environment that were not approved in terms of the original authorisation
- Change in effluent volume or composition (a licence is issued based on a specific effluent volume and composition, therefore if these change, the discharger legally must re-apply).

Although the DWAF is responsible for the overarching management and administration of the disposal of land-derived wastewater to the marine environment, a key element in the successful implementation of this operational policy is the establishment of local management institutions, representing all the role-players in a designated area, and which fulfil the role of 'local watchdogs' or 'custodians'.

Further information on management and administrative responsibilities is provided in Section 3 of this Document.

1.2.3 Environmental Quality Objectives

The area within which this management framework is applied must be determined, taking into account the anticipated influence of the proposed discharge, both in the near and far fields (e.g. an entire bay or ecosystem).

Environmental quality objectives must be set in consultation with stakeholders. The identification and mapping of sensitive marine ecosystems and the beneficial uses in the affected areas provide the basis for the derivation of such site-specific environmental quality objectives.

In order for environmental quality objectives to be practical and effective management tools, they need to be set in terms of measurable target values or ranges for specific water column, sediment and biological parameters.

Further guidance on procedures to be followed to determine the area boundaries, important ecosystems, beneficial uses and associated environmental quality objectives is provided in Section 4 of this Document

1.2.4 Activities and associated Waste Loads

To ensure that possible cumulative and synergistic effects are taken into account, the waste loads of the activities under investigation, as well as those of existing waste inputs to the study area (both in terms of quantity and quality), need to be defined.

Further guidance on determining the specification for different types of wastewater is provided in Section 5 of this Document

1.2.5 Scientific and Engineering Assessment

The objective of this component of the management framework is to refine the environmental quality objectives for a particular marine receiving environment and to establish whether a waste disposal practice can be designed that will comply with such environmental quality objectives. The following are required:

- Characterise the physical and biogeochemical processes and the ecological functioning of the receiving marine environment
- Conduct the hydraulic design of (offshore) outfall, based on preliminarily required dilution estimates and taking into account characteristics of waste loads (both in terms of volume and composition)
- Determine achievable near and far field dilution and deposition/re-suspension patterns, taking into account other anthropogenic influences in the study area, as well as possible synergistic or cumulative effects
- Assess for compliance with environmental quality objectives. Where compliance cannot be achieved, for example, through adjustment of the hydraulic design, either the critical limits for the waste load need to be reduced (e.g. through additional pre-treatment prior to discharge) or the environmental quality objectives need to be re-defined (only in extreme situations, e.g. in cases where the economic/social gains justify such environmental sacrifice).
- Define the structural design and construction considerations of a marine outfall to meet requirements as determined by the above.

Further guidance on the procedures to be followed in the scientific and engineering assessment is provided in Section 6 of this Document. Where appropriate, a distinction is made between requirements for a pre-assessment and a detailed investigation as specified within the authorisation process discussed in Section 3 of this document.

1.2.6 Monitoring and Contingency Plans

Long-term monitoring plans need to be designed and implemented to enable the continuous evaluation of:

- The effectiveness of management strategies and actions to comply with the licence conditions and design criteria (Compliance monitoring and System Performance monitoring)

- The trends and status of changes in the environment in terms of the health of important ecosystems and designated beneficial uses in order to respond to and also to assess if the environmental responses that were predicted during the assessment process match the actual responses (Environmental monitoring).

Monitoring programmes typically become part of the licence issued by the DWAF for a particular discharge under section 21 of the NWA. These monitoring programmes are designed and implemented at the cost of the licensee (following the Polluter Pays Principle).

To be useful from a management perspective, monitoring data must be evaluated against pre-determined objectives. Results need to be presented in clear format, providing the appointed management institution/s with the scientific and engineering information needed for effective decision making (i.e. facilitating effective adaptive management).

NOTE:

It is important to note the difference between baseline measurement programmes (or surveys) and monitoring:

- ***<u>Baseline measurement programmes</u> (or surveys) refer to shorter-term or once-off, intensive investigations on a wide range of parameters to obtain a better <u>understanding of environmental processes</u> (e.g. as part of the Scientific and Engineering Assessment component)***

- ***Long-term <u>monitoring</u> refers to ongoing data collection programmes that are done to evaluate continuously the effectiveness of management strategies/actions designed to maintain a desired environmental state so that responses to potentially negative impacts, including cumulative effects, can be implemented in good time.***

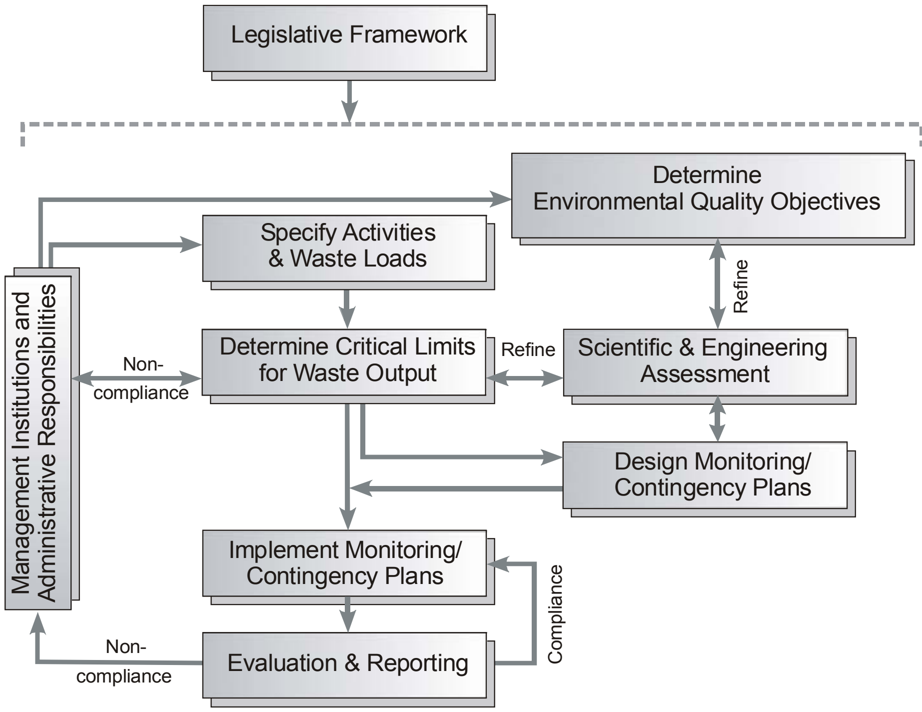
Contingency plans and mitigating actions are required to minimise the risks to the environment in the event of malfunctioning, both during construction and operation. Decommissioning of a wastewater disposal scheme is also addressed.

Further guidance on procedures to be followed in monitoring and contingency planning is provided is in Section 7 and 8 of this Document, respectively.

1.3 USE OF THIS DOCUMENT

The purpose of this document is to provide practical guidance to authorities, managers, engineers and scientists on the implementation of the operational policy for the disposal of land-derived wastewater to the marine environment in the context of the management framework (applicable to both existing and proposed discharges). Although an attempt was made to keep this document as user-friendly as possible so as also to provide the less experienced with an overview of the implementation processes, it is primarily aimed at managers, scientists and engineers who are responsible for the technical implementation of the operational policy.

Guidance on the implementation of the operational policy for the disposal of land-derived wastewater to the marine environment, provided in this document, is described within the context of the management framework (refer to Section 1.2). Important background information and procedures to be followed for each of the components of the management framework are addressed, using the following roadmap:



The authorisation process for a water use (as discussed in Section 3.1) identifies two distinct levels or stages of assessment in the licence application process, namely:

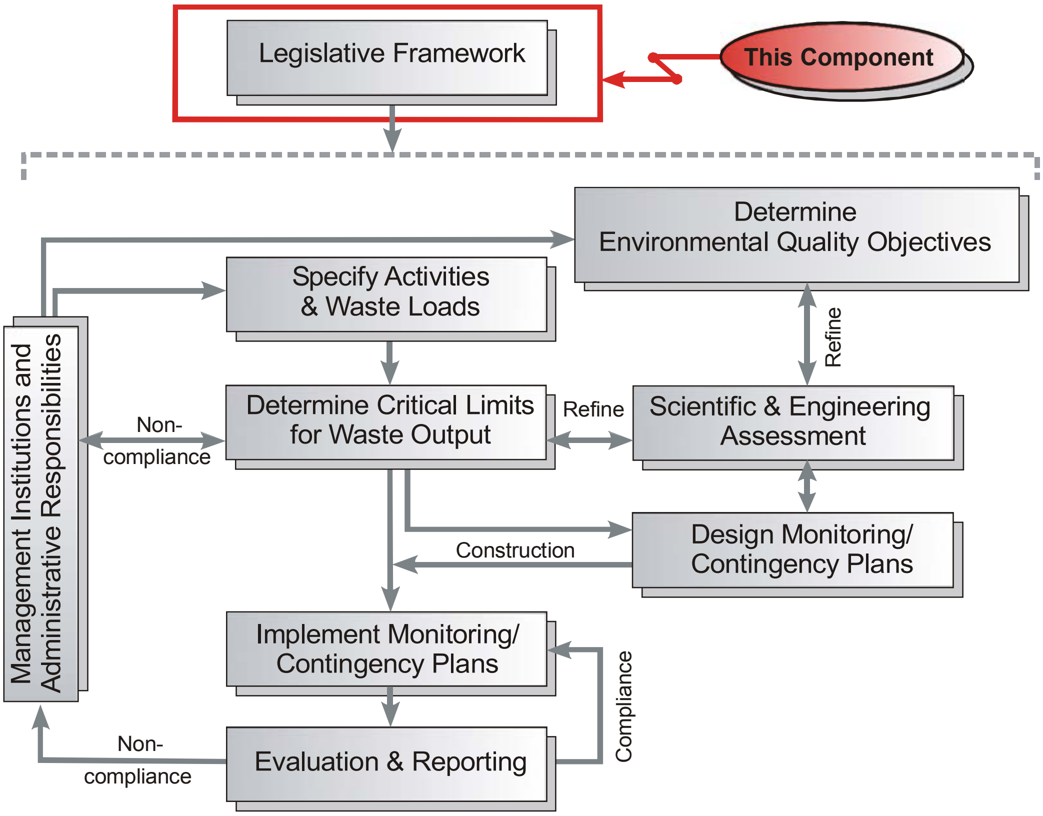
- **Pre-assessment** (also referred to as a pre-feasibility assessment or a 'fatal flaw analysis') of which the primary purpose is to establish the Best Practical Environmental Option/s for a particular water use, in this case the disposal of land-derived wastewater.

- **Detailed investigation** of which the purpose is to conduct detailed assessments to determine and quantify potential negative impacts of the selected 'Best Practical Environmental Option/s', as well as to define the design and construction considerations of the disposal scheme.

This document distinguishes between requirements for a Pre-assessment and for a Detailed Investigation, particularly in terms of the data and information required for the *Scientific and Engineering Assessment* component *(referring to Section 6 of this document).*

SECTION 2:
LEGISLATIVE FRAMEWORK

SECTION 2: LEGISLATIVE FRAMEWORK



PURPOSE:

The purpose of this component is to identify both national and international legislative obligations pertaining to the disposal of wastewater to the marine environment.

The legislative framework pertaining to an operational policy for the disposal of land-derived wastewater in coastal areas of South Africa is discussed in detail in Appendix B (in the *Operational Policy for disposal of land-derived water containing waste to the marine environment of South Africa: Appendices* (RSA DWAF Water Quality Management Sub-Series No. 13.4).

Legislative requirements for the disposal of land-derived wastewater to the marine environment are consolidated into the *Basic Principles and Ground Rules* provided in the *Operational Policy for disposal of land-derived water containing waste to the marine environment of South Africa* (RSA DWAF Water Quality Management Sub-Series No. 13.2).

In summary, five *Basic Principles* apply, namely:

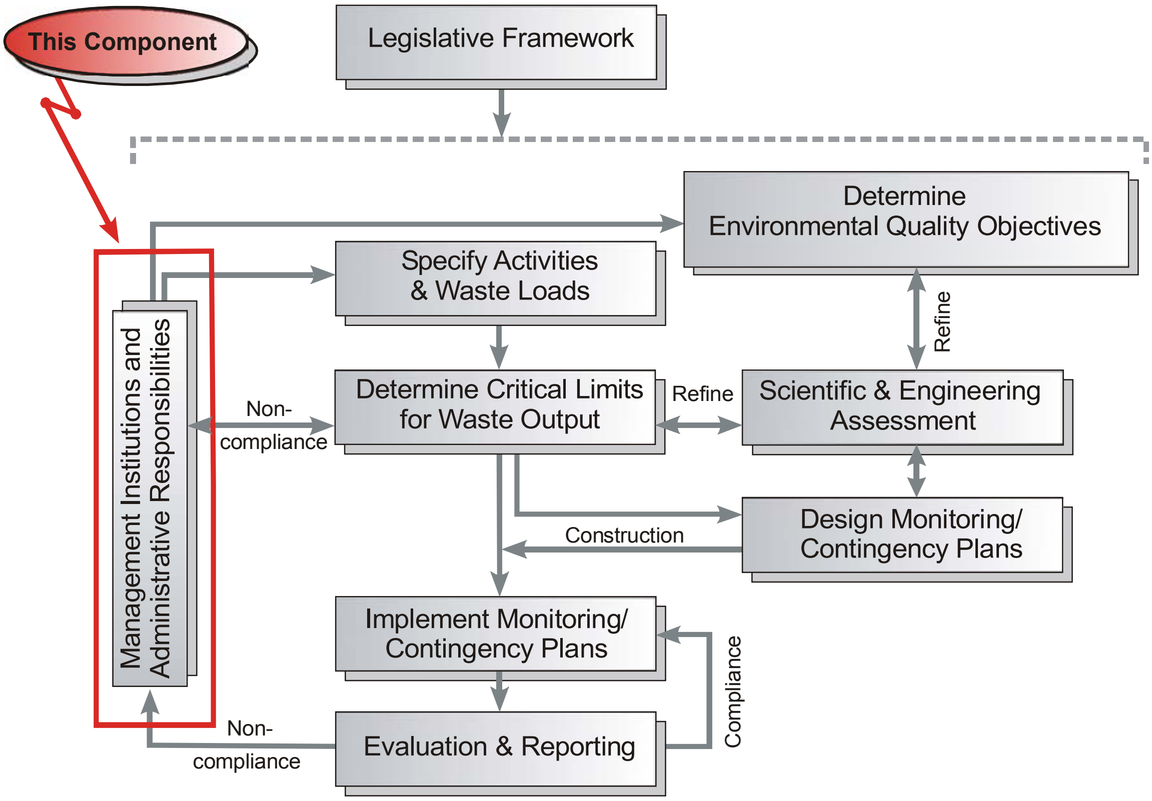
- Pollution prevention, Waste Minimisation & Precautionary Approach
- Receiving Water Quality Objectives Approach
- Integrated Assessment Approach
- Polluter Pays Principle
- Participatory Approach

In turn, the *Ground Rules*, providing more specific criteria or rules that will be applied when considering licence applications. For this operational policy, the Ground Rules are addressed under specific themes considered to be of particular importance in the disposal of land-derived wastewater to the marine environment (in alignment with the key components of the management framework), namely:

- Legislative Framework
- Management Institutions and Administrative Responsibilities
- Environmental Quality Objectives
- Activities and Associated Waste Loads
- Scientific and Engineering Assessment
- Monitoring and Contingency Plans.

SECTION 3:
MANAGEMENT INSTITUTIONS AND ADMINISTRATIVE RESPONSIBILITIES

SECTION 3: MANAGEMENT INSTITUTIONS AND ADMINISTRATIVE RESPONSIBILITIES



PURPOSE:

The purpose of this component is to identify the management and administrative responsibilities pertaining to the disposal of wastewater to the marine environment. These include:

- ***The licence authorisation process (under section 21 of the National Water Act 36 of 1998)***
- ***Appointment of local management institution, including all role players.***

3.1 LICENCE AUTHORISATION PROCESS

The disposal of land-derived wastewater to the marine environment is currently governed under the National Water Act 36 of 1998. In the context of this operational policy, water use authorisation, under section 21 of the National Water Act, will be required for:

- New applications to dispose of land-derived wastewater to the marine environment
- Existing discharges of land-derived wastewater to the marine environment that are not classified as existing lawful water use in terms of Section 32 of the NWA
- Upgrading or extension of existing WWTW or industries discharging to the marine environment that were not approved in terms of the original authorisation.

NOTE:

If for instance, an industry or WWTW applies for a licence knowing that there will be future, planned expansions, these could be catered for in the application in order to avoid going through the whole process of applying for a new licence for the actual expansion. Future, planned expansions should also be catered for as part of the EIA process to ensure alignment between the two processes.

- Change in effluent volume or composition (a licence is issued based on a specific effluent volume and composition, therefore if these change, the discharger legally needs to re-apply).

These activities would typically also be subject to the EIA process (DEAT, 1998).

NOTE:

All existing (lawful) discharges of land-derived wastewater to the marine environment should comply with the **Basic Principles** ***and*** **Ground Rules** ***of this Operational policy (as set out in*** **Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa** ***[RSA DWAF Water Quality Management Sub-Series 13.2]).***

Therefore, where the potential impact of an existing lawful wastewater discharge has not been assessed properly or where there is reason to believe that such discharge has a negative impact on the receiving marine environment, the responsible authority or organisation will be requested to engage in specific studies within the management framework as set out in this document. The extent of such investigations will depend on the potential risks and sensitivity of the receiving marine environment.

An EIA, as such, will not necessarily be needed in such instances, unless upgrades are involved. Unacceptable impacts or water demand in the catchment could lead to a revision of decisions made during the licence authorisation process and a possible "no go" decision. These issues need to be addressed in the five-yearly revisions of licences. Revisions will be motivated on grounds of impact to environment and compliance to licence conditions.

To assist applicants in the authorisation process, the DWAF has compiled a manual entitled *Water Use Authorisation Process for Individual Applications* (RSA DWAF, 2000), which describes the administrative procedures and parties to be involved at different stages of the process. Also, to assist applicants with the preparation of the water quality management reports to support the licence application, the DWAF has compiled an Aide Mémoire (RSA DWAF 2003a). These documents provide a detailed listing of the type of data and information that needs to be included in the reports for pre-assessment and detailed investigations.

Note that this operational policy provides guidance on aspects related to the disposal of land-derived wastewater to the marine environment that are primarily addressed in *Final Waste Disposal Evaluation* of the water quality management report.

Another important aspect that needs to be addressed in the water management report concerns the details on *Management Systems and Pollution Prevention Methods*, which judge the applicant's ability to effectively manage the proposed wastewater disposal facility.

Links between the authorisation process and specific components in the management framework are illustrated in Figure 3.1.

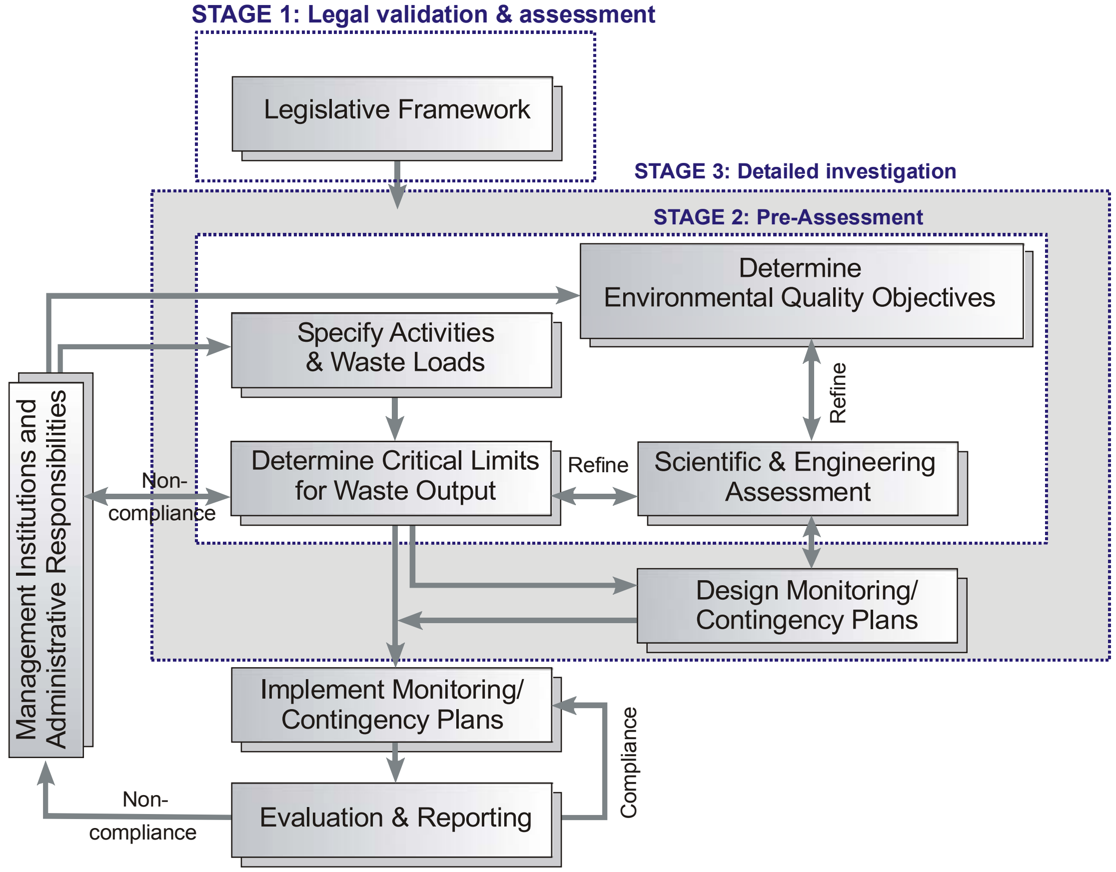


FIGURE 3.1: *Links between the authorisation process and specific sections in the management framework*

A linear progression of the generic stages in the authorisation process and its alignment with the Environmental Impact Assessment Regulations promulgated under Sections 21, 22 and 26 of the Environment Conservation Act (DEAT, 1998) is illustrated in Figure 3.2.

An overview of the procedures and responsibilities relevant to the authorisation process for the *disposal of land-derived wastewater to the marine environment* is provided in the following sections. These were extracted from the generic manual on the authorisation process of the DWAF (RSA DWAF, 2000).

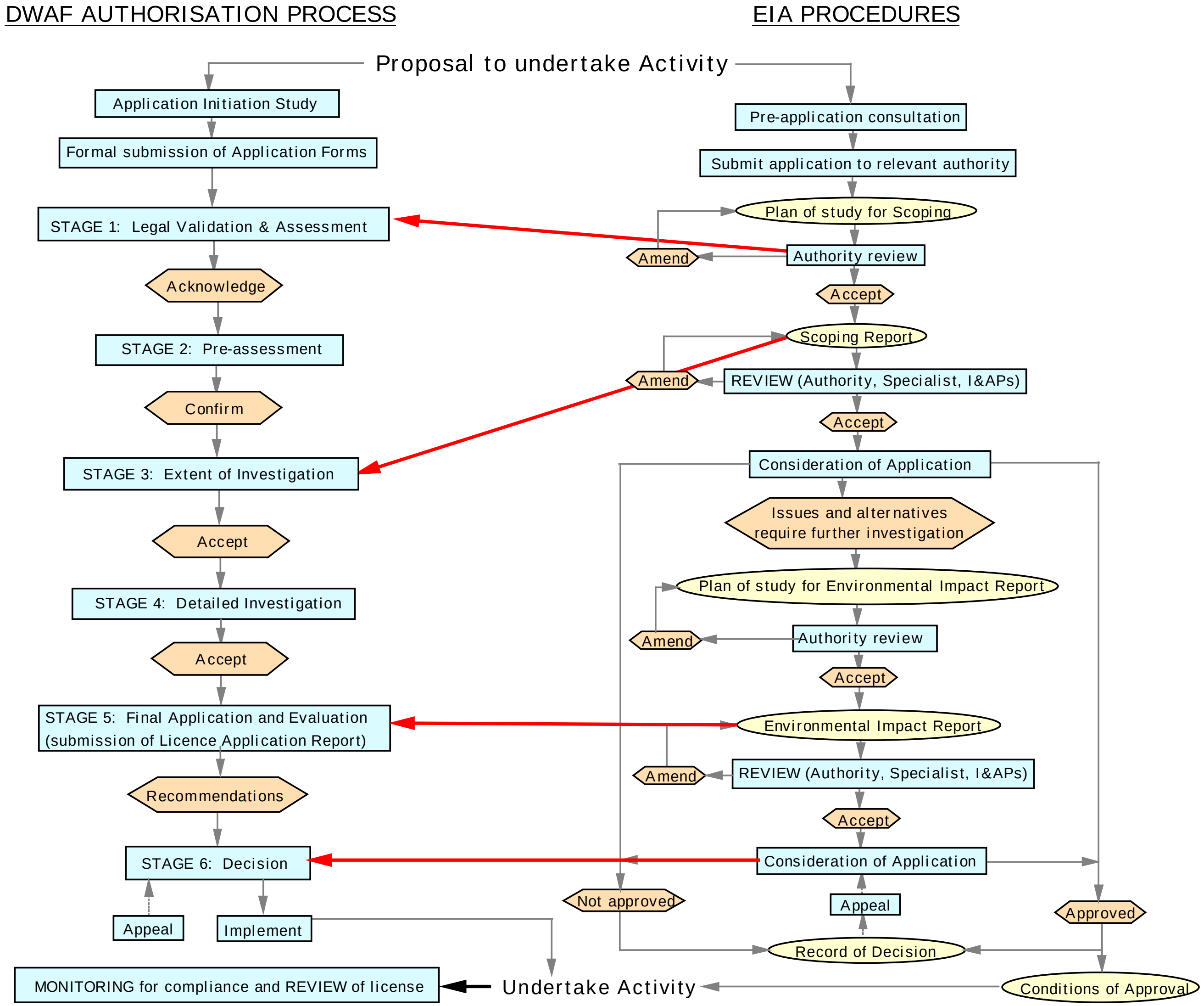


FIGURE 3.2: Linear progression of the stages of the licence application process, as well as an indication of the levels at which different government departments need to be involved (adapted from RSA DWAF, 2000). Also indicated are the links between the DWAF Authorisation Process and the EIA Procedures

NOTE:

An EIA authorisation cannot replace a water use licence application, since the former does not address all the requirements of the National Water Act. For example, the EIA process often excludes the legal validation (Stage 1) and pre-assessment (Stage 2) stages of the licence authorisation process under the National Water Act.

The granting of an authorisation under the EIA regulations does not necessarily mean that a water use licence will be granted (RSA DWAF, 2000). As there are overlaps in the types of outputs required at certain stages of these processes (refer to Figure 3.2), it is very important that the applicant be aware of these and that action to prevent duplication or unnecessary work.

3.1.1 Initiation of application

PURPOSE:

To ensure that:

- ***Discussions take place with the correct official in the DWAF***
- ***Application is legally necessary***
- ***Involvement of other authorities is clarified***
- ***All legal provisions that are, or could be, applicable to the (proposed) activity are identified, e.g. application of EIA regulations***
- ***Correct documentation is provided to the applicant to provide guidance***

The initiation of an application involves initial consultation taking place between the **potential applicant** and the correct official in the **Regional Office of DWAF** or the **CMA**. Alternatively, the DWAF can make an enquiry to undertake such actions (usually to an existing use).

NOTE:

Although all licence applications should be dealt with in an efficient and effective way so as to conclude the process in the shortest possible time, it is important to realise that the evaluation of licence applications should be timeous and, therefore, applications must be submitted promptly.

Once an enquiry has been lodged with the Regional Office of DWAF or the CMA, the official responsible is required to:

- Consult with the *lead water use directorate* in the DWAF, which in this case is the **Manager: Waste Discharge and Disposal,** and obtain all the relevant *procedural and information requirements and process guidelines* (NOTE: guidelines should include those of all relevant sub-directorates, e.g. Industries, Urban Development and Agriculture, and Waste Management)

- Inform the **potential applicant**, in writing, regarding the need to apply for a licence from a legal perspective. In cases where no licence is required or instances where licensing will not be allowed, a written response must also be made to the enquiry, which can be signed by the Regional Director (NOTE: Where an application form has been submitted by an applicant the latter needs to be signed by the delegated authority in the DWAF, in this case the **Manager: Water Use**)

- Provide the **potential applicant** with the relevant *procedural and information requirements and process guidelines and the relevant authorisation process guidelines* relevant to the disposal of land-derived wastewater to the marine environment, as well as the relevant *authorisation process guidelines.*

- Request the **potential applicant** to apply for a licence on the correct and most recent forms (obtainable from the DWAF website http://www.dwaf.gov.za)

- Request the **potential applicant** to initiate discussions with other identified Departments for associated authorisations, e.g. Provincial Department of Environmental Affairs *re* implementation of EIA regulations or Department of Minerals and Energy *re* preparation of Environmental Management Plans.

3.1.2 Formal submission of application form

PURPOSE:

*The formal authorisation process is initiated by the submission of a completed licence application form by the **applicant** to the **Regional Office of DWAF**. These forms submitted need to be accompanied by the appropriate fee.*

The official responsible in the Regional Office of DWAF or the CMA is responsible to ensure that the form is handed to the correct DWAF Registry. This Registry ensures that the application form is date-stamped, that a numbered sticker is placed on the form, that the sticker number is recorded on each page of the application form and on the receipt given to the applicant for the application fee.

NOTE:

Where there is a lack of capacity in the Regional Office to handle a specific licence application, the Regional Office may request assistance from the Manager: Waste Discharge and Disposal, in which case an official will be tasked to assist in this regard. The Regional Office will however remain primarily responsible for the licence application.

The Registry then forwards the date-stamped application forms to the Regional Director for signing. The Regional Director then allocates responsibility to the appropriate official, preferably the same official that initiated discussion with the applicant, referred to as the primary responsible officer (**PRO**). Where no official in the Regional Office can fulfil this role, the Regional Director forwards the application to the *Lead Water Use Directorate* in the DWAF, in this case the **Manager: Waste Discharge and Disposal**, who then assigns such duties to one of the officials in the directorate.

Responsibilities of the **PRO**, as part of this step, are to:

- Ensure that application form is completed correctly from an administrative perspective and that desired time frames are included.

- Where applications require revision, return forms to the applicant with of a letter indicating such shortcomings.

- Where applications are correct, ensure that details are recorded on file.

3.1.3 Stage 1: Legal validation and assessment

PURPOSE:

The purpose of the legal validation and assessment stage is to:

- ***Formally validate the application against legal requirements of the DWAF***
- ***Confirm whether legislation of other Government departments is, or could be, applicable to the water use to ensure cooperative governance, including:***
  - **National Department of Environmental Affairs and Tourism** ***re legislation pertaining to the protection and conservation of the marine environment, e.g. under the National Environmental Management Act, Marine Living Resources Act***
  - **Provincial Department of Environmental Affairs** ***re EIA regulations promulgated under sections 21, 22 and 26 of the Environment Conservation Act***
  - **Department of Minerals and Energy** ***re statutory requirements under the Minerals Act (only applies to disposal of land-derived wastewater associated with mining activities)***
  - **Department of Health** ***re statutory requirements pertaining to human health issues under the Health Act (e.g. recreational use).***
  - **Department of Trade and Industry** ***re statutory requirements pertaining to industries (only applies to disposal of land-derived wastewater associated with industrial activities).***

The **PRO** is required to:

- Verify the water use by confirming with the *Lead Water Use Directorate* in the DWAF (**Manager: Waste Discharge and Disposal)**, who will be responsible for the administration and the preparation of the final submission for decision-making regarding the licence by the delegated authority, in this case the **Manager: Water Use**
- In the case of discharges to estuaries, write a letter to the **Manager: Resource Directed Measures** to establish if the appropriate level of Reserve determination has been done. In other cases, a Reserve determination is not requested at this stage, since the outcome of the legal assessment [this stage] or the pre-assessment [next stage] could indicate that the application will not be successful. The purpose of the letter is merely to alert the directorate to a potential need to incorporate a Reserve determination into their prioritisation process, depending on the specific circumstances associated with the application.
- Once the status of the Reserve has been received, to discuss the application with the relevant parties in the DWAF, which may include:
  - **Directorate: Waste Discharge and Disposal** (advising on water use authorisation)
  - **Directorate: Water Allocation** (administering water use licence applications and review; accessing or providing legal advice and support to the Manager: Water Use on water use authorisations and appeals - DWAF, P&R and Ops Restructuring, Head Office Organisational Design, Version 5.2, March 2003)
  - **Directorate: Options Analysis** (analysis of national strategic options to meet future water requirements – especially in terms of re-use of water discharged to the sea through marine outfalls - DWAF, P&R and Ops Restructuring, Head Office Organisational Design, Version 5.2, March 2003).

- Once the potential use has been verified against DWAF requirements, the **applicant** could be requested (in writing) to conduct a legal assessment to determine the legislation applicable by other government departments. This is important since the **PRO** may not be aware of all activities associated with the application, or any associated legal provision that may even prohibit such activities.

Where the applicant has submitted a legal assessment, it needs to be evaluated by the **PRO** and relevant parties of the DWAF. If applicable, the **PRO** can also request written comment from other government departments.

Guidance on the legislative framework for the disposal of land-derived wastewater to the marine environment is provided in Section 2 of this document.

Once legal validation of the application has been completed one of the following decisions is made regarding the status:

- Terminated, in which case the **PRO** forwards the application, with the reasons for the termination, through the *Lead Water Use Directorate* (**Manager: Waste Discharge and Disposal)** to the delegated authority (**Manager: Water Use)** for a decision

- On hold, in which case the **PRO** requests, in writing, that the **applicant** revise the application, specifying the required information

- Proceed, in which case the **PRO** informs the **applicant** in writing that the application may proceed from a legal perspective.

3.1.4 Stage 2: Pre-assessment

PURPOSE:

The overriding purpose of the pre-assessment stage is to establish the Best Practical Environmental Option of dealing with the proposed water use, in this case, to dispose of land-derived wastewater to the marine environment.

The **PRO** is required to:

- Determine, together with the **Manager: Waste Discharge and Disposal** and all **other relevant managers,** requirements for the pre-assessment (note that in the case of wastewater discharges to estuaries, a Reserve and Resource Quality Objectives must be determined)

NOTE:

A preliminary Ecological Reserve determination on a Rapid level only provides an estimate of the Ecological Category and the recommended Ecological Flow Requirements Scenario. It does not provide Resource Quality Objectives - a key requirement for the review of existing lawful discharges of land-derived wastewater to estuaries (i.e. it provides the Environmental Quality Objectives).

- Establish parties, both within the Department of Water Affairs and Forestry as well as other government departments, that are to be involved in the evaluation of the pre-assessment, and obtain the information required from them. In the case of disposal of land-derived wastewater to the marine environment, these may include:

- **National Department of Environmental Affairs and Tourism** *re* legislation pertaining to the protection and conservation of the marine environment, e.g. under the National Environmental Management Act, Marine Living Resources Act
- **Provincial Department of Environmental Affairs** *re* EIA regulations promulgated under section 26 of the Environment Conservation Act
- **Department of Minerals and Energy** *re* statutory requirements under the Minerals Act (only applies to disposal of land-derived wastewater associated with mining activities)
- **Department of Health** re statutory requirement pertaining to human health issues under the Health Act (e.g. recreational use)
- **Department of Trade and Industry** *re* statutory requirements pertaining to industries (only applies to disposal of land-derived wastewater associated with industrial activities)
- **Local authority** *re* local statutory requirements pertaining to land use and infrastructural aspects on which the wastewater disposal scheme may have an influence.

(However, the pre-assessment may also include other departments, for example, where alternative technologies are involved in disposal to a landfill site or atmospheric disposal.)

Guidance on aspects that need to be addressed as part of a pre-assessment for marine disposal of land-derived wastewater is discussed in further detail in Section 6: Scientific and Engineering Assessment of this document.

- Where a pre-assessment is required, inform the **applicant** in writing of the information requirements of the different parties (see above) and request the **applicant** to conduct the pre-assessment.

- Where a Reserve determination is required (i.e. involving an estuary), request the **Manager: Resource Directed Measures** in writing to conduct a Reserve determination.

The **applicant** is required to conduct the pre-assessment. Amongst requirements from other government departments, a pre-assessment needs to include:

- Substantiation for the purpose, objectives, efficiency and actual need for the proposed discharge of water containing waste to the marine environment (taking into account future water demand and supply)

- Investigation showing that the proposed discharge of water containing waste to the marine environment is the best alternative (i.e. Best Practical Environmental Option), by addressing source directed measures such as:

  - Re-use or recycling
  - Pollution prevention and waste minimisation
  - Cleaner technologies
  - Other waste disposal options, e.g. to land or air.

Once the applicant has submitted the pre-assessment to the **Regional DWAF Office** or the CMA, the **PRO** is required to:

- Request comments in writing from the different parties (see above) to evaluate the pre-assessment so as to determine:
  - the need for the water use
  - the applicable water use/s
  - if such use/s are deemed necessary
  - the purpose and objectives of each (proposed) use.

Based on the above, one of the following decisions is made regarding the status:

- *Terminate*, in which case the **PRO** forwards the application, with the reasons for the termination, through the *Lead Water Use Directorate* (**Manager: Waste Discharge and Disposal)** to the delegated authority (**Manager: Water Use)** for a decision

- *On hold*, in which case the **PRO** requests, in writing, that the **applicant** revise the application, specifying the information required. (For example, in the execution of the pre-assessment, the applicant may find that irrigation using wastewater is a more appropriate option than disposal to the marine environment, in which case the water use change and the application details need to be revised.)

- *Proceed* (i.e. where the pre-assessment indicates an acceptable water use), in which case the **PRO** informs the **applicant** in writing confirming:
  - the water use that applies
  - that there appears to be an actual physical need for an application of a water use licence
  - that the DWAF is satisfied with the purpose and objectives of each water use applied for in the pre-assessment.

3.1.5 Stage 3: Extent of Detailed Investigation

PURPOSE:

Where Stage 2: Pre-assessment indicated that wastewater disposal to the marine environment is possibly the Best Practical Environmental Option, potential impacts associated with that option need to be evaluated. The purpose of determining the extent of such detailed investigations is:

To establish whether detailed investigations are required
If so, determine what such detailed investigations should entail, who will conduct such investigations, and in what time frames.

The **PRO** is required to:

- Determine, together with the relevant **Directorate within the DWAF** (in the case of wastewater discharges to estuaries, the Reserve and Resource Quality Objectives need to be determined) if a detailed investigation is required.
- Obtain the information requirements and guidelines for the detailed investigation from the **DWAF parties**, if a detailed investigation is required.

Guidance on aspects that need to be addressed as part of a detailed investigation for marine disposal of land-derived wastewater is discussed in further detail in Section 6: Scientific and Engineering Assessment of this document.

- Where a Reserve determination would be required (i.e. involving an estuary), request the **Manager: Resource Directed Measures** in writing to establish the extent of the investigations pertaining to the determination of Resource Directed Measures, including the Reserve and Resource Quality Objectives.

- Provide in writing to the **applicant**:
  - the information requirements of the **DWAF parties** (refer to box above)
  - a request the applicant to obtain information from **other government departments** that could be involved in aspects relating to the application
  - the instruction, if necessary, to immediately publish the application details, also specifying the media (i.e. involving **Interested and Affected Parties**).

The **applicant** is required to:

- If applicable, obtain information requirements from other relevant legislative authorities. In the case of disposal of land-derived wastewater to the marine environment these could include:
  - **National Department of Environmental Affairs and Tourism** *re* legislation pertaining to the protection and conservation of the marine environment, e.g. under the National Environmental Management Act, Marine Living Resources Act
  - **Provincial Department of Environmental Affairs** *re* EIA regulations promulgated under Sections 21, 22 and 26 of the Environment Conservation Act
  - **Department of Health** *re* statutory requirements pertaining to human health issues under the Health Act (e.g. recreational use)
  - **Department of Minerals and Energy** *re* statutory requirements under the Minerals Act (only applies to disposal of land-derived wastewater associated with mining activities).
  - **Department of Trade and Industry** *re* statutory requirements pertaining the industries (only applies to disposal of land-derived wastewater associated with industrial activities)
  - **Local authority** *re* local statutory requirements pertaining to land use and infrastructural aspects, on which the wastewater disposal scheme may have an influence.

- If required, publish the application in the specified media (e.g. newspaper or notice in local library), detail and record the responses and information requirements from **Interested and Affected Parties**.

- Determine the extent of the detailed investigations based on:
  - information requirements from **DWAF parties** (refer to box on *page 6-10*)
  - information requirements from other appropriate **government departments** or **legislative authorities** (e.g. refer to box on *page 6-10*)
  - issues and concerns raised by any relevant **Interested and Affected Parties.**

- Prepare a report and submit it to the **PRO**, in a format understandable to lay persons. The Report will include the following:
  - Name and address of applicant
    - Description of information requirements of the various authorities and issues raised by Interested and Affected Parties

- Description of proposed wastewater disposal activity, including (a) concept design of the wastewater disposal system, as well as a description of any proposed phases in development and implementation, and (b) details on waste loads (both in terms of volume and constituent composition)
- Description of sensitive ecosystems and other beneficial uses in the study area (this information should be available from the pre-assessment stage)
- Description of the additional scientific and engineering studies that will have to be performed to meet information requirements
- An indication of time frames for finalising the detailed investigations.

NOTE:

This report will be similar to the 'Scoping Report' that would have had to be submitted as part of the EIA process. For activities that are subject to the Minerals Act (e.g. disposal of wastewater from mining activities on land to the marine environment), this report will serve the same purpose as the 'Aide Mémoire'

After submission of the above-mentioned report by the **applicant**, the **PRO** is required to:

- Obtain a report from the **Manager: Resource Directed Measures** containing the extent of the department's detailed investigations, as well as the time frames that are required to conduct the department's investigations, if a Reserve determination is required (e.g. if an estuary is involved)
- Ensure that all relevant **legislative authorities** and **Interested and Affected Parties** (if applicable) evaluate the extent of the detailed investigations and that such authorities or parties submit a report stating if a detailed investigation will be necessary and whether their information requirements will be met (all legislative authorities must confirm acceptance of the extent of the detailed investigations to prevent additional information from being requested from the applicant at a later stage, thus delaying the process)
- Together with the **DWAF parties** (identified at the onset of this stage), decide whether to:
  - *Terminate the application*, in which case the **PRO** forwards the application, with the reasons for the termination, through the *Lead Water Use Directorate* (**Manager: Waste Discharge and Disposal)** to the delegated authority (**Manager: Water Use)** for a decision
  - *Put the application on hold*, in which case the **PRO** requests, in writing, that the **applicant** revise the application, specifying the information required
  - *Proceed without a detailed investigation* (e.g. information gathered during the pre-assessment stage sufficed), in which case the **PRO** informs the **applicant** in writing and requests the applicant to prepare a final licence application.
  - *Proceed, but where a detailed investigation* (refer to box on *page 6-10*) would be necessary to reach a final decision (and where the extent of the detailed investigation provided by the applicant meets all requirements), the **PRO**:
    - Develops and records a work schedule for the execution of the detailed investigation, based on the extent of detailed investigations and time frames of the applicant and the **Manager: Resource Directed Measures**
    - Provides the work schedule, in writing, to both the **applicant** and the **Manager: Resource Directed Measures**, hereby accepting the extent of detailed investigations.

3.1.6 Stage 4: Detailed Investigation

PURPOSE:

With regard to the marine disposal of land-derived wastewater, the aim of this stage is to investigate potential impacts of the proposed wastewater disposal system on the receiving marine environment. It is the responsibility of the applicant to demonstrate technically (at the appropriate level of detail) that the proposed activity will result in negligible harm.

The **applicant** is required to:

- Conduct the detailed investigations (refer to box on page 6-10), in consultation with qualified environmental consultants
- Prepare and submit a report containing the findings of the detailed investigation to the **PRO.**

The **Manager: Resource Directed Measures** is required to:

- Conduct the determination of the Reserve, in consultation with qualified environmental consultants (where applicable)
- Submit a report on the Reserve determination to the **PRO**.

The **PRO** is required to:

- Monitor the progress of these investigations and request updates for time frames where these appear to deviate from those proposed in the work schedule
- Where applicable, request the **applicant** to submit the report/s to other **relevant legislative authorities** for evaluation

NOTE:

These reports serve the same purpose as the detailed specialist studies required as part of the EIA process.

- Evaluate the detailed investigations, in consultation with the relevant **DWAF parties,** to determine if requirements and issues were addressed adequately. Based on the outcome the application is either:
  - *Terminated*, in which case the **PRO** forwards the application, with the reasons for the termination, through the *Lead Water Use Directorate* (**Manager: Waste Discharge and Disposal)** to the delegated authority (**Manager: Water Use)** for a decision
  - *Put on hold*, in which case the **PRO** requests, in writing, that the **applicant r**evises the application, specifying the information required
  - *Allowed to proceed*, in which case the **PRO** accepts by informing the **applicant** in writing.

3.1.7 Stage 5: Final Licence Application & Recommendations

PURPOSE:

The purpose to this stage is to compile a final licence application report and to make recommendations regarding the application of the water use, in this case the disposal of land-derived wastewater to the marine environment in consultation with Interested and Affected Parties.

The **PRO** is required to:

- Provide the information obtained from the detailed investigation, including the Reserve to the **applicant**
- Request, in writing, that the **applicant** prepare a summary integrated licence application report and, if applicable, revise the original licence application forms.

The applicant is required to:

- Prepare the summary integrated licence report, revise the licence application forms, and update the forms where necessary with information obtained from the detailed investigation. This report will contain:
  - Revised licence application forms
  - A summary of the outcome of the detailed investigation, including an estimation of the impact on the Reserve and Resource Quality Objectives (e.g. where estuaries are involved)
  - Detailed plans that are associated with the implementation of the wastewater disposal system, e.g. monitoring plans and contingency plans

Guidance on the monitoring and contingency planning, to be undertaken as part of licence conditions for the disposal of land-derived wastewater to the marine environment, is provided in Section 7 and 8 of this document, respectively.

  - A plan on the allocation of financial resources for proper construction and sustainable operations of the proposed marine disposal facility, including resources related to contingencies.
- Submit the report to the **PRO**.

NOTE:

Where the EIA regulations are applicable, this report will serve the same purpose as the Environmental Impact Report, and where the Minerals Act is applicable, this report should also address the requirements of the Environmental Management Plan Report.

On receiving the summary integrated licence report, the **PRO** is required to:

- Check the revised licence application forms and the content of the summary report, inform the **applicant,** in writing, of any shortcomings and request a revision of aspects as required, and also ensure that the final and revised applications are recorded
- Evaluate, together with the relevant **DWAF parties** (identified at the onset of Stage 3), the final, acceptable application and the content of the summary integrated licence report against technical criteria, in accordance with section 26 of the National Water Act

- Evaluate the application on the basis of socio-economic criteria in accordance with sections 22 and 27 of the National Water Act, in consultation with relevant **DWAF parties**, other **relevant government departments** and **Interested and Affected Parties**

- Ensure that all decisions, recommendations and any conditions established during the technical and socio-economic evaluations are recorded in a **Record of Decisions.** If the issue of a licence is not recommended the **PRO** also needs to record the reason in the Record of Decisions.

3.1.8 Stage 6: Decision

PURPOSE:

The purpose of this stage is to ensure cooperative governance and compliance with all legal requirements associated with the activity.

Where the issue of a licence is recommended to the **Manager: Water Use**, the PRO is required to:

- Ensure that any charges relevant to the disposal of land-derived wastewater to the marine environment are applied (e.g. the policies *re* waste discharge charges)

- Request proof from the **applicant**, in writing, that all other (non-National Water Act) legislation has been complied with (refer to Appendix B in the *Operational Policy for disposal of land-derived water containing waste to the marine environment of South Africa: Appendices* [RSA DWAF Water Quality Management Sub-Series No. 13.4]).

- Compile a draft licence with conditions and distribute that to the relevant **DWAF parties**, and on receiving comments, prepare the final draft licence (reasons for including and excluding of comments must be recorded in a **Decision of Record** and provided to the relevant DWAF parties). In the case of wastewater discharges, a licence should, for example, include:

  - Specifications on the volume (flow rate) and constituent concentrations of the wastewater

  Guidance on specification of wastewaters is provided in Section 5 of this document.

  - Specification on monitoring programmes
  - Time frames of submission of monitoring reports.

  Guidance on the design of monitoring programmes, to be undertaken as part of licence conditions for the disposal of land-derived wastewater to the marine environment, is provided in Section 7 of this document.

- Submit the following documentation to the **Manager: Waste Discharge and Disposal**:
  - Record of Decisions
  - Licence application forms
  - Summary integrated licence application report
  - Final draft licence
  - Routing form indicating all relevant DWAF parties.

On receiving the above submission, the **Manager: Waste Discharge and Disposal** is required to:

- Verify all documentation

- Submit all verified documentation to the delegated authority in the DWAF, in this case the **Manager: Water Use**, for a decision via the routing form to the **relevant DWAF parties.**

The **Manager: Water Use** decides, on the basis of the information provided, whether to issue the licence or not. The approved/disapproved application for the licence and the Record of Decision and all other relevant documentation is then returned to the **PRO.**

Once the decision has been made, the **PRO** is required to:

- Inform, in writing, the **applicant,** all other **relevant DWAF parties,** and any **other person** who has objected to the application, of the outcome

- Record the status of the application

- Manage objections to the decision, and must refer appeals to the Water Tribunal or to any other applicable appeal mechanisms

- Ensure that the licence is issued to the **applicant**, together with non-DWAF authorisations as decided during the licence application process

- Review the licence according to the National Water Act provisions, i.e. every five years.

3.1.9 Monitoring and review

After the licence has been issued, the **licence holder** (both existing and new) is required to:

- Construct and operate the wastewater disposal system in accordance with licence conditions

- Conduct ongoing monitoring of the wastewater disposal system (the ‘source’) and the receiving marine environment (the ‘resource’), as stipulated in the licence, and implement appropriate management strategies and actions in the case of non-compliance, after consultation with the DWAF through the **PRO.**

A detailed Monitoring Report must be supplied to the DWAF, other relevant authorities (where and if required) and the local management institution clearly stipulating the following:

- List of Monitoring objective/s
- Details of the design and implementation of the monitoring programme
- Evaluation of the monitoring data in relation to related monitoring objectives
- Statement on whether the monitoring objectives have been complied with
- Management strategies and actions required to address non-compliance
- Recommendations on refinements to the monitoring programme
- Appendices containing, for example, laboratory reports, raw data tables etc.

A reporting schedule needs to be negotiated with the DWAF, as well as with the local management institution, but it is feasible to expect Monitoring Reports after each set of monitoring surveys, e.g. on an annual basis.

Where components of the monitoring programme are conducted at shorter time scales, e.g. microbiological monitoring programmes at a recreation area, these need to be submitted to the DWAF as, for example, monthly interim reports, clearly highlighting preliminary indications of non-compliance to monitoring objectives as well as management strategies and actions that will be taken to address the issue in good time.

Further guidance on monitoring associated with disposal of land-derived wastewater to the marine environment is provided in Section 7 of this document.

In accordance with provisions in the NWA, the PRO is responsible for initiating the review process of a licence every five years. As part of the review process, the following needs to be taken into account:

- Compliance with all licence conditions
- Re-assessment of the activity's alignment with Policy pertaining to the disposal of land-derived wastewater to the marine environment, and in particular, whether the licence conditions could still be considered as the *Best Practical Environmental Option*
- Review of monitoring reports to assess if, for example, the critical limits and performance of the wastewater disposal system are still meeting the desired environmental quality objectives.
- Based on the outcome of the above, the applicant could be requested to conduct further investigations for confirmation, on the basis of which the licence may be withdrawn, revised or maintained
- Refinement of monitoring programmes, where applicable.

NOTE:

As a standard condition in licences, non-compliance must be reported to the Regional Director of the DWAF and actions taken to ensure compliance. The policy of the DWAF is to work together with water users in order to improve compliance but directives could be issued to the licensee for non-compliance. Only after failure to react to such a directive, will prosecution follow. DWAF works together with the Police Service and Public Prosecutor in order to prosecute a case of non-compliance or pollution. Evidence is needed for a successful prosecution. Samples must be taken in the presence of a witness and analysed in order to obtain evidence of a pollution incident. Once evidence is collected the Police Service will take over the investigation, which is often a lengthy process and can take a year or longer before it comes to court.

3.2 LOCAL MANAGEMENT INSTITUTIONS

Although the DWAF is responsible for the overarching management and administration of the disposal of land-derived wastewater to the marine environment, a key element in the successful implementation of this operational policy is the establishment of local management institutions, representing all the role players in a designated area, and which fulfil the role of 'local watchdogs' or 'custodians'. Local management institutions will play a leading role in identifying non-compliance (i.e. they will become the local 'watchdogs'), based on information provided by scientifically sound monitoring programmes. In the case of non-compliance, this information will provide the local management institution with an informed, scientific base from which to challenge the responsible authority (e.g. DWAF) to respond appropriately (e.g. prosecuting the offender) where such authorities are reluctant to do so. However, water services providers (operating WWTW) and industries are ultimately responsible in terms of their individual licence agreements with the DWAF.

Where multiple developments and activities occur in a study area, it is usually extremely difficult and financially uneconomical to manage marine environmental issues in isolation because of, for example, their potential cumulative or synergistic effect on the receiving environment. Collaboration is often best achieved through a joint local management institution. Local management institutions are also considered the appropriate platform for facilitating the joint funding of studies (such as impact assessments and monitoring) where two or more developments/activities may be responsible for pollution in a particular area.

It is essential that the local management institution include all relevant interested and affected parties or stakeholders in order to facilitate a participatory approach in decision-making. These stakeholders include, for example, representatives from:

- Department of Water Affairs and Forestry (regional office)
- Department of Environmental Affairs and Tourism
- Department of Health (where applicable)
- Department of Minerals and Energy (where applicable)
- Department of Transport (where applicable)
- National Ports Authorities (where applicable)
- Provincial Department of Environmental Affairs
- Nature Conservation Board
- Local authorities (municipalities)
- Industries
- Tourism Board and recreation clubs
- Local residents, e.g. ratepayers association
- Non-government organisations.

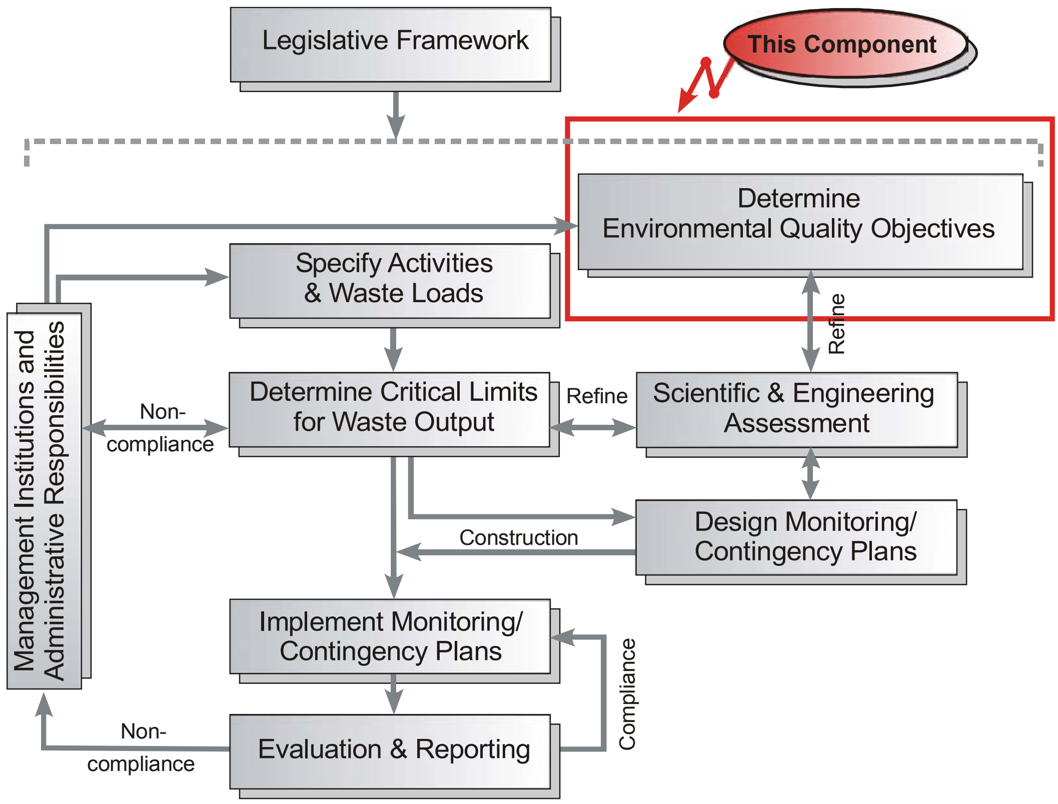
Institutions that are already partly fulfilling the role envisaged for the local management institutions include:

- Catchment management forums
- Pipeline monitoring committees
- Pipeline advisory committees
- Pipeline forums (e.g. KZN coastline)
- Water quality forums (e.g. Saldanha Bay and False Bay/Table Bay)
- Pipeline technical steering committees (e.g. Hout Bay).

Although such institutions could be initiated from local level it is, however, crucial that these be coordinated from a national (or regional) level by the responsible government authorities, such as the DEAT and DWAF. It is therefore recommended that the responsible government departments jointly investigate a legal route whereby local management institutions can be formally constituted to assist in the integrated management and control quality of marine water resources in South Africa. Towards enforcing the involvement of local role players, the DWAF already requires the establishment of a local monitoring committee, as a licence condition for the disposal of land-derived wastewater to the marine environment.

SECTION 4:
ENVIRONMENTAL QUALITY OBJECTIVES

SECTION 4: ENVIRONMENTAL QUALITY OBJECTIVES



PURPOSE:

The purpose of this component is:

- ***To define the extent of the study areas (i.e. study area boundaries)***
- ***To produce a map (preferable a geo-referenced map) indicating important ecological and conservation areas and the location of the beneficial use areas in the study areas***
- ***To determine site-specific environmental quality objectives for the identified beneficial uses, as well as the ecosystem's requirements. For environmental quality objectives to be practical and effective management tools from a water quality point of view, they need to be set in terms of measurable target values or target ranges for specific chemical or microbiological constituents in the water column, sediment and/or biological tissue.***

4.1 IDENTIFICATION OF STUDY AREA BOUNDARIES

Definition of the extent of the area within which this management framework should be applied is very important. The extent of the anticipated influence of the proposed discharge, both in the near and far field, must be taken into account. The selection of study area boundaries is site specific, depending on the physical and biogeochemical processes, as well as the quantity and quality of waste inputs to the area. Important issues that need to be taken into account in the selection of the study boundaries include:

- Proximity of depositional areas that could result in cumulative effects associated with waste inputs to the area

- Possible synergistic effects in which the negative impact from a wastewater discharge could be aggravated through interactions with other waste inputs to the area, or with even natural processes.

Recognised and approved technologies applied by a qualified scientist, such as numerical modelling, have been successfully used to assist in the determination of study area boundaries. These models integrate physical and biogeochemical processes in the marine environment and their interaction with waste inputs over space and time, providing a quantitative means of determining the extent of significant influence.

The scope of the study area must cover the far field scale (e.g. an entire bay). For example, any estuaries that lie within the far field domain of an offshore or surf zone wastewater discharge should also be included, as these estuarine environments could possibly be the most important long-term depositional environments for the particulate loads.

Consequently, at the start of an investigation, the definition of the spatial limits of the study area and the selection of sampling locations should be carried out with reference to all existing information on physical (hydrodynamics and geophysics) and biogeochemical processes and the marine ecology, as well as the results of any predictive modelling that has already been carried out (WRc, 1990).

In the case in which wastewater disposal takes place at a particular point in an enclosed bay, it is not only important to understand the processes occurring throughout the bay, but also those at its boundaries. For example, hydrodynamic processes generated outside the bay can ultimately influence transport and fate processes inside the bay, as is the case in Saldanha Bay, a semi-enclosed bay on the west coast of South Africa.

4.2 IDENTIFICATION OF IMPORTANT ECOSYSTEMS AND BENEFICIAL USES

Measurable environmental objectives need to be set in consultation with stakeholders to ensure the successful implementation of any management plan. The identification and mapping of key marine ecosystems and beneficial uses in a particular area provide the basis for the determination of the site-specific environmental quality objectives.

In addition to identifying sensitive marine ecosystems, it is also important that designated beneficial uses be identified. The following activities are defined as beneficial uses of marine waters in South Africa (RSA, DWAF, 1995):

- recreation
- mariculture (and fisheries)
- industrial uses (e.g. abstraction of seawater for cooling and fish processing).

NOTE:

Although the South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995) lists 'Maintenance of Ecosystems' as a beneficial use, a more recent approach is to recognise the aquatic ecosystems (e.g. marine ecosystems) as a resource that needs protection in its own right so as ultimately to support designated beneficial uses. For this reason, this document deals with the resource (i.e. 'Marine Ecosystem') and its requirements separately from the 'Beneficial uses'

The beneficial uses of a particular area should not only include existing uses, but should also take into account any future activities or uses planned for the area. An example of a beneficial use map is provided in Figure 4.1.

The following need to be considered in establishing future uses of an area:

- Strategic planning related to the study area on a national and regional/provincial level
- Local authority structure plans
- Future planning of industries and uses in the area.

Environmental quality objectives can be based on:

- National and international legal requirements e.g. target values for toxic substances in sediments in terms of the *London Convention* (refer to refer to Appendix B in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices* [RSA DWAF Water Quality Management Sub-Series 13.4])

- Generic target values, e.g. as recommended in the *'South African Water Quality Guidelines for Coastal Marine Waters'* (to assist managers in setting environmental quality objectives, this set of documents was published in 1995 [RSA DWAF, 1995])

- Site-specific conditions (e.g. obtained through site-specific field measurements and numerical modelling outputs).

CLICK TO VIEW GRAPHIC

FIGURE 4.1 ***Example of a map illustrating sensitive marine ecosystems and beneficial use areas (adapted from Taljaard & Monteiro, 2002)***

Although objectives can also be set, for example, in terms of the abundance and diversity of biotic components or in terms of broad objectives for a specific beneficial use (e.g. 'safe for swimming'), such objectives 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.

NOTE:

International marine water quality guideline documents that could also be consulted in setting environmental quality objectives, (e.g. where South Africa currently does not have recommended target values) include:

- ***Australia and New Zealand (ANZECC, 2000a)***
- ***Canada (Environment Canada, 2002)***
- ***US-EPA (US-EPA, 2002a).***

4.2.1 Marine Ecosystems

The South African marine environment can be subdivided into three main biogeographical regions, each with its own climatic, physical and biogeochemical characteristics (Figure 4.2).

CLICK TO VIEW GRAPHIC

FIGURE 4.2: Biogeographical regions along the South African coast

Although marine ecosystems function as units, with no clear boundaries, the aquatic domains can be categorised to some extent into:

- Estuaries
- Surf zone areas
- Offshore marine environment.

NOTE:

Methodology for the* **Determination of the Preliminary Ecological Reserve for Estuaries** *(RSA DWAF 2004), issued under the National Water Act, through the Directorate: Resource Directed Measures, provides guidance on setting resource quality objectives for estuaries. To ensure alignment with these methods (or future updates thereof), they need to be consulted in setting resource quality objectives.

Within these domains, marine ecosystems typically occur in different zones, namely:

- Intertidal benthic zone (i.e. area between spring low-water mark and spring high-water mark)
- Subtidal benthic zone (i.e. sediments beyond the spring low-water mark)
- Pelagic zone (i.e. water column).

Intertidal and subtidal benthic zones comprise rocky or soft sediment substrata. Soft sediment substrata range from sandy to muddy and support a range of benthic communities.

It is important to understand the relationship between trophic levels, namely:

- Primary producers, i.e. algae and the other marine plants
- Primary consumers, i.e. organisms that primarily live off plants
- Secondary consumers, i.e. organisms that mainly live off other animals.

With regard to waste disposal activities, the impact on marine ecosystems can broadly be categorised into (RSA DWAF, 1995):

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

NOTE:

In defining site-specific ecological objectives to maintain ecological integrity, the US-EPA uses the concept of balanced indigenous populations (US-EPA, 1994). A balanced indigenous population is defined as:

> **An ecological community which (a) exhibits characteristics similar to those of nearby healthy communities existing under comparable but unpolluted/unaffected environmental conditions, (b) may reasonably be expected to become re-established in the polluted water body segment from adjacent waters if the source of pollution were to be removed.**

(Balanced indigenous populations generally occur in unpolluted areas. The second part of the definition concerning re-establishment of communities is included because of its relevance to proposed improved quality of discharges and to discharges into areas that are already stressed by anthropogenic influences other than their own.)

Typical biological characteristics to be assessed in the determination of a balanced indigenous population include:

- ***Species composition, abundance (or biomass), dominance and diversity***
- ***Spatial and temporal distribution***
- ***Growth and reproduction of populations***
- ***Disease frequency***
- ***Trophic structure and productivity patterns***
- ***Presence/absence of certain indicator species***
- ***Bioaccumulation of toxic compounds***
- ***Occurrence of mass mortalities, e.g. of fish and invertebrates.***

From a water quality management perspective, it is necessary to define specific water quality requirements that need to be attained to achieve ecological objectives, for example, as defined by a *balanced indigenous population* (see note box above). Such water quality requirements need to be presented as measurable target values or ranges for specific biogeochemical constituents. In this regard, the *South African Water Quality Guidelines for Coastal Marine Waters* provides recommended target values for a range of water quality constituents to prevent negative impacts on marine ecosystem functioning (RSA DWAF, 1995).

The *South African Water Quality Guidelines for coastal marine waters* do not provide target values for organic constituents such as poly-aromatic hydrocarbons. Where these are a potential concern, target values should be established by means of chemical analysis, analysis of accumulator organisms and/or bioassays (e.g. toxicity testing). Synergistic effects (the interactive effect of numerous compounds) should also be taken into account. In principle, no parameter should exceed its local background value by more than 10% unless sufficient evidence exists to suggest that such deviations will not adversely affect marine ecosystem functioning.

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

ANNEX I Substances (units in ppm)

SUBSTANCE	*SPECIAL CARE*	*PROHIBITION*
Cadmium	*1.5 – 10.0*	*> 10.0*
Mercury	*0.5 – 5.0*	*> 5.0*
Combined levels of above	*1.0 – 5.0*	*> 5.0*
Organohalogens	*0.05 – 0.1*	*> 0.1*
Oils	*1000 – 1500*	*> 1500*
Persistent plastics: 4% by volume, suitably comminuted		
Radioactive materials: to be determined by the IAEA		

ANNEX II Substances (units in ppm)

SUBSTANCE	*SPECIAL CARE*	*PROHIBITION*	*AGREEMENT AT 8th CONSULTATIVE MEETING**
Arsenic	*30 – 150*	*> 150*	*1000*
Chromium	*50 – 500*	*> 500*	
Copper	*50 – 500*	*> 500*	*1000*
Lead	*100 – 500*	*> 500*	*500*
Nickel	*50 – 500*	*> 500*	
Zinc	*150 - 750*	*> 750*	*1000*
Combined levels of above	*50 – 500*	*> 500*	*1000*
Cyanides	-	*0.1*	*1000*
Fluorides	-	-	*1000*
Organosilicon compounds	-	-	*1000*
Pesticides	-	-	*500*

* *According to the agreement at the 8th consultative Meeting of Contracting parties to the London Convention, significant amounts for these substances were $\geq$ 0.1% by weight, or 0.5% by weight for lead and pesticides.*

Current practice in most other countries is to define what is referred to as 'List I' and 'List II' substances (refer to Appendix C in the *Operational Policy for disposal of land-derived water containing waste to the marine environment of South Africa: Appendices* [RSA DWAF Water Quality Management Sub-Series No. 13.4]). List I substances are regarded as being particularly hazardous because of their toxicity, persistence and bioaccumulation and need to be *eliminated* from wastewater discharges. List II substances, in contrast, are considered less hazardous but nevertheless have a deleterious effect on the aquatic environment. List II substances must be *controlled*. List II substances, therefore, are typically those for which specific target values need to be determined.

List I and List II substances, and associated target values are currently not available for South Africa and should be addressed in future revisions of the *South African Water quality Guidelines for Coastal Marine Waters.* The following are recommended for consideration as List I and List II substances for South Africa:

PROPOSED LIST I SUBSTANCES

Families and groups classified as List I substances are:

- *Merury: Metalloids and metals and their compounds*
- *Cadmium: Cadmium and its compounds*
- *Poly-aromatic hydrocarbons derived from industrial processes, e.g. refinements of crude oil*
- *Organohalogen compounds and substances which may form such compounds in the marine environment*
- *Organophosphorus compounds and substances which may form such compounds in the marine environment*
- *Organotin compounds and substances which may form such compounds in the marine environment*
- *Persistent synthetic materials which may float, sink or remain in suspension and which may interfere with any legitimate use of the sea*
- *Substances having proven carcinogenic, teratogenic or mutagenic properties in or through the marine environment*
-

PROPOSED LIST II SUBSTANCES

Families and groups classified as List II substances are:

- *Metalloids and metals and their compounds*

Zinc	*Selenium*	*Tin*	*Vanadium*
Copper	*Arsenic*	*Barium*	*Cobalt*
Nickel	*Antimony*	*Beryllium*	*Thallium*
Chromium	*Molybdenum*	*Boron*	*Tellurium*
Lead	*Titanium*	*Uranium*	*Silver*

- *Cyanides and fluorides*
- *Pathogenic micro-organisms*
- *Thermal discharges*
- *Substances which have, directly or indirectly, an adverse effect on the oxygen content of the marine environment, especially those which may cause eutrophication, e.g. inorganic nitrogen and phosphate*
- *Substances which have an adverse effect on the oxygen balance owing to the quantities in which they are discharged, such as particulate organic matter*
- *Crude oils and hydrocarbons of any origin*
- *Biocides and their derivatives not covered in List I.*
- *Organosilicon compounds and substances which may form such compounds in the marine environment, excluding those which are biologically harmless or are rapidly converted into biologically harmless substances*
- *Non-biodegradable detergents and other surface-active substances*
- *Substances which have a deleterious effect on the taste and/or smell of products for human consumption derived from the aquatic environment, and compounds liable to give rise to such substances in the marine environment*
- *Acid or alkaline compounds of such composition and in such quantity that they may impair the quality of seawater*
- *Substances which, though of a non-toxic nature, may become harmful to the marine environment or may interfere with any beneficial use of the marine environment owing to the quantities in which they are discharged.*

4.2.2 Beneficial Uses

i. Recreational Use

The recreational use of the coastal marine waters can be sub-divided broadly into three major groups, i.e.:

- **Full contact recreation**, referring to activities such as swimming, diving (scuba and snorkelling), water skiing, surfing, paddle skiing, wind surfing, kite surfing, parasailing and wet biking. During these activities full body contact with the water and ingestion of water is likely to occur frequently. Tidal pools are also classified as contact recreation sites

- **Intermediate contact recreation**, including activities such as boating, sailing, canoeing, wading, and angling, where users may come in contact with the water or swallow water, but to a much lesser extent than is the case with contact recreation

- **Non-contact recreation**, involving all recreational activities taking place in the vicinity of marine waters, but which do not involve direct contact, such as sightseeing, picnicking, walking, horse riding, hiking, etc.

With respect to the recreational use of marine waters, the impacts of waste disposal activities can be categorised broadly into:

- 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 matter damages boat propellers).

The *South African Water Quality Guidelines for Coastal Marine Waters* provides recommended target values for a range of water quality constituents relating to the recreational use of marine waters (RSA DWAF, 1995).

NOTE:

It has been proposed that the target values recommended for microbiological parameters in the South African water quality guidelines for coastal marine waters (DWAF, 1995) be revised so as to take into account recent scientific findings, as well as recent trends and developments on the international front. The guidelines should also address issues concerning day-to-day management of microbiological quality where it is often difficult to work with percentile values. For example, present monitoring programmes only provide single samples from a specific site on a particular monitoring run and it will be useful, therefore, if the guidelines could also accommodate 'single-value-cut-off' objectives (Taljaard et al., 2000).

ii. Mariculture (including harvesting of seafood) and Fisheries

Mariculture refers to the farming of marine and/or estuarine organisms in land-based (i.e. 'off-stream' tanks using pumped seawater) or water-based (i.e. 'in-stream') systems. Typically, mariculture focuses on:

- Seaweeds (e.g. *Gracilaria*)
- Molluscs (e.g. mussels and oysters)
- Crustaceans (e.g. prawns)
- Finfish (e.g. trout and salmon).

Seaweed culture is a well-established industry internationally and is used, amongst other things, to produce agars. In South Africa, attention is focused on the collection of *Gracilaria* (Saldanha Bay). Seaweeds are primary producers requiring sufficient light and inorganic nutrients to grow.

In South Africa, mollusc culture mainly comprises mussels, oysters and abalone. Mussel farming is concentrated in the Saldanha Bay and St Helena Bay areas, while oyster farming is more widely distributed, extending from Alexander Bay on the west coast, to Port Alfred along the south-east coast. Abalone farming also extends from the west coast (Port Nolloth) to immediately north of East London. Bivalves (e.g. mussels and oysters) are filter-feeding organisms, and as a result, they can accumulate pollutants and toxins during their feeding processes. Abalone is primarily fed on macrophytes (e.g. kelp) or fishmeal-based artificial food.

Efforts to culture crustaceans in South Africa are limited to the Kwazulu-Natal coast where the temperature regime is more suitable for producing prawns efficiently (i.e. warmer waters).

Although finfish farming presently is not practised extensively in South Africa, the bulk of international mariculture production is in the form of finfish.

Marine organisms, such as those listed above, are also harvested directly from the sea for human consumption. These are harvested by:

- Commercial fisheries
- Subsistence fisheries
- The general public.

With respect to mariculture activities, harvesting of seafood and fisheries, the impacts of pollution can broadly be categorised into:

- 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).

Recommended target values for a range of water quality constituents to prevent negative impacts in water used for mariculture activities are provided in the *South African Water Quality Guidelines for Coastal Marine Waters*, which also recommend similar target values for the maintenance of marine ecosystems (RSA DWAF, 1995).

In South Africa, standards (i.e. concentration limits of constituents as required by law) controlling the quality of <u>*fish and shellfish flesh*</u> for human consumption are set out in the following legislation:

- Foodstuffs, Cosmetics and Disinfectants Act (Act 54 of 1972), Regulation - Marine food, 2 November 1973

- Foodstuffs, Cosmetics and Disinfectants Act (Act 54 of 1972), Regulations related to metals and foodstuffs, 9 September 1994.

In principle, these food quality standards should be met if the quality of the water from which these organisms are harvested or cultured complies with the recommended target values for mariculture, as specified in the *South Africa Water Quality Guidelines for Coastal Marine Waters* (RSA DWAF, 1995).

iii. Industrial Use

Industrial uses of the marine environment consist of numerous activities such as:

- Fish processing: In the processing of seafood, seawater in often abstracted from the sea to be used in the processing. Such waters are usually subjected to further treatment, e.g. flocculation and UV irradiation. Treatment generally consists of passing water through bar or wire screens to remove larger particles. The quality of seawater used in processing, washing and canning of seafood is critical since any water quality problems can easily be passed onto the final product.
- Salt Production: Seawater is pumped into solar ponds from where the water evaporates under the influence of wind and solar radiation.
- Desalination: Currently, desalination of seawater is not a major activity in South Africa, but in areas such as the Middle East, desalination is widely used for obtaining potable water.
- Aquariums and Oceanariums: Marine aquaria and oceanariums use large quantities of seawater pumped directly from the sea. Between 10 – 100% of the total tank volumes may be replaced daily.
- Harbours and Ports: Harbours and ports are primarily industrial entities which, as a result of their sheltered nature, tend to accumulate pollutants. Of particular concern in harbour areas in which regular dredging is required, is the chemical contamination of sediments. Areas that require dredging need to meet guidelines provided in terms of ANNEX I and ANNEX II substances under the London Convention (refer to Section 3 for details). Dredging operations are governed by the London Convention, which is given legal effect in South Africa by the Dumping at Sea Control Act 73 of 1980.
- Cooling water: The intake of seawater for cooling is mainly associated with conventional and nuclear power plants (e.g. Koeberg Nuclear Power Station).
- Ballast water: Intake of ballast water, used for vessel trim, stability and manoeuvrability, usually occurs inside harbours and ports.
- Coastal Mining: Coastal mining includes activities such as diamond mining along the west coast of South Africa which abstracts seawater for use in various processes.
- Make-up water for marine outfalls: In the operation of some offshore marine outfalls, seawater is used as make-up water to ensure the proper hydraulic functioning of the outfall system.
- Exploration Drilling. This use mainly refers to oil and gas exploration drilling operations, which generally occur in the offshore marine environment.
- Scrubbing and Scaling: There are industries that use seawater, for example, to scrub smoke stack emissions (e.g. Alusaf in Richards Bay). Seawater is pumped to the top of the stacks and the smoke emissions are passed through the seawater to remove ('scrub') dust particles.

With respect to the industrial uses of seawater, the impact of waste disposal activities primarily relate to:

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

The *South African Water Quality Guidelines for Coastal Marine Waters* provide recommended target values for a range of water quality constituents relating to the industrial uses of marine waters (RSA DWAF, 1995).

SECTION 5:
ACTIVITIES AND WASTE LOADS

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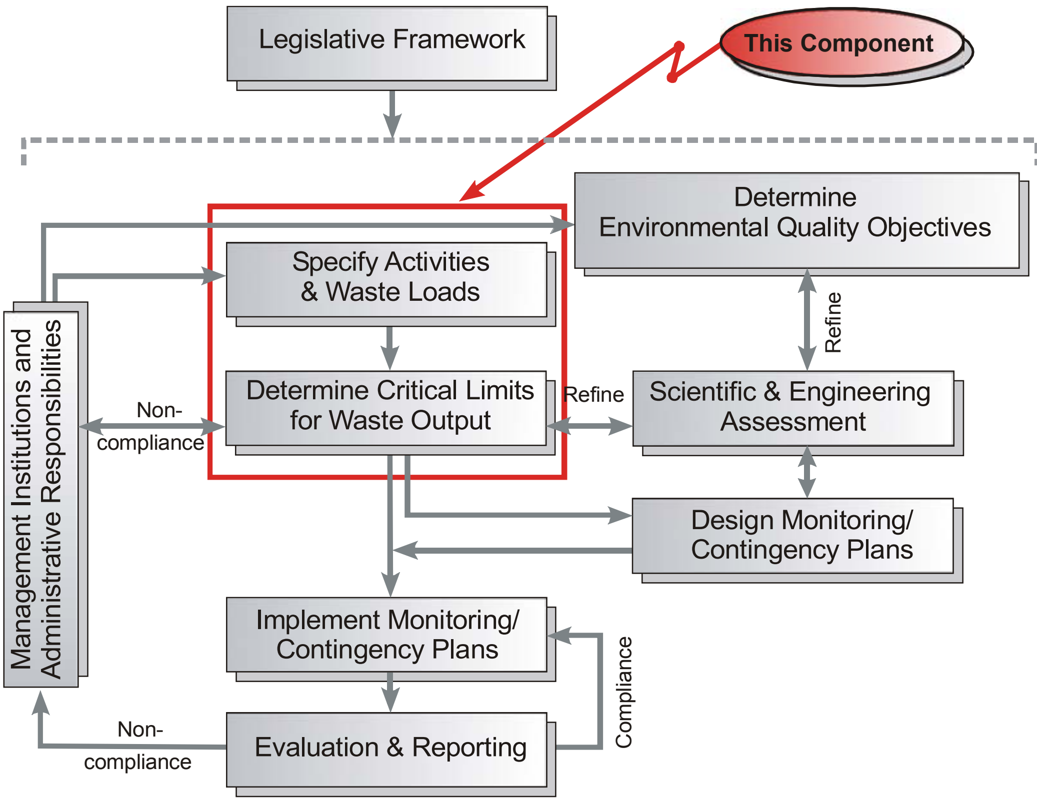

PURPOSE:

The purpose of this component is to quantify waste loads, not only from the wastewater discharges under investigation, but also other waste loads discharged into the area originating from anthropogenic (human) sources. The quantification of waste loads includes:

- ***Flow patterns, including temporal variation***
- ***Identification of constituents present in wastewater***
- ***Concentrations of constituents, as well as any temporal variation thereof.***

Waste sources to the marine environment can be categorised into four sub-categories, namely:

- *Point sources of land-derived wastewater*, including municipal and industrial wastewater
- *Diffuse sources of land-derived wastewater*, including urban stormwater run-off
- *Shipping and harbour activities*, including pollution from oil and garbage
- *Dumping at sea*, including the dumping of waste matter and dredge spoil.

Although this operational policy addresses land-derived wastewater inputs to the marine environment, it is important also to take into account activities and waste loads from other sources (for example shipping and dredging activities) to ensure that any cumulative and/or synergistic effects are considered.

An example of a map illustrating activities, of which the waste inputs can potentially have a negative impact on the marine environment in a specific area, is provided in Figure 5.1

Information typically needed to define wastewater characteristics include:

- Description of treatment processes

- Density, viscosity and temperature of the wastewater stream (average, maximum, minimum – specify if diurnal/seasonal variations occur

- Flow rates (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios

- Composition of the wastewater - in terms of all relevant constituents (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios.

An overview of the characteristics of various types of waste sources that could or have been disposed of to the marine environment is provided below.

5.1 MUNICIPAL WASTEWATER

Municipal wastewater refers to domestic wastewater (sewage) or a mixture of domestic wastewater and industrial wastewater (also referred to as trade effluent) and/or urban stormwater run-off.

The domestic wastewater component of municipal wastewater is mainly composed of water (> 99.9%) and solid wastes, primarily composed of organic material, which will eventually decay or decompose. The wastewater also contains some inorganic matter and heavy metals as well as grit/sand and debris such as cellophane, wood, plastic, etc.

Municipal wastewater also contains many bacteria, 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 stream and form the basis of the wastewater biological treatment process. A group of microorganisms, known as faecal coliforms, is present in large numbers and serves as convenient indicator for the presence of pathogens in the waste stream and, ultimately, in the environment.

An indication of the strength of sewage is related to the total suspended solids load (SS) and biochemical oxygen demand (BOD). A typical composition of raw sewage under dry weather conditions, according to WRc (1990), is provided in Table 5.1.

CLICK TO VIEW GRAPHIC

FIGURE 5.1: Example of a map illustrating activities that may affect water quality (adapted from Taljaard & Monteiro, 2002)

TABLE 5.1: Typical composition of raw sewage under dry weather conditions (WRc, 1990)

CONSTITUENT	*CONCENTRATION*	
	WRC(1990)	*SOUTH AFRICA**
Suspended solids	*250 – 400 mg/ℓ*	*300 - 330 mg/ℓ*
BOD	*300 – 500 mg/ℓ*	
Ammonia-nitrogen	*20 – 50 mg/ℓ*	*25 mg/ℓ*
Total phosphorus	*15 – 25 mg/ℓ*	*10-15 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	*2 – 30 x 10^6 per 100 ml*	

** Average values for the Green Point and Camps Bay offshore outfalls (Cape Town)*

The volume of municipal wastewater flow varies during the day with peaks in the morning, noon and late afternoon. A typical diurnal flow pattern is illustrated in Figure 5.2. However, each area will have a characteristic flow pattern, depending on the socio-economic factors as well as the physical layout of the sewerage system(s) with regard to retention times.

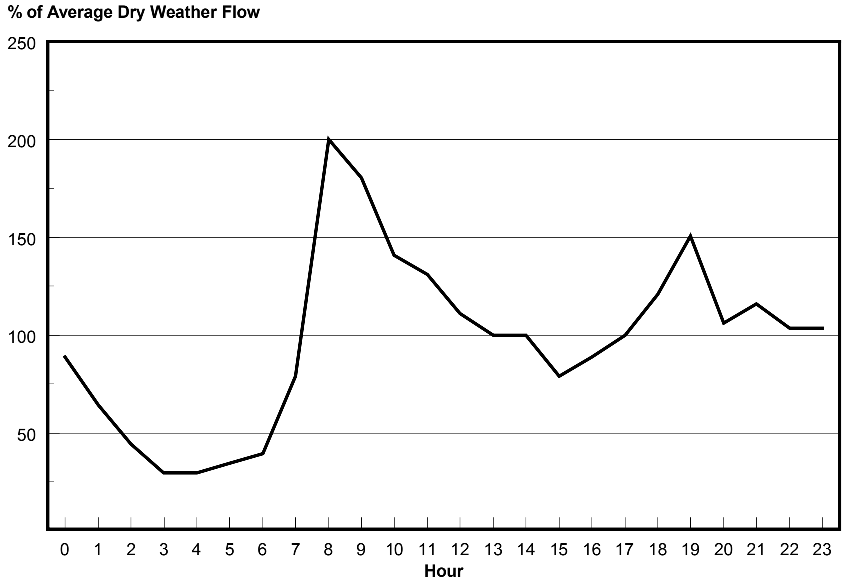

FIGURE 5.2: Typical diurnal flow pattern of municipal wastewater

For municipal wastewater discharges, it is also very important to take seasonal variation in the flow patterns into account, particularly for small coastal holiday resorts where such variation can be very large. For example, infiltration (due to damaged pipes) during the wet season or during a rainstorm will increase the flow. This must be taken into account in the assessment of treatment and disposal options of the wastewater.

Future flow scenarios should be based on the future water demand of a community with regard to future population and development trends.

Treatment of municipal wastewater (sewage) can be broadly categorised into:

- Preliminary treatment
- Primary treatment
- Secondary treatment
- Tertiary treatment
- Disinfection.

Each of these treatments is discussed in further detail in Sections 5.1.1 to 5.1.5 below.

The typical treatment process for domestic sewage is schematically illustrated in Figure 5.3.

5.1.1 Preliminary treatment

Preliminary treatment involves the removal of coarse solids and objects such as pieces of wood, paper, rags and plastic that are often present in raw wastewater. This treatment facilitates the operation and maintenance of the next treatment phase and improves the aesthetic quality of the wastewater. Preliminary treatment includes coarse and fine screening, and grit removal (maceration of large objects can also be introduced if required). Instruments (flow meters) to record the sewage flow are necessary for the management of the effluent after preliminary treatment.

CLICK TO VIEW GRAPHIC

FIGURE 5.3: A schematic illustration of the different treatment processes for municipal wastewater (sewage)

5.1.2 Primary treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25% to 50% of the BOD in the incoming wastewater, 50% to 70% of the SS, and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is also referred to as primary effluent (FAO, 1992).

5.1.3 Secondary treatment

During secondary treatment, micro-organisms and oxygen are utilised to stabilise the sewage after primary treatment. During secondary treatment 85% to 95% of the suspended solids and the BOD load can be removed. Secondary treatment processes include:

i. Percolating filters (Trickling filters or rotating biological filters)

A trickling filter or biofilter consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Micro-organisms become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolised. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. The thickness of the biofilm increases as new organisms grow. Periodically, portions of the film 'slough off' the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing.

Clarified liquid from the secondary clarifier is the secondary effluent and a portion is often recycled to the biofilter to improve the hydraulic distribution of the wastewater over the filter (FAO, 1992).

ii. Rotating biological contactors

Rotating biological contactors are fixed-film reactors similar to biofilters in that organisms are attached to support media. The support media are slowly rotating discs that are partially submerged in flowing wastewater in the reactor. Oxygen is supplied to the attached biofilm from the air when the film is out of the water and from the liquid when submerged, because oxygen is transferred to the wastewater by surface turbulence created by the discs' rotation. Sloughed pieces of biofilm are removed in the same manner described for biofilters.

iii. Aeration tanks

In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and micro-organisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices that supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. The hydraulic retention time in the aeration tanks usually ranges from 3 to 8 hours but can be higher with high BOD wastewaters. Following the aeration step, the micro-organisms are separated from the liquid by sedimentation and the clarified liquid is termed secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids level. The remainder is removed from the process and sent for sludge processing to maintain a relatively constant concentration of micro-organisms in the system. Several variations of the basic activated sludge process, such as extended aeration and oxidation ditches, are in common use and operate on the same principles (FAO, 1992).

5.1.4 Tertiary treatment

Tertiary treatment is used for further removal of specific constituents either not permitted to be discharged or that need to be reduced to meet environmental quality objectives. This includes filtration (sand filters, reed beds, etc.), phosphorus removal, ammonia stripping or other special treatment.

5.1.5 Disinfection

EPA Victoria (2002) provides guidelines for the disinfection of treated sewage effluent and group the methods as:

- *Chemical*, e.g. chlorination and ozonation
- *Physical*, e.g. ultraviolet radiation and microfiltration
- *Biological*, e.g. detention ponds.

What is most important is that the quality of the effluent will determine the effectiveness of any disinfection method. According to EPA Victoria (2002), the required pre-treatment to ensure that disinfection of the effluent is effective is secondary treatment.

The three most used disinfection methods are chlorination, UV radiation, and detention ponds.

Chlorine can be applied in gaseous form or as hypochlorite salts. The disadvantage is that free and combined chloride residues are toxic to aquatic life.

There is a potential for toxic organo-chlorinated derivatives to be formed, which tend to be persistent and bio-accumulate. However, experience from operational treatment works has shown that the ability to form these compounds is low. Dechlorination techniques remove all or part of the total combined chloride residues.

UV radiation is the exposure of a film of wastewater to ultra violet lamps, the efficiency of which depends on the quality of the effluent at the time of exposure. The main advantage of UV-radiation is that no consequent adverse effect on the environment has been observed.

Natural disinfection occurs when an effluent is stored in detention ponds for a sufficient length of time. The effectiveness depends on factors which influence the penetration of sunlight, such as the depth of the ponds and the turbidity and concentration of suspended solids in the wastewater.

The effectiveness of chlorination and UV radiation depends on the quality of the effluent and EPA Victoria (2002) recommends that concentrations of suspended solids be less than 20 mg/ℓ and 10 mg/ℓ for chlorination and radiation respectively. Gunnerson (1988) suggests a suspended solids concentration of 15 mg/ℓ for effective chlorination.

Where wastewater is discharged directly into areas used, for example, for the collection of seafood for human consumption or for recreation (e.g. surf zone or estuary discharges), EPA Victoria (2002) recommends the following disinfection methods:

BENEFICIAL USE AREA	***SUGGESTED BEST PRACTICE TREATMENT***	***SUGGESTED BEST PRACTICE DISINFECTION***	***ACCEPTABLE DISINFECTION (required site specific assessment)***
Shellfish harvesting	*Tertiary treatment*	*UV, micro-filtration or ozone*	*Chlorination/dechlorination*
Direct contact recreation	*Secondary treatment*	*UV, micro-filtration or ozone*	*Chlorination/dechlorination*
Other seafood harvesting	*Secondary treatment*	*UV, ozone or detention lagoons*	*Chlorination/dechlorination*

A summary of the comparison of different disinfection methods is provided in Table 5.2 (EPA Victoria, 2002).

TABLE 5.2: A summary of the comparison of different disinfection methods (EPA Victoria, 2002)

CONSIDERATION	CHLORINE	OZONE	UV	MICRO-FILTRATION	DETENTION PONDS
Effectiveness against					
Bacteria	*High*	*High*	*High*	*High*	*Medium to high*
Viruses	*Low to medium*	*High*	*High*	*Medium to high*	*High if >14 days*
Pathogens	*Medium to low*	*High*	*Not fully assessed*	*High*	*High if >30 days*
Practicality					
Process control	*Well-developed*	*Developing*	*Developing*	*Developing*	*Well-developed*
Complexity	*Simple to moderate*	*Complex*	*Simple to moderate*	*Simple to moderate*	*Simple*
Maintenance/cleaning	*Low to moderate*	*Moderate to intensive*	*Intensive*	*Intensive*	*Low to moderate*
Reliability	*High*	*High*	*Medium*	*Medium*	*Medium to high*
Costs					
Operation	*Medium*	*Medium*	*Medium*	*High*	*Low*
Capital (small to medium plant)	*Medium*	*High*	*Low to medium*	*High*	*Low to medium*
Capital (medium to large plant)	*Low to medium*	*High*	*High*	*High*	*Medium to high*
Adverse effects					
Safety risks: Transportation	*Yes*	*No*	*No*	*No*	*No*
Safety risks: on-site	*Substantial*	*Moderate*	*Minimal*	*Minimal*	*Minimal*
Fish toxicity	*Toxic (can be reduced by de-chlorination)*	*Unlikely*	*No*	*No*	*Potential toxicity from algae*
Formation of toxic by-products	*Potential*	*Unknown*	*Unknown*	*None*	*Potential toxic algal by-products*
Disposal of cleaning products	*No*	*No*	*Yes*	*Yes*	*No*
High energy consumption	*No*	*No*	*Yes*	*Yes*	*No*

5.2 INDUSTRIAL WASTEWATER

Numerous land-based industries discharge their wastewater to the marine environment. The pollutants associated with industrial waste discharges are largely dependent on the type of industry. Examples of industries known to have discharged or that are discharging wastewater to the sea (particularly in South Africa) as well as the major pollutants associated with such discharges are briefly discussed below.

5.2.1 Fertilizer factories

In South Africa, the fertilizer industry produces mainly nitrogenous and phosphatic fertilizers.

Wastewater pollutants from the factories producing nitrogenous fertilizers are typically nitrogen nutrients (nitrate, ammonia and urea) (Begg *et al.*, 1980; Van Eeden, 1982).

Phosphatic plants, on the other hand, produce acidic (i.e. low pH) wastewater that could contain high levels of:

- phosphates
- fluoride (where fluorideapatite is used in feedstock)
- gypsum (i.e. calcium sulphate)
- heavy metals (derived from the raw materials).

(Sources: Arnold and Wolfram, 1975; UNEP, 1982; Lord & Geldenhuys, 1986; WRC, 1988)

5.2.2 Pulp and paper mills

The wastewater composition of pulp and paper mills depends on the process that is used to produce the pulp or paper, which is typically the:

- Kraft or sulphate process
- Soda process
- Sulphite process
- Groundwood pulp manufacture.

(Sources: Southgate, 1948, Rudolfs, 1953; Billings & Dehaas, 1971)

In the Kraft process, wood is digested with a mixture of sodium salts such as hydroxide, sulphate and sulphide. Since a large fraction of the waste is re-used, wastewater from such a factory mainly originates from the washing of the pulp. Wastewaters from such plants can typically be contaminated by:

- Suspended solids, of which 70-90% are settleable solids
- Biodegradable organic matter
- Reducing compounds, e.g. sulphides and mercaptans.

(Sources: Southgate, 1948; Rudolfs, 1953; Billings & Dehaas, 1971; Gurnham, 1955):

The soda pulping process is similar to the Kraft process except that the soda process may use smaller quantities of sulphides, resulting in the wastewater containing smaller amounts of reducing compounds than, for example, effluent from the Kraft process (Rudolfs, 1953).

In the sulphite process the wood is treated with a calcium sulphite solution. During this process materials are not recovered from the spent liquid (also know as 'black liquor') as is done, for example, during the Kraft process. As a result, the waste contains as much as 50% of the wood processed. One of the major waste products is lignin, which is present as lignosulphonic acid or calcium salts. The wastewater from a plant using the sulphite process contains:

- Low pH, i.e. it is usually acidic
- High suspended solids
- High biodegradable organic matter
- The 'black liquor' causes discolouring of the receiving waters
- The presence of lignins results in surface foaming.

(Sources: Fijen, 1988; Southgate, 1948; Rudolfs, 1953; Billings & Dehaas, 1971; Gurnham, 1955; Murray, 1987)

The wastewater from groundwood pulp manufacture uses zinc hydrosulphite as a bleaching agent. The wastewater from such a plant includes:

- Suspended solids
- Biodegradable organic matter
- Heavy metals (e.g. zinc).

(Source: Billing & Dehaas, 1971)

Chlorine is usually used in the bleaching processes of pulp. Free chlorine as well as chlorinated organic compounds (e.g. chlorinated phenolic compounds) could, therefore, be present in wastewater from the bleaching plant (Murray, 1987).

5.2.3 Chemical and explosives factories

There are numerous types of chemical factories. Wastewater produced by such industries is consequently very diverse and the composition is largely dependent on the chemicals that are produced (Imhoff *et al.*, 1971; Spencer, 1971). Depending on the processes involved, pollutants in such wastewater may include:

- Suspended solids
- Biodegradable organic matter
- Reducing agents such as sulphides
- Nutrients
- High acidity
- Toxic inorganic compounds (e.g. cyanide and fluorides)
- Toxic organic compounds (e.g. heavy metals and hydrocarbons).

(Sources: Southgate, 1948; Rudolfs, 1953; Van Eeden, 1982; Gurnham, 1955; Spencer, 1971)

The above list of pollutants is far from complete and wastewater from these types of factories should be analysed individually to identify any other potentially harmful pollutants.

5.2.4 Oil refineries

A large variety of pollutants may be present in the wastewaters of oil or petroleum refineries. Pollutants can originate from a large number of sources in the plant. Pollutants generally can be grouped as follows:

- 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 oil emulsion which is suspended in the water. Although free oils can usually be separated from wastewater by gravity or by means of differential oil-water separators, emulsions are usually not that easily removed.

- Condensate waters, which originate from distillation processes, contain high organic loads and reducing chemicals. They can also contain ammonia, heavy metals, cyanides and phenols.

- Acid wastes, which originate from processes in which sulphuric acid is used as a treating agent. Not only are these wastewaters acidic but they also contain high organic loads.

- Caustic wastes which originate from washing of certain oils to remove acidic materials naturally occurring in crude oil. These wastes are very alkaline (i.e. high pH) with a high organic content. They may also contain substances such as mercaptans, sulphides and phenols.

- Cooling water which typically is very hot.

(Sources: Rudolfs, 1953; UNEP, 1982)

The above list of pollutants contained in oil refinery wastewater is far from complete and, as with chemical factories, wastewater should be analysed individually to identify any other potentially harmful pollutants.

5.2.5 Sugar mills

The major processes in the production of sugar from sugar cane include:

- extraction of juices
- clarification of juices
- production of sugar crystals from juices.

(Source: Murray, 1987)

Lime and sulphur dioxide are usually used in the clarification processes, while activated carbon is used in the bleaching process of the final product. Pollutants that may be present is the wastewater from the sugar industry include:

- suspended solids
- biodegradable organic matter
- high temperatures (e.g. cooling water).

5.2.6 Fish factories

Wastewater originating from the processing of fish into fishmeal, oils and canned products can be broadly divided into:

- Blood water which refers to all the liquid separated from fish prior to the cooking process
- Stick water which is the waste that arises from the dewatering processes after cooking and during the pressing of the fish
- Oil polisher wastewater.

Pollutants in all of the above wastewater typically consist of:

- Suspended solids
- Biodegradable organic matter
- Nutrients, such as nitrogen.

(Source: Binnie & Partners, 1986)

5.2.7 Textile factories

Fibres used in the textile industry can be divided into two main categories: 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 (Southgate, 1948; Rudolfs, 1953, Murray, 1987; Schlesinger *et al.*, 1971).

Pollutants in wastewater from textile factories vary greatly and depend on the chemicals and treatment processes used. Pollutants that are likely to be present include:

- High acidicty/alkalinity
- Suspended solids
- Biodegradable organic matter
- Colour originating from dye processes
- Heavy metals, e.g. chromium and mercury
- Toxic organic compounds, e.g. phenols
- High temperatures (originating from cooling water).

(Sources: UNEP, 1982; Murray, 1987; Schlesinger *et al.*, 1971)

5.2.8 Food canning factories

Food canning (e.g. fruit, vegetables and meat) consists of a series of processes including washing, peeling and blanching, all of which produce wastewater. Major pollutants in these wastewaters include:

- Suspended solids
- Biodegradable organic matter
- High alkalinity (originating from the peeling process in which caustic soda is used)
- Discolouration (e.g. from the canning of beetroot).

(Sources: UNEP, 1982; Southgate, 1948; Rudolfs, 1953; Glide, 1971; Cruickshank, 1965; Thatcher & Clark, 1968)

5.2.9 Aluminium smelter

The major harmful pollutant in the wastewater from an aluminium smelter is fluoride (UNEP, 1982, Lord & Geldenhuys, 1986; Murray, 1987).

5.2.10 Power stations (including nuclear power stations)

Both fossil fuel and nuclear power stations use large amounts of cooling water. If such waters are not re-cycled but discharged into the marine environment, thermal pollution can result (i.e. high water temperature), especially if discharged in sheltered areas such as estuaries and harbours (UNEP, 1982). Discharges from nuclear power stations may also contain traces of radio-active materials.

5.2.11 Return flow: Oceanariums

Wastewater or return flow of seawater from oceanariums is likely to contain higher levels of suspended solids, degradable organic matter and possibly ammonia, compared to the intake waters. These items are the result of excretion from animals or remaining excess food particles.

5.2.12 Return flow: Coastal mining

Wastewater or return flow seawater used in coastal mining activities, e.g. the diamond mining industries along the South African west coast, usually contains high levels of suspended and settleable matter.

5.3 STORMWATER RUN-OFF

Stormwater run-off is one of the major non-point sources of pollution. It is, however, very difficult to characterise stormwater 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, has limited the treatment of such wastewater, which often contains toxic and refractory compounds (Meyer, 1985). The pollutants present in stormwater run-off include plant material, debris, plastics, oxygen demanding substances, suspended solids, nutrients, heavy metals, pathogenic bacteria and viruses, and toxic organic compounds (e.g. pesticides and petroleum hydrocarbons) (Bradford, 1977; Helsel *et al*, 1979; Hunter *et al*, 1979; Wigington *et al*, 1983; Brown *et al*, 1985; Green *et al*, 1986; Schmidt & Spencer, 1986).

Stormwater run-off can be divided into two broad categories namely (Hoffman, 1986):

- urban run-off (residential including formal and informal developments, industrial and commercial)
- rural run-off (e.g. rural settlements, agricultural and forestry areas)

The quality and quantity of stormwater run-off is determined to a large extent by catchment characteristics, rainfall characteristics and antecedent moisture conditions.

Stormwater run-off from agricultural catchments (more of a problem to inland water resources) was found to contain a high suspended solids load, high iron and manganese concentrations as well as high nutrient and pesticide concentrations, while copper, lead, zinc and petroleum hydrocarbons were predominant in run-off from urban catchments. The levels of these compounds increased with an increasing volume of vehicle traffic (Helsel *et al*, 1979; Hoffman, 1986; Duda, 1982; Moore *et al*, 1988). Concern about the rapid development of informal townships along the South African coastline is increasing. In most of these areas, a low level of sanitary services is provided with the result that the pollution of stormwater run-off, which usually drains directly into the surf zone, is more serious than in formally developed areas (Miles, 1984).

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 seems to increase in frequency and intensity as the degree of urbanisation increases (Brown *et al*, 1979; Simpson, 1986). In general, highly urbanised catchments produce the greatest concentration of pollutants in stormwater run-off and rural catchments the least (Green *et al*, 1986).

Pollutants in stormwater run-off, therefore, are numerous and may include:

- Suspended solids
- Biodegradable organic matter
- Nutrients
- Heavy metals
- Toxic organic compounds (e.g. petroleum hydrocarbons)
- Pathogenic organisms (e.g. bacteria and viruses)
- Plastics and other litter.

Concern about the pollution effect of stormwater run-off in South Africa has increased dramatically over the past years. However, the data available on the quantity, and especially the quality, of this run-off are very limited. An overview of pollutant inputs from stormwater run-off, originating from different source areas, is provided in Pegram & Görgens (2001).

5.4 OTHER WASTE SOURCES

Although they are not specifically addressed as part of this operational policy, it is important to realise that shipping and harbour activities also contribute to the waste load entering the marine environment and that they cannot be ignored when assessing cumulative impacts. However, quantifying waste inputs from these activities is often extremely difficult owing to the unpredictable and sporadic nature of such events. Therefore, in situations in which such activities occur in a particular area, and which may have synergistic effects with land-derived wastewater discharges, a scenario-based approach is typically used.

5.4.1 Oil spills

Major sources of oil pollution originating from shipping activities include (Taljaard & Rossouw, 1999):

- 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.)
- large oil spills as a result of a collision or severe structural damage to oil tankers or other vessels while at sea.

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 metal (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 trace metals.

In addition to the harmful chemicals released into the sea during an oil spillage, the oil slick also causes physical damage by creating aesthetically unpleasant conditions, clogging water intake systems and smothering benthic marine fauna and flora (Taljaard & Rossouw, 1999).

5.4.2 Ballast water

Ships take on ballast water at sea to increase their stability. Up to 125 000 tonnes per vessel are taken from the coastal waters of the world. As South Africa is a net exporter of raw materials, such as coal and mineral ores, it receives a large amount of ballast water from overseas sources. It is estimated that the annual discharge of ballast water into South African harbours is in the order of 20 million tonnes, compared with about 66 million tonnes in Australia. 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.

5.4.3 Harbour activities

Activities in harbour 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 ships
- 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 these can include:

- Suspended solids
- Biodegradable organic matter
- Nutrients
- Heavy metals
- Toxic organic compounds (e.g. petroleum hydrocarbons, antifouling paint)
- Pathogenic organisms (e.g. bacteria and viruses)
- Exotic organisms
- Plastics and other litter.

Regular monitoring of the key contaminants in the water and sediments best assesses pollution input to harbours.

5.4.4 Dumping of dredge spoil

Sediment removed during regular maintenance dredging, for example, 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. Common pollutants associated with all dredged spoil, based on its inherent character, are suspended and settleable solids. Harbour sediments are often heavily contaminated with toxic chemicals such as trace metals and hydrocarbons (McGlashen, 1989; Henry *et al*, 1989; Kleinbloesem & Van der Weijde, 1983). When spoil is dumped at sea these trace metals may be released, under suitable chemical conditions, to the receiving marine environment. In contrast, dredged material from ecologically productive areas such as estuaries may contain high concentrations of <u>biodegradable organic matter</u> and <u>nutrients</u> (Badenhorst, 1986; McGlashen, 1989). Deep dredging in harbours can also yield sediments that are naturally high in trace metals of geological origin. For example, in South Africa the concentration of chrome and arsenic is often elevated in such sediments.

5.4.5 Dumping of sludge

Sludge is a concentrated source of pollutants and as a result many countries have placed a ban on the dumping of sludge at sea. The pollutants present in sludge depend on the source. Sewage sludge, for example is a major source of:

- suspended and settleable solids
- biodegradable organic matter
- heavy metals, including chromium, copper, lead, tin and zinc
- toxic compounds, such as pesticides
- pathogenic organisms.

(Sources: West & Hatcher, 1980; Reed, 1975; Waldichuk, 1977; Hatcher *et al*, 1981; O'Connor & Rachlin, 1982; Babinchak, *et al*, 1977; Hadeed, 1976; Lear *et al*, 1881)

5.4.6 Dumping of other waste

Dumping of other forms of waste includes ammunition, and containered pharmaceuticals and chemicals. Pollutants associated with such dumping are strongly dependent on the type of waste dumped. In areas where dumping of waste is known to have occurred, it is necessary to identify the type of waste and to determine the associated pollutants on an individual basis.

5.5 TOXICITY TESTING

It is recognised that point source discharges, such as municipal and industrial wastewater, and diffuse sources, such as urban stormwater run-off, can be complex mixtures that may contain unknown compounds which may act together to increase or ameliorate the toxic effects to the receiving marine environment (RSA DWAF, 2003b). Rather than attempting to identify all the chemicals in a sample or where the toxic effects of specific chemicals are not known, toxicity tests (bioassays) using living organisms provide a useful means of determining the potential toxicity of wastewater to the marine life. In the case of complex mixtures, toxicity testing of the waste stream (also referred to as the Whole Effluent Toxicity [WET] test) is therefore very important (ANZECC, 2000a; US-EPA, 2002b).

5.5.1 Types of 'whole effluent toxicity' tests

Acute (or short-term) toxicity tests typically measure the survival of a specific organism over a prescribed period. Chronic tests determine toxicity over significant portions of an organism's lifespan (ranging from weeks to years) or use sensitive early life stages.

The US-EPA (2002b) has identified three categories of toxicity tests:

- Static non-renewal: where test organisms are exposed to the same test solution for the duration of the test
- Static renewal: where test organisms are exposed to a fresh solution of the same concentration of sample every 24 hours or other prescribed interval, either by transferring the test organisms from one test chamber to another, or by replacing all or a portion of solution in the test chambers
- Flow-through: where either the test sample is pumped continuously from the sampling point directly to the dilutor system or, where grab or composite samples are collected periodically, placed in a tank adjacent to the test laboratory, and pumped continuously from the tank to the dilutor system.

The type of toxicity test and test species are selected to suit particular case studies, depending on the type of wastewater and the receiving marine environment.

EXAMPLES…

An example of the use of a short-term toxicity test to set a target for the required dilution was for the extension of an offshore marine outfall from a paper mill. While the required dilution for individual chemical constituents within the near-field was less than 500, a set of urchin gamete toxicity tests set a target dilution of 1450 (Dinnel 1984; Airey 1989; Connell, Airey & Rathbone, 1991).

Another example of the use of these tests to assess the toxicity of a specific contaminant was for an offshore wastewater discharge ocean outfall from a phosphate fertilizer factory. In this case the key component in the wastewater was fluoride, for which there was no target value available. The urchin gamete test proved relatively insensitive to fluoride but life-cycle tests using an amphipod, cultured in various concentrations of fluoride in seawater, showed impaired reproduction at levels of fluoride above 5mg/ℓ. Thus the pipelines was designed to ensure that fluoride levels did not exceed this level beyond the initial mixing zone, taking into account ambient seawater concentration (1.2-1.5mg/ℓ) (Connell & Airey 1981)

The decision to collect grab or composite wastewater samples depends on the knowledge of variability in wastewater composition. Where the variability is expected to be low, composite samples are usually collected over a 24-hour period. However, where instantaneous elevations ('spikes') of toxicity are expected, the maximum toxicity can only be determined by scheduled grab sampling. In such instances, 24-hour composite samples will mask the toxic 'spikes'.

The type of dilution water used in toxicity tests depends on the objectives of the study:

- If the objective of the test is to estimate the absolute acute toxicity of the wastewater, then synthetic (standard) dilution water needs to be used. This type of dilution water will typically be used in monitoring changes in the toxicity of wastewater over time.

- If the objective of the test is to estimate the acute toxicity of the wastewater on entering the receiving water, the dilution water to be used in the toxicity test needs to be obtained from a sample (grab) at the discharge location. For an existing outfall, the sample must be taken 'outside' the plume or the influence thereof (e.g. upstream of the diffuser).

If the test organisms have been cultured in water that is different to that of the test dilution water, a second set of controls, using culture water, should be included in the test.

The US-EPA (2002b) recommends that wastewater toxicity tests consist of a control and five or more concentrations of wastewater (i.e. a range of wastewater dilutions). These tests are used to estimate:

- LC_{50}, i.e. the wastewater concentration which is lethal to 50% of the test organisms in the time period prescribed by the test, or

- No-Observed-Adverse-Effect Concentration (NOAEC), i.e. the highest wastewater concentration at which survival is not significantly different from the control, and/or

- Minimum Acceptable Toxicant Dilution (MATD), which lies between a dilution with a response which is not significantly different from a control test (NOAEC) and the highest observed effect dilution.

Note that, where changes in, for example, pH, temperature, salinity, total residual chlorine, unionised ammonium and dissolved oxygen concentrations may occur in the test solutions during the test period and which may interfere with the toxicity results, such changes need to be monitored throughout the test period.

5.5.2 Data analysis

i. LC_{50} values

The LC_{50} value can be determined by the Probit, Graphical, Spearman-Karber or trimmed Spearman-Karber method, of which the latter three methods also provide 95% confidence intervals for the LC_{50} estimates. These well-proven methods are discussed in more detail in US-EPA (2002b) and can be applied by scientists proficient in basic statistics. However, where there are anomalies in the data or an alternative method is applied, a statistician should be consulted. Basic guidance for the selection of the appropriate method for LC_{50} determination, related to the number of mortalities, is provided in Figure 5.4 (US-EPA, 2002b).

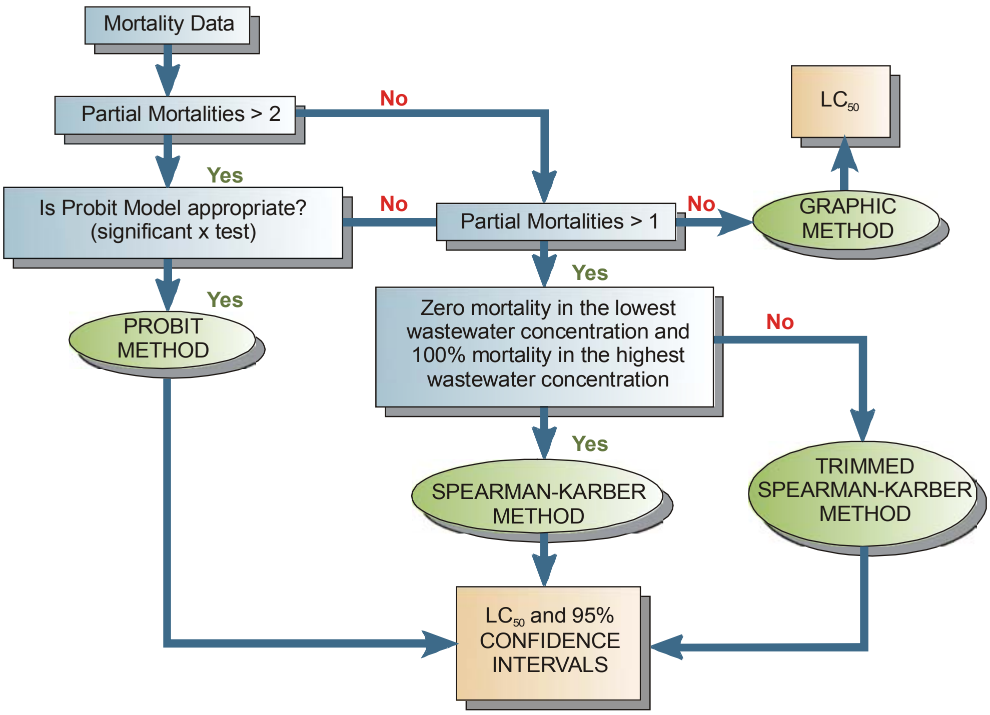

FIGURE 5.4: Guidelines on selection of the appropriate method for the determination of LC_{50} values (US-EPA, 2002b)

ii. NOAEC/MATD

Determination of the No-Observed-Adverse-Effect Concentration (NOAEC) and/or Minimum Acceptable Toxicant Dilution (MATD) is accomplished using hypothesis testing. The concept of hypothesis testing is based on the ability to distinguish statistically significant differences between a control treatment and other treatments (wastewater concentrations), where the null hypothesis (i.e. the wastewater is not toxic) yields no difference between a control treatment and a test treatment. The null hypothesis is rejected (i.e. the wastewater is toxic) if for a selected nominal error rate, there is a significant difference between the control treatment and the test treatment (an error rate of 0.05 is associated with a 95% confidence level).

A range of methods can be applied to determine NOAEC/MATD including Dunnett's test, T-test with Bonferroni adjustment, Steel's many-one rank test, and Wilcoxon rank sum test with Bonferroni adjustment. These methods are discussed in more detail in US-EPA (2002b) and can be applied by scientists proficient in basic statistics.

However, where there are anomalies in data or an alternative method is applied, a statistician should be consulted. Basic guidance for the selection of the appropriate method for NOAEC determination is provided in Figure 5.5 (US-EPA, 2002b).

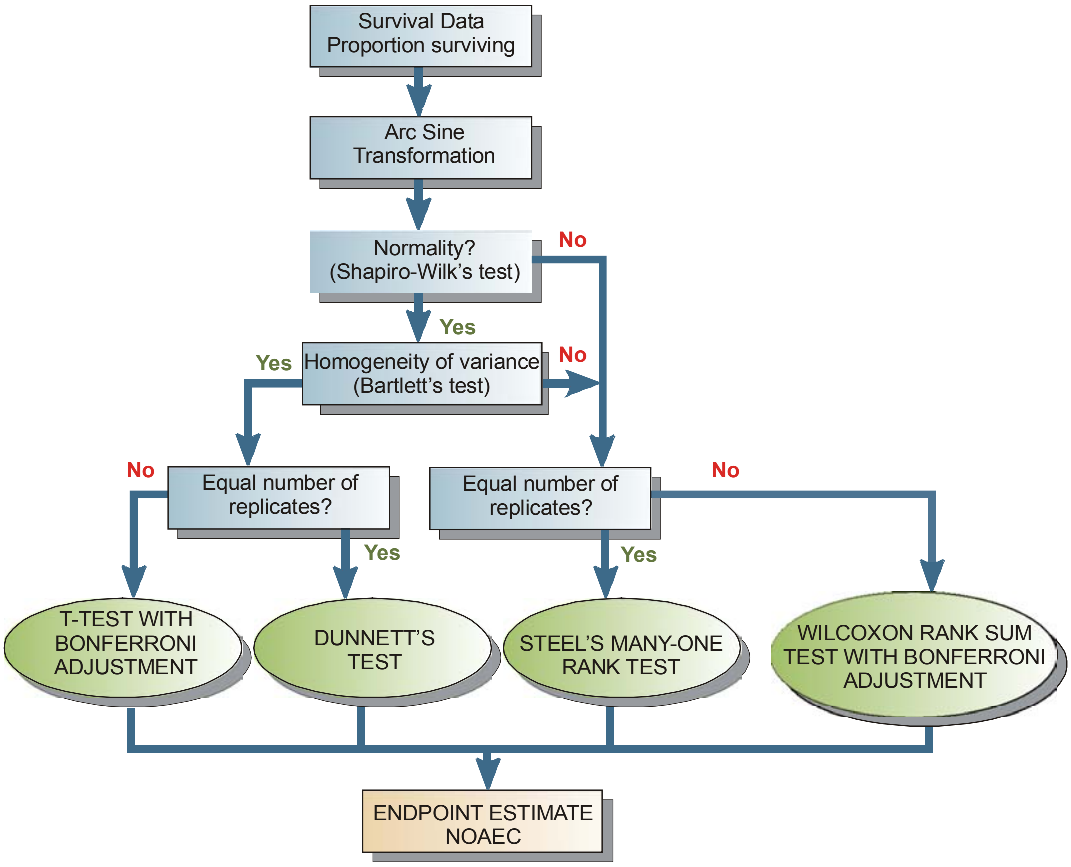

FIGURE 5.5: Guidelines on selection of the appropriate method for the determination of the NOAEC (US-EPA, 2002b)

5.5.3 Reporting

It is essential for the effective evaluation of long-term variations in wastewater toxicity that all relevant information be recorded, including:

- Details of the **wastewater sample**, including treatment operations, composition and flow volumes at the time of grab or 24-hour composite sampling
- Details of the **dilution water** (i.e. the water that is used in the experiment to dilute the wastewater), including source, pre-treatment, physical and chemical characteristics
- Description of the **test and quality controls**, including the test method, test conditions and test organisms (species, age, life stage, physical characteristics, source) and reference toxicants
- Description of the **data analysis**, including, raw toxicity data (tabular and graphical format), physical and chemical data (wastewater and dilution water), end-points and statistical methods to calculate end-points.

SECTION 6:
SCIENTIFIC AND ENGINEERING ASSESSMENT

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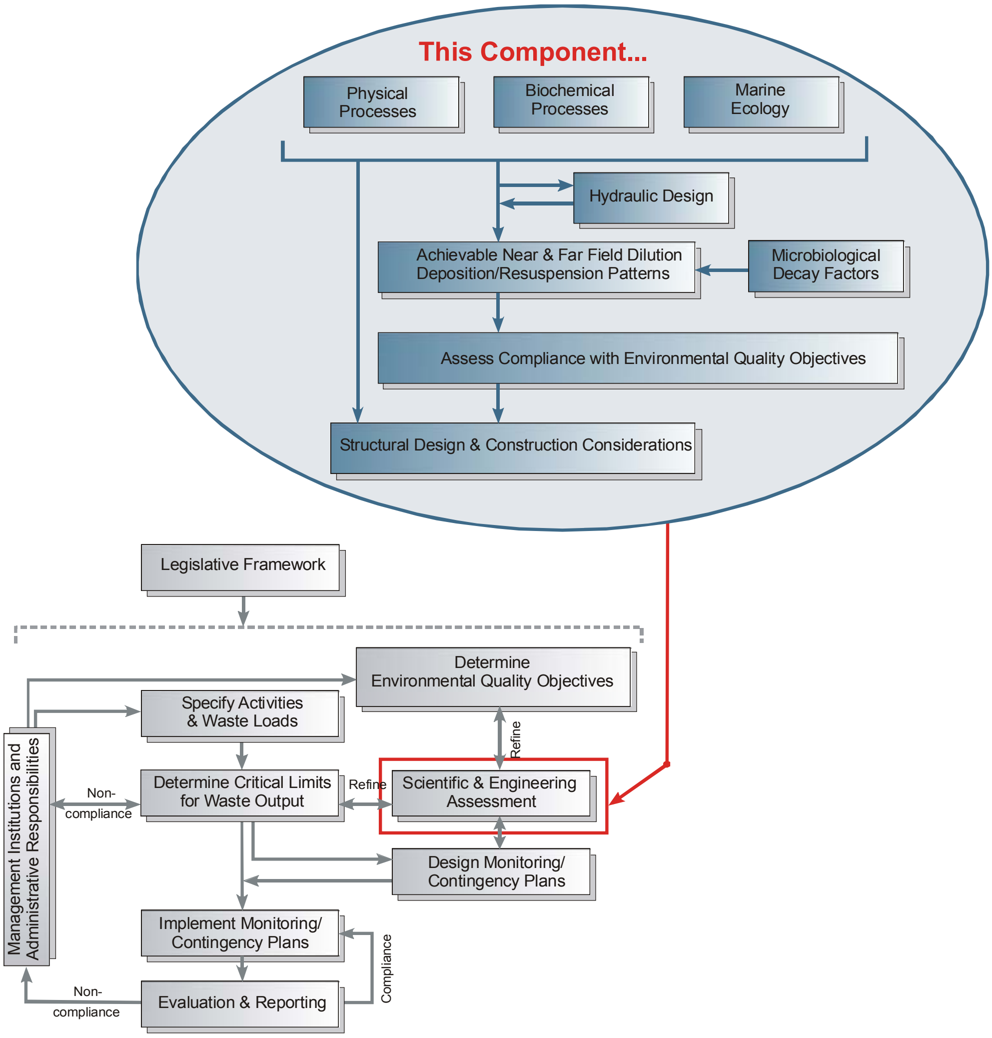


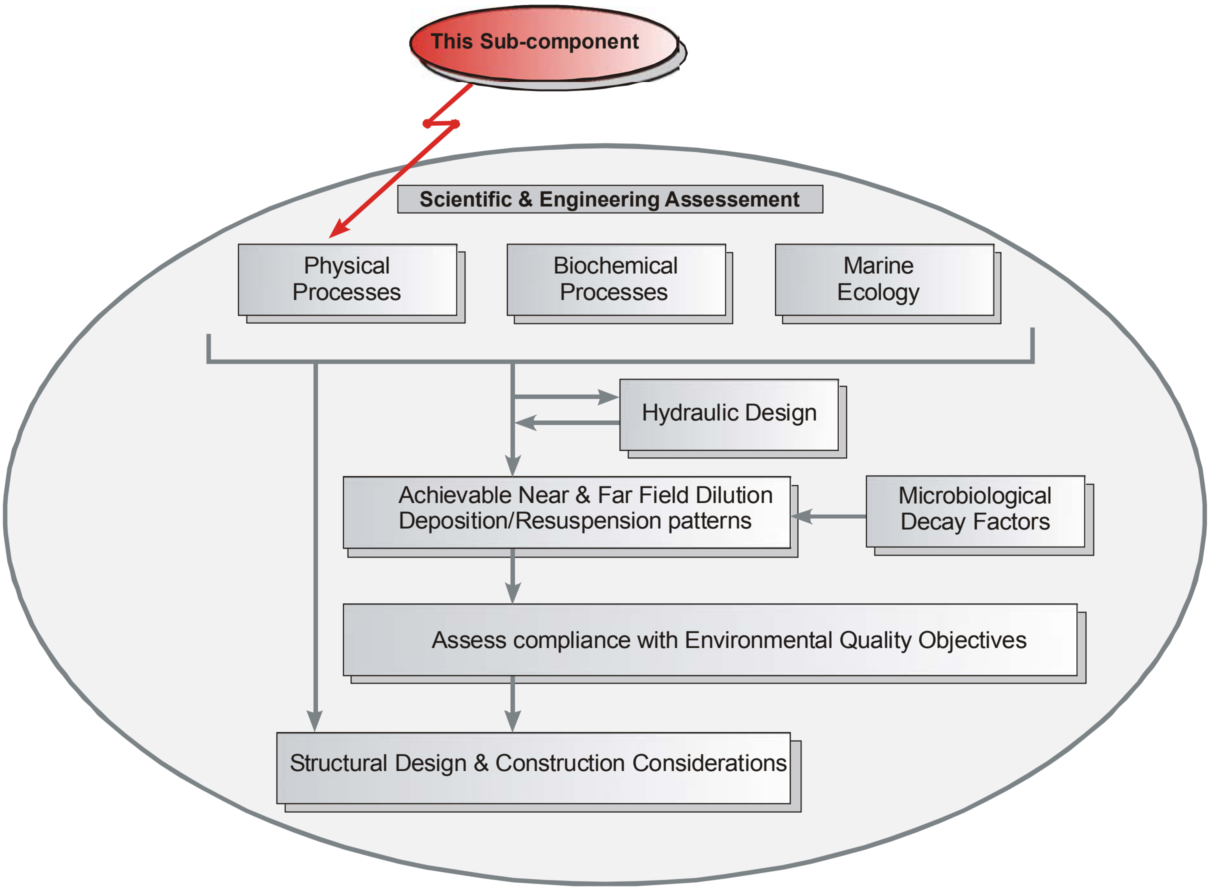
PURPOSE:

The objective of this component is to refine the environmental quality objectives and establish if a waste disposal practice will comply with the environmental quality objectives set for a particular marine environment. This is achieved through the following steps:

- ***Characterise physical and biogeochemical processes and the ecological functioning***
- ***Conduct the hydraulic design of the (offshore) outfall based on preliminarily required dilution estimates and taking into account the characteristics of the waste load (volume and composition)***
- ***Determine the achievable near and far field dilution and the deposition/re-suspension patterns of the proposed wastewater discharge. Also assess possible synergistic or cumulative effects, taking into account other anthropogenic influences in the study area.***
- ***Assess for compliance with environmental quality objectives. Where non-compliance with environmental quality objectives is evident, the hydraulic design of the outfall needs to be adjusted. Where compliance cannot be achieved through adjustment of the hydraulic design, either the critical limits for the waste load need to be reduced (e.g. through additional pre-treatment prior to discharge) or the environmental quality objectives need to be re-defined (i.e. only in extreme situations, e.g. in cases where economic/social gains justify such environmental sacrifice).***
- ***Define the structural design and the construction considerations of a marine outfall to meet requirements as determined by the above***

Where applicable, a distinction is made between requirements for* Pre-assessments *and for* Detailed Investigations *(with reference to* Section 3.1: Licence Authorisation Process*).

6.1 PHYSICAL PROCESSES



PURPOSE:

The purpose of this component is to gain an understanding of the hydrodynamic and geophysical characteristics and processes in the study area by:

- ***Producing a geo-referenced map of physical features, such as coastline configuration, topography, bathymetry and geological characteristics of the sea bottom***
- ***Assessing hydrodynamic processes (i.e. currents, water column stratification, water temperature variability and turbulence) for a range of environmental conditions (i.e. for various tides, waves, winds and air-sea fluxes as experienced in the marine environment).***

An additional purpose is to provide a basis to be used in the hydraulic design, as well as the assessment of achievable near and far field dilutions and deposition/re-suspension patterns of particles.

6.1.1 Overview

i. Bathymetry

A bathymetric survey is carried out to provide water depth contours, indicating the slope of the sea-floor and irregularities such as protruding reefs and offshore sandbars (Figure 6.1).

During a bathymetric survey, seawater depths at a large number of sites are determined using an echo-sounder operated from a survey boat. Depths are recorded as the boat travels at predetermined parallel lines perpendicular to the coast. In order to obtain a review of the area, lines spaced about 100 m apart are adequate whereas along the pipeline route itself, line spacing of 25 m or less is required. Corrections for tidal height and swell interference must be undertaken. The use of an integrative survey software package, providing accurate position fixing, bathymetric data and corrections for tide/swell, is necessary for the production of accurate contour plots and profiles.

NOTE:

Anthropogenic perturbations of marine water and sediment quality are usually perceived to be the result of biogeochemical modifications. However, developments that modify circulation dynamics, such as harbour structures and marina developments, can also modify sediment and water quality characteristics of the marine environment.

CLICK TO VIEW GRAPHIC

FIGURE 6.1: Example of bathymetric contour map and typical profile

ii. Seabed physiography

The physiography of the seabed not only determines the method and cost of construction of the outfall but also indices the type of biological communities that may be present along the proposed outfall route based on the nature of the seabed type. For example, biological communities generally are more diverse on rocky reefs than on sandy seabeds. Reefs thus should be avoided if at all possible.

A side scan sonar survey is conducted to provide a graphic picture ('aerial photo') of the seabed in order to define the location of reefs, gravel and boulder beds and sandy areas, and the height and direction of sand waves and ripples as well as obstructions such as wrecks, anchors or other pipelines or cables (Figure 6.2).

A side scan sonar transmits a very narrow sound beam to either side of a sound source unit (normally called a "side scan fish"), towed at a predetermined depth behind a survey vessel. Projections and irregularities on the seabed, such as reefs, sand waves and wrecks, reflect the sound back to the sensing transducers on the unit and the magnitude of sound energy reflected is recorded on a continuous graph. As the unit is towed along a co-ordinated survey line, the seabed is mapped in a strip up to 250 m wide on either side of the unit's path. Diver observations complement the sonar records by the 'calibration' of the side scan images with collected bed material. Probing by divers will confirm the depth of sand cover over rocky material. Underwater videos and photographs can also complement the survey, not only for the planners and designers, but also to enable the public to study real observations along the outfall route and conditions prior to, and after, construction of the outfall.

CLICK TO VIEW GRAPHIC

FIGURE 6.2: Example of a side scan sonar survey providing a graphic picture of the seabed characteristics

iii. Sub-seabed conditions

An outfall may be required to be installed in a trench. The trench may have to be excavated several metres into the seabed at certain locations along its length. The method and cost of trenching will depend on the sub-seabed composition. Normally, seabed conditions beyond the surf zone are reasonably stable and consist of either sandy sediments and/or gravels, which can be excavated relatively easily, or rock, which is difficult and costly to excavate. It is possible for both extremes to be present along the length of an ocean outfall.

Seismic surveys 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. The transducer beams sound down through the seabed, and sub-bottom features reflect a fraction of the sound energy that are received on a hydrophone array that is towed behind the boat. The magnitude of the sound energy reflected depends on the interface between layers with different acoustic properties, including changes in rock type, degree of weathering or major fissures and interfaces (Figure 6.3). The received sound is then transmitted from the hydrophone to a plotter on the survey boat as the boat travels along a predetermined path.

Exploratory drilling is required to verify the results of the seismic survey. Further geotechnical investigation for the detailed design will be required:

- Soil analysis – classification, cohesive and shear strengths, angle of repose (internal friction), density properties
- Rock analysis – classification, hardness
- Seismic stability.

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FIGURE 6.3: Sub-bottom profile derived from a seismic trace

iv. Sediment movement (erosion and sedimentation)

In the surf zone, wave wave-induced turbulence and currents can result in large seasonal changes in the depth of sand, especially during storms. An outfall is normally installed in a trench extending across the shore and surf zone, which is then backfilled so that after completion, the outfall is not exposed. Thus the lowest depth of the sand across the beach and surf zone has to be determined, i.e. the profile resulting from storm erosion, so that the outfall can be securely installed below this level. An example of an 'envelope of variability', that is, the maximum (accretion) and minimum (erosion) levels over time is shown in Figure 6.4.

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FIGURE 6.4: Example of beach profile envelope, showing maximum and minimum profiles

The degree (rate) of sediment transport and the probability of scouring have to be determined using historical data and supplemented with appropriate numerical modelling outputs, if required.

v. Waves

Although wave data is not crucial with regard to the behaviour of the wastewater plume, it is critical for the initial deposition and redistribution of 'solid' phase particles. Wave energy is also the major consideration for the detailed (structural) design of an outfall with regard to the construction phase as well as to the forces to which exposed parts of the outfall will be subjected during its lifetime. Waves are also the crucial factor in determining the sediment dynamics in shallower water and in the shoreline geomorphology. In the case of surf zone discharges, the mixing, transport and dispersion of the wastewater plume are controlled by the breaking waves and the currents generated by waves approaching the shoreline.

Waves are defined in terms of:

Wavelength (λ in metres):	Distance between two wave crests or two wave troughs.
Wave height (H in metres):	Vertical measure between the bottom of a trough and the peak of the crest.
Wave period (T in seconds):	Time required for two crests to pass a fixed point. The period is also expressed as a frequency (Hz) = 1/T.
Wave celerity (c in m/s):	Where $c = (g\lambda/2\Pi)^{1/2}$

In the ocean, ‘waves’ are generated by numerous processes and can range from a period of 1 second (wind chop) to several days (lunar and solar tidal components). The type of waves that are significant for the structural design of an outfall, for the nearshore geomorphology and the hydrodynamics related to the transport and dispersion of the wastewater plume in shallow water are the wind-generated waves or swell, which are generated by the drag of the wind on the sea surface. Along the South African coastline, the wave/swell period is typically in the range of 8 to 14 seconds. The water itself does not proceed with the wave, but moves in circular orbits, clockwise in the direction of the wave (Figure 6.5). The diameter of the orbits reduces with depth until the orbital motion ceases at a depth equal to approximately half the wavelength. In water depths less than half the wavelength, the circular orbits becomes elliptical and wave action starts to act as shear forces on the seabed material or exposed structures such as pipelines. When the orbiting pattern collapses, breakers are formed. Smaller waves with long wavelengths on a gently graded beach slope will spill and lose energy during the run-up, whereas steeper (high, short-wavelength) waves will tend to plunge with a subsequent strong backwash, causing erosion.

The above description of waves refers to a regular wave train. However, the wave regime in the sea is highly irregular and it is very unlikely that two consecutive waves will have exactly the same characteristics with regard to height, length and period. Numerous waves (different frequencies), superimposed on one another, can also occur at the same time and location. Therefore, statistical measures/procedures have to be applied to a wave condition for a certain length of time in order to describe the wave conditions in terms of significant wave height and period. Typically, the statistical parameters to describe wave conditions relate to a recording period at least 20 minutes long:

H_S	= Significant wave height. The average height of the highest 1/3 of the waves in a recording period
T_S	= Significant wave period. The average period of the highest 1/3 of the waves in a recording period
H_{max}	= Maximum wave height. Maximum trough to crest height in a recording period

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FIGURE 6.5: Description of a wave

Energy based parameters (Rossouw, 1984), which are the standard deviation of sea-surface elevation of all the data values obtained from the digital spectral analysis, are:

H_{mo}	= characteristic wave height (m)	
	= $4.m_o^{1/2}$ which is equivalent to $4.\sigma$	
where	m_o	= the area under the wave spectrum
	σ	= square root of the variance
T_p	= Peak energy wave period (s)	
	= $1/f_p$ where f_p is the peak energy frequency (Hz)	

Confusion can arise when H_S and H_{Mo} values are ulitised. CERC (1984) describes this relationship between H_S and H_{Mo} with regard to the influence of water depth on the wave profile. In deep water, H_S is approximately equal to H_{Mo}, but can be at least 30% greater in shallow water for breaking waves. A wave height H for a monochromatic wave train with the same energy as an irregular wave train with a height of H_{Mo} is given as:

$$H = H_{Mo}.2^{1/2}$$

Wave data are typically presented as time-series plots of wave height and period, occurrences and exceedances for wave height and period and persistence of calms and storms. For the structural design of an outfall, maximum wave heights for return periods of 1, 10, 50 and 100 years must be determined with the associated wave periods and wave directions. The persistence curves are important for construction planning and scheduling, as the probability of seasonal durations of calm or storm conditions can be estimated from these curves. To determine seasonal variations, at least one full year's data from the site are needed for correlation with other available long-term data. A standard procedure for measuring wave height is the mooring of a wave measurement buoy (e.g. Waverider) at a representative location along the pipe route. The buoy samples the relative elevation of the sea surface on which it floats at 0.5-second intervals, normally for 20-minute periods each day (at six-hour intervals). The data are transmitted by the buoy to shore station receivers, where they are digitally recorded. Acoustic-Doppler-Current-Profilers (ADCP) are rapidly becoming the norm for measuring wave data as these instruments are also able to measure other parameters, such as temperature and current velocity and direction, through the water column.

Examples of wave data outputs required are provided in Figures 6.6a to 6.6e. Directional wave data can be displayed in a manner similar to the wind rose in Figure 6.11.

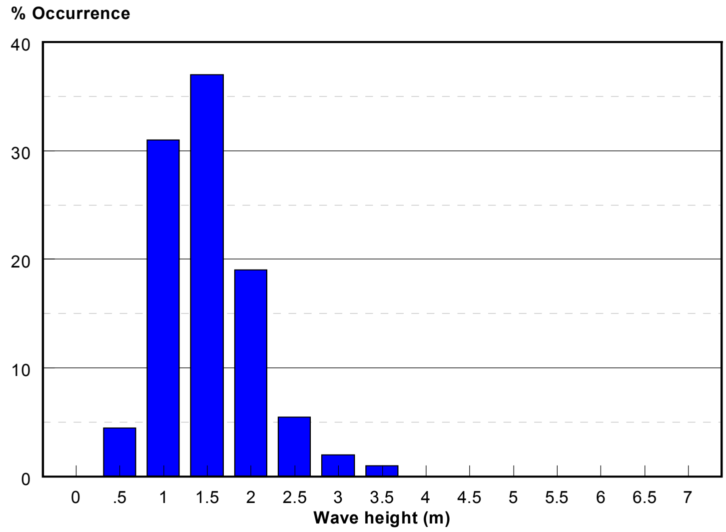

FIGURE 6.6 a: Example: Annual wave height occurrence (%)

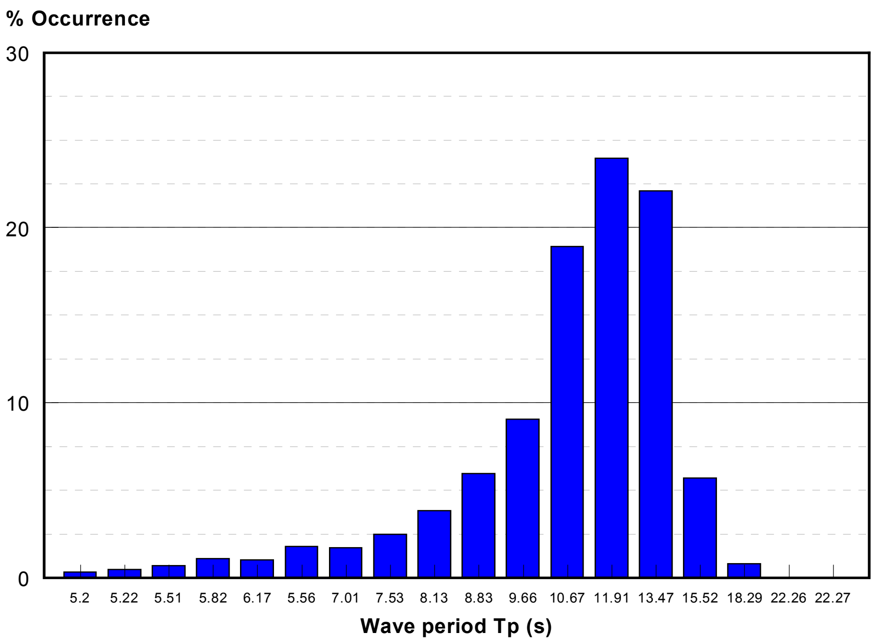

FIGURE 6.6 b: Example: Annual wave period occurrence (%)

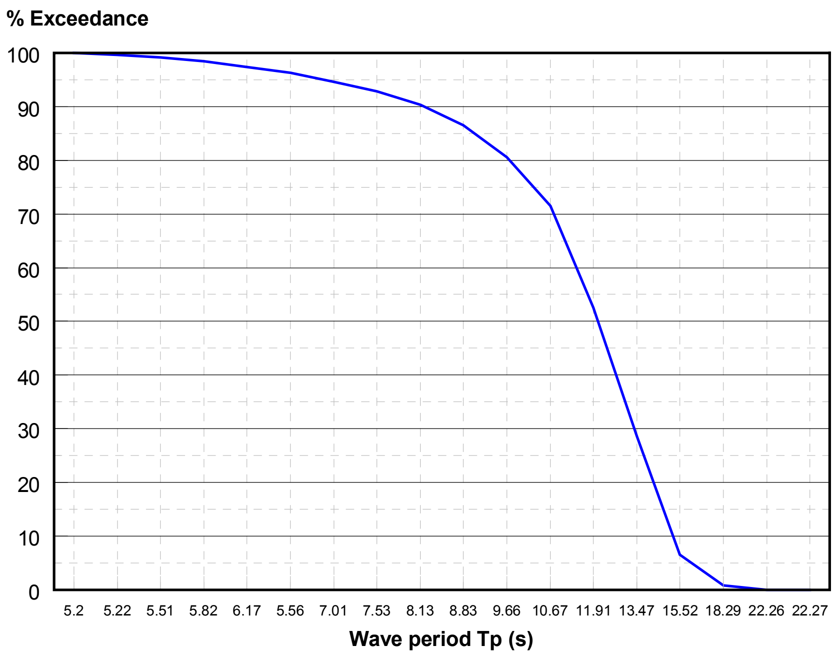

FIGURE 6.6 c: Example: Annual wave period exceedance (%)

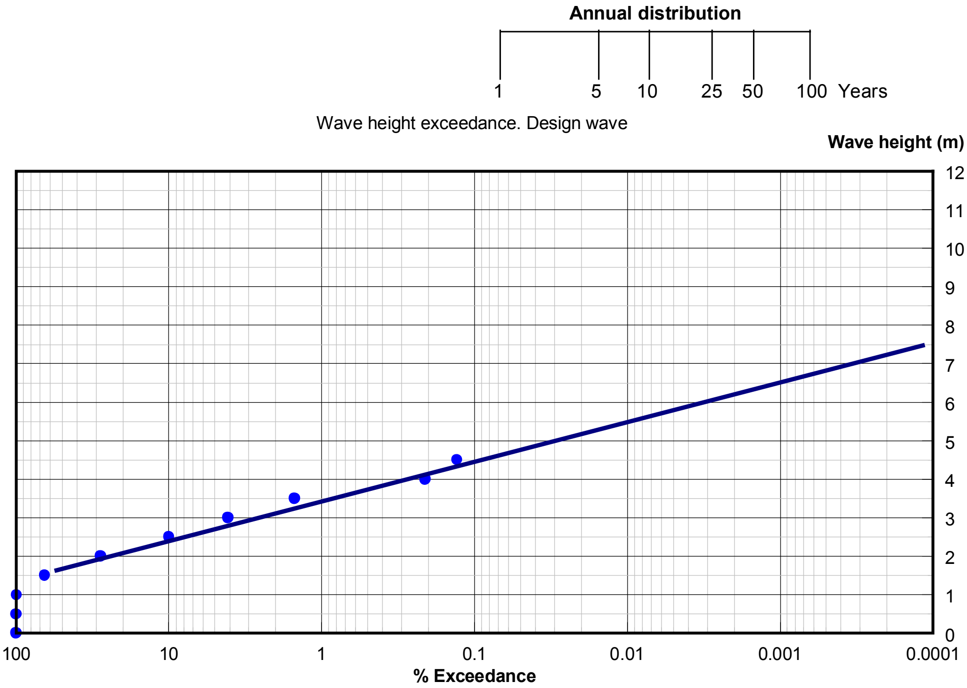

FIGURE 6.6 d: Example: Design wave heights

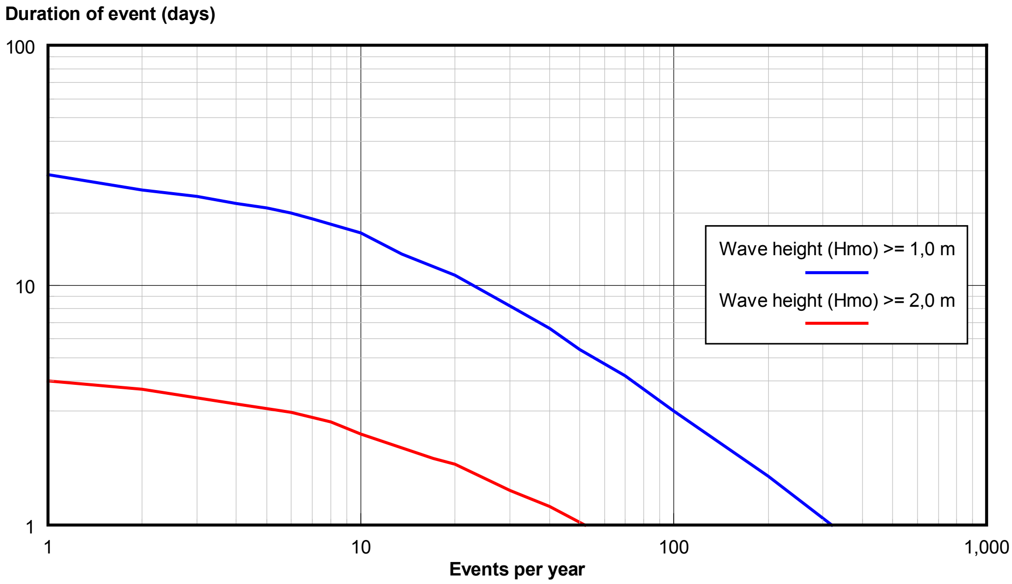

FIGURE 6.6 e: Example: Persistence of storms

A summary of all available wave data along the coast of South Africa up to 1984 was summarised by Rossouw (1984) and is listed in Table 6.1. The variation of wave height along the South African coastline is illustrated in Figure 6.7.

TABLE 6.1: A summary of all available wave data along the coast of South Africa up to 1984 (Rossouw, 1984)

LOCATION	***SIGNIFICANT WAVE HEIGHT (H_s in metres) FOR DIFFERENT % EXCEEDANCES***			***WAVE PERIOD (T_P in seconds) FOR 50% EXCEEDANCE***
	0.01%	***0.1%***	***1.0%***	
Oranjemund	*7.5*	*6.0*	*4.4*	
Saldanha Bay	*7.7*	*6.3*	*4.8*	
Koeberg	*8,3*	*6.5*	*4.8*	*12.8*
Slangkop	*9.3*	*7.5*	*5.6*	*12.5*
Gans Bay	*8.1*	*6.4*	*4.6*	
Mossel Bay	*6.0*	*5.0*	*3.9*	
Durban	*5.8*	*4.7*	*3.5*	
Richards Bay	*5.5*	*4.5*	*3.4*	*11.4*

Source: Rossouw (1984)

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FIGURE 6.7: Wave heights (1% exceedance) along the South African coastline

vi. Wind

Wind is an important phenomenon in that the wind-field can govern the behaviour of surface currents and the subsequent transport (speed and direction) of a buoyant wastewater plume to distant locations. Winds exert a stress on the water surface that is down through the water column by shear between the moving surface water and the lower layers. In the absence of stronger ocean currents, wind-driven currents dominate. Most of the time, the only available long-term data records at a study site are for wind. Long-term wind data records is therefore used to verify the representativeness of detailed, short-term data set measured during the study period, not only short-term wind data, but also other data influenced by wind such as currents. It is important to understand the interaction between the wind and the ocean processes, especially the nearshore circulation characteristics, in the study area.

In the offshore region, the surface wind-induced current vector is approximately 45 degrees left of the wind direction in the Southern Hemisphere, deflecting more to the left as the depth increases (at approximately 10 m depth the direction can be 90 degrees to the left of the wind direction). This phenomenon is related to the earth's rotation and is known as the Coriolis force (Neumann, 1968). In shallower water, the Coriolis effect reduces with subsequent reduction of the deflection of the current direction from the wind direction. This phenomenon is included in 3-D numerical models used for detailed investigations. For pre-assessment studies, the wind-induced surface current can be taken as 3% of the wind speed (Williams, 1985). For the transport of floatable material on the surface, a value of 7% can be used.

In the case of shallow outfalls (e.g. surf zone discharges), the diurnal land and sea breezes (resulting from the difference in temperature between the land and the sea) will result in diurnal changes of the transport (onshore/offshore) of surface waste fields (Figure 6.8). During the day the land temperatures will be higher than the sea temperatures, causing the air to rise over the land and cooler air from the sea to flow towards the land. The maximum temperature difference between the land and the sea will occur at approximately 15h00, with the sea breeze at its maximum velocity (Hydrographic Office, 1994). During the summer, the onshore wind will prevail from early morning to midnight, the season and the time of day when the South African beaches are heavily utilised for recreation. During the winter, the sea breeze will occur from noon to early evening. Typical conditions in Algoa Bay are illustrated in Figure 6.9 (Hydrographic Office, 1994).

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FIGURE 6.8: Land and sea breezes (Hydrographic Office, 1994)

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FIGURE 6.9: Typical diurnal land- sea breeze variations (Hydrographic Office, 1994)

Wind speed and direction are measured by automatic wind recorders connected to data loggers. Wind speed and direction at almost any predetermined sampling interval can be digitally recorded, transferred to a computer and processed. The coastal topographic features may have a local effect on the prevailing wind-fields and, in the case of a complex coastline configuration, several such recorders should be operated around a proposed outfall area to avoid biased results that may be brought about by sheltering or deflection of winds by topographic features.

Typical data outputs include annual and seasonal wind speed and directional occurrences as shown in Figure 6.10. An example of a wind-rose is shown in Figure 6.11. Exceedance data are presented in a similar manner to that for waves (refer to Figures 6.6a to 6.6e).

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FIGURE 6.10: Example of graphs showing speed and direction occurrence of wind

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FIGURE 6.11: Wind-rose, showing the typical wind direction and speed at a particular site

The Hydrographic Office (1994) provides monthly wind direction occurrences for a number of coastal locations, based on more than 20 years of data. The mean annual occurrences of wind direction and speed for selected locations are presented in Table 6.2 and illustrated in Figure 6.12.

TABLE 6.2: Mean annual occurrences of wind direction and speed for selected locations along the South African coastline

LOCATION	PERCENTAGE OCCURRENCE FOR WIND DIRECTIONS									MEAN SPEED (m/s)	
	N	NE	E	SE	S	SW	W	NW	Calm	8h00	14h00
Port Nolloth	3	1	2	5	32	5	2	8	43	2.1	5.7
Cape Columbine	7	6	2	12	42	10	4	10	7	4.6	6.2
Cape Town	7	3	0	10	28	10	3	16	23	3.1	6.2
Cape Point	4	6	3	33	9	14	10	13	8	9.3	8.2
Agulhas	1	10	17	12	6	16	23	8	7	4.6	6.2
Mossel Bay	3	5	9	12	8	29	10	15	9	4.1	6.2
St. Francis	2	5	20	3	3	9	40	5	13	5.1	7.2
Port Elizabeth	2	6	15	5	5	23	20	3	21	3.6	7.2
East London	5	16	11	4	7	18	17	7	15	3.6	6.2
Port Shepstone	7	27	3	2	5	25	5	12	14	3.6	6.7
Durban	7	19	6	3	13	15	2	2	33	2.1	5.7
St.Lucia	9	22	4	10	11	14	6	17	7	5.7	7.2

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FIGURE 6.12: The coastal wind regime (Hydrographic Office, 1994)

vii. Tides

The astronomical tides together with the nearshore bathymetry and the coastline configuration are amongst the most influential and significant factors governing the nearshore hydrodynamics and the hydrodynamics of estuaries and bays. Tidal variations (ranges) also have to be taken into account in the hydraulic design with respect to the available head (pressure or gravity) required to discharge the wastewater.

The dominant tide is semidiurnal (period of approximately 12 hours and 20 minutes). Differences between high and low water can range from 2 m during spring tide (full moon and new moon) to 0,5 m at neap tide. The lowest and highest astronomical tides predicted for South African coastal towns, based on 19 years of data, are given in Table 6.3 (SAN, 2003). These levels can be exceeded when extreme meteorological conditions coincide with the neap and spring tides.

TABLE 6.3: Approximate spring tide ranges for the main South African coastal towns

PLACE	*LOWEST ASTRONOMICAL TIDE (LAT) (m)*	*HIGHEST ASTRONOMICAL TIDE (HAT) (m)*
Port Nolloth	*0*	*2.41*
Saldanha Bay	*0*	*2.03*
Cape Town	*0*	*2.02*
Simon's Town	*0*	*2.09*
Hermanus	*0*	*2.07*
Mossel Bay	*0*	*2.44*
Knysna	*0*	*2.21*
Port Elizabeth	*0*	*2.12*
East London	*0*	*2.08*
Durban	*0*	*2.30*
Richards Bay	*0*	*2.47*

A typical tidal record for South African conditions is illustrated in Figure 6.13.

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FIGURE 6.13: Typical tidal record for South African conditions measured at Knysna

viii. Coastal currents

The South African coastline is bounded by two major circulation systems, these are the ‘warm’ south-bound Agulhas Current along the east and south coast and the ‘cold’ north moving Benguela System along the west coast (Figure 6.14). The Agulhas Current is powerful: at the surface it can reach maximum speeds of 2 m/s (Gyory *et al.*, 2000). As the Agulhas Current reaches the southern tip of Africa, it begins to turn toward the southwest. Once it reaches the Southern Ocean, the current retroflects, or turns back on itself, and flows eastward as the Agulhas Return Current.

The Benguela Current is the eastern boundary current of the South Atlantic subtropical gyre (Shannon, 1985). It begins as a northward flow off the Cape of Good Hope, skirts the western African coast equator-wards to about 24°S-30°S from where it moves further offshore. The sources of the Benguela System include Indian and South Atlantic subtropical thermocline water; saline, low-oxygen tropical Atlantic water; and cooler, fresher sub-antarctic water. Shannon (1985) gathered all available information on surface current speeds from previous studies and calculated the mean speed of the Benguela System to be 17 cm/s. Wedepohl *et al*. (2000) found that the mean speeds of the current vary from less than 11 cm/s to a maximum of 23 cm/s. Apparently the highest speeds occur in the south during summer and in the north during winter, a pattern that corresponds with seasonal wind fields. The prevailing winds are responsible for strong Ekman transport and the resulting coastal upwelling of cool, nutrient-rich water that stimulates primary productivity (Boyer *et al*. 2000; Skogen 1999).

Although the main ocean currents along the east coast of South Africa are much more dynamic than the currents along the west coast, the inshore circulation (less than 40 m water depth) is mostly tidal and wind driven. This was demonstrated by using drogues to determine surface current velocities at various locations along the South African coastline between 1980 and 1992 (CSIR 1986, CSIR 1988, CSIR 1991b, CSIR 1992). Data gathered for a minimum of one year at each location are presented in Table 6.4.

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FIGURE 6.14: South Africa's major coastal circulation systems

TABLE 6.4: Measured surface current velocities at various locations along the South African coastline based on drogue tracking between 1980 and 1992 (minimum 1 year)

LOCATION	*DISTANCE FROM SHORE*	*AVERAGE CURRENT SPEED (cm/s)*	
		SURFACE	*SUB-SURFACE (-5 m)*
North West Bay (north of Saldanha)	*2 km*	*20*	-
	6 km	*30*	-
Hout Bay	*1 km*	*16*	*11*
False Bay	*2 km*	*17*	*9*
	5 km	*15*	*9*
Mossel Bay (Dana Bay)	*1 km*	*18*	*12*
	2 km	*21*	*15*
East London			
Tongaat	*1,2 km*	*18*	*15*
	1,9 km	*23*	*20*

Offshore. The offshore circulation characteristics (speed and direction of currents) are the main oceanographic processes that would influence the initial dilution of a buoyant wastewater stream and its subsequent transport and dispersion to distant locations. The seasonal variation in current speeds also influences the selection of the appropriate method of construction and the structural design of the outfall.

The net (resultant) current which will transport and disperse a waste field is the result of a complex of numerous driving forces. These forces include the local wind forcing, ambient continental currents (for example the Agulhas current), surf zone long-shore and rip currents generated by waves, tidal currents and density differences. In the nearshore zone, the circulation is strongly influenced by the seabed topography and the configuration of the coastline.

Measurement of currents at sea is complicated because of the varying spatial and temporal nature of currents. The ultimate (resultant) current measured is a composite of numerous driving forces. Instantaneous measurements cannot be compared directly with the various generating forces because, for example, currents measured during a particular wind condition may be unrelated to that condition since they may still be subject to the inertia of a previous wind forced circulation. All these and other effects require that any current measurement programme be carefully designed to avoid bias.

Eulerian measurements are continuous recordings of current data collected at pre-determined time intervals by the use of moored current meters at fixed points in the study area. Eulerian data provide the basis for statistical estimates of occurrence and persistence of current speed and direction. Typically the information is measured and recorded by the instrument at 15-minute or 30-minute intervals. Moored current meters use a variety of methods for sensing speed and direction and it is important to understand the limitations and performance of each type of meter when designing a current recording programme. Current profilers, lowered to a specific depth from an anchored platform or vessel, can also be used. If the survey vessel is allowed to drift during the current measurement, accurate position fixing (using global positioning fixing (GPS) techniques) must be recorded as the drift vector must be vectorially subtracted from the measured velocity to produce the true ambient current vector.

Lagrangian measurements include spatial studies with drogues, drifters, or dye, in which the path and velocity of a particle are determined. Surface and subsurface current recordings can be made by the tracking of the movement of floats (Lagrangian) in the current field at the outfall location. Floats consist of either drogues or drift cards. Dye patch observations are also sometimes used.

Drogues are surface or subsurface floats, identified by a flag number, which drift with the current. Drogue pairs (surface and subsurface) are released at pre-determined locations around a proposed pipeline/diffuser to detect the probable path of the surface wastewater plume. A survey vessel equipped with GPS is used to track the drogues. The actual surface and subsurface current vectors for the particular day of observation can be obtained. Vectors from various drogues are then combined to produce a reliable indication of the general current pattern on that particular day. These results can also be used for the spatial calibration of a far field numerical model.

Radio drogues that transmit a signal to the shore at a predetermined frequency can also be used for larger scale spatial observations. At three shore stations, directional receivers are tuned to receive the signal and thereby provide an accurate fix of the drogue’s location.

In the design of drogues, the influence of the wind on the above-water part and the influence of the current on the nylon line connecting the float has to be minimised to ensure that current measurements are not seriously affected (Botes, 1988).

Drift cards are plastic cards, typically 10 x 15 cm in dimension, that are dumped in lots of 200 at a time at specific locations. The fate of the cards is recorded by the location and time of their deposit on the shoreline. This is used as a crude but effective way of predicting what the fate of a surface wastewater release at the same location would be. Cards of various colours can be dropped from different proposed outfall locations. The results are meaningful but cannot be used for quantitative assessments.

Dye patches provide another method of recording surface current patterns. A quantity of concentrated dye (such as Rhodamine-B dye) is released at a specific location or at several locations in the study area. The movement and spreading of the dye patch is then monitored by aerial photography or by tracing the perimeter of the patch using a survey vessel equipped with GPS.

Typical graphical output data for understanding the nearshore circulation processes for the optimisation and assessment of the potential impact of marine discharges include:

- Time series data for current velocities, directions and vectors (Figure 6.15)

- Current roses or a scatter diagram summarising the directional behaviour (refer to Figure 6.16)
- Current profiles showing the vertical variation in current velocities in the water column (Figure 6.17)
- Tracer (e.g. Rhodamine-B) data demonstrating the spatial behaviour of a wastewater plume under specific current conditions (Figure 6.18)
- Radio-buoy tracks recording the direction and speed of surface and sub-surface currents in a study area (Figure 6.19).

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FIGURE 6.15: Time series data for current velocities, directions and vectors

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FIGURE 6.16: Current scatter diagram

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FIGURE 6.17: Example: Current Profile

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FIGURE 6.18: Prototype tracer studies

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FIGURE 6.19: Circulation patterns recorded over three days in False Bay using radio-buoy tracking (Botes, 1988)

Surf zone. Currents in the surf zone (littoral zone) are wave-dominated, and initial mixing is rapid due to the vigorous processes of which long-shore and cross-shelf transport are the most dominant. 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, which will result in the diffusion of surf zone water into the offshore waters. For wave fronts parallel to the coast, symmetrical circulation ‘cells’ will be formed and the surf zone width will be determined by factors such as the wave height/period and the beach slope. For example, along the Kwazulu-Natal coastline average cell widths of 600 m, with rip currents 30 to 60 m wide and offshore velocities varying between 0.3 m/s and 1 m/s, have been recorded (NTRPC, 1969). Results showed that some of the rip current water is forced back into the cells by the onshore wave transport. Observations along the Kwazulu Natal coastline indicate a typical offshore flow of approximately 400 m (NTRPC, 1969). In the case of oblique waves, the circulation ‘cells’ will be asymmetrical and the tendency is for the rip currents to flow to the downstream cell only. Some of the water expelled beyond the surf zone may be transported back into the surf zone by the next set of waves. It is important to note that onshore winds and the incoming tide will tend to keep water in the surf zone, whereas offshore winds and the outgoing tide will contribute to the transport of water away from the shoreline.

Estuaries. There are about 250 estuaries in South Africa that fall within the definition of an estuary (see *Glossary of Terms*) (Whitfield, 1992). The water movement (hydrodynamics) and related processes in South African estuaries will depend on the status (open or closed) of the estuary mouth. About 75% of South Africa’s estuaries are temporarily open/closed systems.

In permanently open estuaries, the flow in the estuary and the subsequent exchange of water between the estuary and the sea is dependent on the diurnal and semi-diurnal differences in water levels in the estuary and in the sea (due to tidal variation), the ‘size’ (cross-sectional area) of the estuary mouth and the volume and timing of source inflows (e.g. river inflow). Salinity distribution patterns in the estuary also affect hydrodynamic behaviour associated with the density difference between saline and freshwater. Usually, in deeper estuaries, the more dense seawater creates a salt wedge along the bottom, resulting in strong vertical stratification. In a shallower system, however, the strong tidal currents are usually sufficient to break down any vertical stratification, resulting in a well-mixed system. Each estuary has a unique salinity regime, which continuously changes according to the state of the tide and freshwater inflows. The fresh and saline water structure of a ‘partially-mixed’ estuary is illustrated in Figure 6.20.

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FIGURE 6.20: Illustration of vertical mixing in an estuary

In temporarily open/closed estuaries, in which the mouth is closed for periods when there is little or no river inflow, the water movement will depend mainly on wind stress. Elevated water levels resulting from river inflows and possible seawater input from waves overtopping the sandbar at the mouth during storms and spring tides, also play a role in the water movement within these systems. The only exchange to the sea then will be through seepage. When the mouth is open, the dynamics will be similar to those of permanently open estuaries. However, as the river inflow declines, the volume of water exchanged through the estuary mouth is reduced. Ultimately, the estuary mouth will be closed by sand transported by a combination of wave and tidal energy.

ix. Stratification

Stratification is the term used to describe the phenomenon of denser sea water underlying lighter sea water thereby causing a vertical density gradient in the water column, depending on the vertical temperature gradient between warmer upper water layers and colder deeper water (thermocline) and the salinity gradient (halocline). Seawater density is a function of temperature, salinity and pressure (depth). An example of the relationship between temperature, salinity and depth is shown in Figure 6.21.

Density stratification is the major factor that influences the rising of a buoyant wastewater plume and thus determines whether the discharge from an ocean outfall remains beneath the surface as a submerged field or continues to rise to become a surface field.

The conversion formula to calculate the density as a function of temperature, salinity and depth (ρ_{STP}) is as follows:

$$\rho_1 = 999.842594 + 0.06793952T – 0.00909529T^2 + 0.0001001685T^3 + -0.000001120083T^4 + 0.000000006536332T^5$$

$$\rho_2 = \rho_1 + S(0.824493 – 0.0040899T + 0.000076438T^2 – 0.00000082467T^3 + 0.0000000053875T^4) + (-0.00572466 + 0.00010227T – 0.0000016546T^2) \times S^{3/2} + 0.00048314S^2$$

$$K_1 = 19652.21 + 148,4206T – 2.327105T^2 + 0.01360477T^3 – 0.00005155288T^4$$

$$K_2 = 3.239908 + 0.00143713T + 0.000116092T^2 – 0,000000577905T^3$$

$$K_3 = 0.0000850935 – 0.00000612293T + 0.000000052787T^2$$

$$K_{ST0} = K_1 + S(54.6746 – 0.603459T + 0.0109987T^2 – 0.00006167T^3) + (0.07944 + 0.016483T – 0.00053009T^2).\ S^{3/2}$$

$$A = K_2 + S(0.0022838 – 0.000010981T – 0.0000016078T^2) + 0.000191075S^{3/2}$$

$$B = K_3 + S(-0.00000099348 + 0.000000020816T + 0.00000000091697T^2)$$

$$K_{STP} = K_{ST0} + A \times D/9.81 + B \times (D/9.81)^2$$

$$\rho_{STP} = \rho_2 / [(1-D/9.81)/K_{STP}]$$

Where:

T = Temperature (^oC)
S = Salinity (ppt)
D = Water depth (m)

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FIGURE 6.21: Seawater density versus temperature and salinity

Warming of the surface waters as a result of solar radiation, upwelling of colder deep ocean water (particularly on the west coast) and the movement of warmer (less dense) water towards the coast because of ambient ocean currents (an east coast phenomenon), typically cause stratification along the South African coast. An overview of the winter and summer sea surface temperatures along the South African coast is shown in Figure 6.22 (Hydrographic Office, 1994).

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FIGURE 6.22: Typical sea surface temperatures along the South African coast for summer and winter (Hydrographic Office, 1994)

Between 1980 and 1992, temperature and salinity profiles were measured for a minimum of a year at various locations along the South African coastline (CSIR 1985, CSIR 1986, CSIR 1988, CSIR 1991b, CSIR 1992). These are summarised in Table 6.5.

TABLE 6.5: Temperature (in ^{o}C) and salinity (in ppt) profiles measured at various locations along the South African coastline based on drogue tracking between 1980 and 1992 (minimum 1 year)

LOCATION	*DISTANCE FROM SHORE (km)*	*WATER DEPTH (m)*	*TEMPERATURE (SURFACE)*			*TEMPERATURE (BOTTOM)*		
			Maximum	*Minimum*	*Average*	*Maximum*	*Minimum*	*Average*
North West Bay	*2*	*30*	*15.5*	*9.3*	*12.3*	*11.4*	*9.4*	*10.3*
	4	*35*	*15.3*	*9.3*	*12.5*	*13.0*	*8.8*	*10.6*
Hout Bay	*1*	*30*	*16.6*	*10.4*	*14.0*	*15.9*	*9.7*	*12.2*
False Bay	*2*	*20*	*21.1*	*13.8*	*17.8*	*20.3*	*12.4*	*15.9*
	5	*30*	*21.0*	*14.5*	*17.7*	*16.1*	*12.0*	*14.3*
Mossel bay	*1*	*20*	*21.6*	*15.2*	*18.0*	*21.0*	*13.6*	*16.7*
	2	*40*	*21.2*	*15.7*	*18.0*	*18.2*	*11.3*	*15.6*
Tongaat	*1,2*	*26*	*24.8*	*18.5*	*21.17*	*24.2*	*16.4*	*20.7*
	1,9	*34*	*24.7*	*18.7*	*21.3*	*24.2*	*16.1*	*21.0*

LOCATION	*DISTANCE FROM SHORE (km)*	*WATER DEPTH (m)*	*SALINITY (SURFACE)*			*SALINITY (BOTTOM)*		
			Maximum	*Minimum*	*Average*	*Maximum*	*Minimum*	*Average*
North West Bay	*2*	*30*	*36.25*	*34.86*	*35.28*	*35.35*	*35.03*	*35.13*
	4	*35*	*37.44*	*34.60*	*35.29*	*36.52*	*34.20*	*35.23*
Hout Bay	*1*	*30*	*35.45*	*33.80*	*35.06*	*35.75*	*33.60*	*35.10*
False Bay	*2*	*20*	*35.78*	*34.50*	*35.46*	*35.74*	*35.00*	*35.46*
	5	*30*	*35.96*	*34.50*	*35.36*	*35.67*	*35.00*	*35.32*
Mossel Bay	*1*	*20*	*35.40*	*35.02*	*35.20*	*35.48*	*35.50*	*35.34*
	2	*40*	*35.48*	*35.00*	*35.19*	*35.04*	*35.15*	*35.38*
Tongaat	*1,2*	*26*	*35.45*	*33.6*	*35.01*	*35.45*	*34.43*	*35.1*
	1,9	*34*	*35.39*	*33.57*	*34.94*	*35.72*	*34.35*	*35.08*

In order to detect stratification in the water column, both temperature and salinity profiles should be measured since seawater density is a function of both properties. The stratification measurements should also be done on a similar grid as that used for the current measurements. It is convenient to attach the small temperature and salinity probes to the current profiler to maximise the information obtained from each measured profile.

Stratification is calculated from measured (recorded) vertical profiles of temperature and salinity. Conductivity-Temperature-Depth (CTD) profilers can be used for measurements from a survey boat. For input data to numerical models, continuous records (pre-determined time intervals) are required and can be obtained from the deployment of a thermistor string, consisting of temperature and conductivity/salinity probes, located at regular depth intervals through the water column.

Normally, stratification in the surf zone area will be insignificant because of the vigorous movement and the consequent high degree of mixing. Horizontal density differences may occur as a result of solar heating in sheltered shallow waters.

Depending on the mouth and river flow characteristics of estuaries, the horizontal and vertical distributions of salinity and temperature contribute to a complex distribution of density and the stratification varies continuously with the tidal flow, river discharge, wind shear and solar radiation. An example of the distribution of salinity and temperature measured in the Breede River Estuary on 23 August 2000 is illustrated in Figure 6.23 (CSIR, 2002).

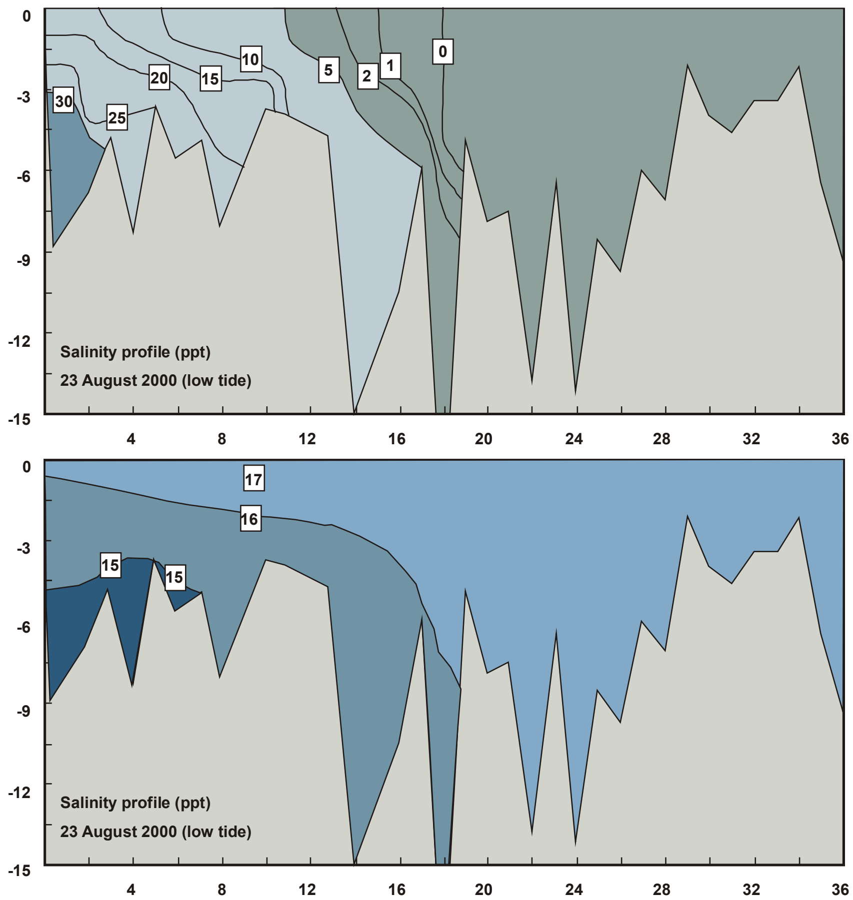

FIGURE 6.23: Salinity and temperature distribution patterns in the Breede River Estuary on 23 August 2000 (CSIR, 2002)

6.1.2 Data requirements for pre-assessment and detailed investigation

i. Pre-assessment

A pre-assessment is usually based on available data and information on the relevant physical processes, as described in Section 6.1.1. In particular, the following important data and information should be obtained:

- Observations of site-specific features, such as coastline configuration and shoreline/beach characteristics, rocky/sandy offshore areas, existing structures/obstructions, navigational routes etc.
- Existing topographical maps (1:50 000), bathymetric charts/surveys, aerial photographs
- Wind data from the nearest weather stations
- Existing wave and tidal data
- Any available data on water circulation and stratification. Where available data are insufficient, some short-term observations, using drogues or dye, can be conducted.
- Identification of potential depositional areas. These typically include areas in which current velocities are low or are protected from wave action. Sediments in these areas usually consist of fine particles.

As part of a pre-assessment, the following items need to be addressed:

- The selection of a feasible outfall site with regard to the proposed location of the head works and a feasible pipeline route (seabed slope, seabed geology, discharge depth and other physical constraints such as existing structure, wrecks, navigational routes, etc.)
- Average, maximum and minimum current velocities at the proposed outfall site for spring, mean and neap tides
- Directional occurrences and average, maximum and minimum current velocities (of particular importance is the onshore directional occurrence and the maximum velocities)
- Diurnal and seasonal variations and the spatial behaviour of the currents (average and maximum current speeds, directional occurrences)
- Wind regime (maximum and average speed, directional occurrences, seasonal and diurnal variations and persistence)
- Wave statistics (wave height and directional occurrences)
- Worst case stratification and the occurrence of density differences through the water column
- Tidal range, mean sea level, tidal currents (in the case of estuaries, the tidal prism for the different tides also needs to be determined)
- Studies involving temporarily open/closed estuaries also require an assessment of the percentage of time when the estuary mouth is likely to close.

A basic overview of statistical techniques that are typically applied in the evaluation of environmental data, where and when appropriate, is provided in Section 7.4.2. It highlights important factors that need to be taken into account when applying statistical analyses to data sets and is by no means exhaustive.

ii. Detailed investigations

A detailed investigation requires intensive field measurement programmes to acquire the data and information on the relevant physical processes, as described in Section 6.1.1. In particular, the following important data and information should be obtained:

- Geophysical data. The following surveys need to be undertaken:
  - Precision bathymetric survey
  - Side scan sonar and seismic profiling
  - Geotechnical investigations (Sea bottom material and exploratory drilling)
  - Surf zone investigation and sediment movement.

- Wind data. Wind recording at the proposed site (one-year deployment of automatic weather station).
  Long-term wind data from nearby weather station need to be correlated with on-site weather station.

- Wave data. Wave recording at the proposed site (one-year deployment of wave buoy or an alternative device). Long-term wave data from nearby recording location to be correlated with on-site wave recordings.

- Current data. The acquisition of quality field data on near-shore currents is extremely costly and time consuming as it must be ensured that the measured data are representative with regard to speed, direction and persistence. It is imperative, therefore, to ensure that all existing data for a specific area have been thoroughly researched, documented and analysed before embarking on any new measurement programme.

  Continuously recording current meters, capable of taking measurements throughout the water column, moored at a number of locations would be the ideal method for describing the current field. However, due to constraints such as the cost of meters, security of meters near the surface, and logistical difficulties in operating several dozen simultaneously recording current meters, compromise is usually necessary. A limited measurement programme, although not ideal, is in most cases sufficient for the design procedures. A limited measurement programme typically consists of:

  - A few moored continuously recording current recorders along and perpendicular to the axis of the proposed diffuser
  - Spatial current profiling from a survey boat at regular intervals (weekly, monthly) at selected locations
  - Regular surface and subsurface current measurements using drogues, dye or drift cards.

  (The output of a calibrated numerical model could be used to supplement the limited current measurements, i.e. provide more extensive spatial information.)

  NOTE:

  The measurement programme must also be arranged to reflect seasonal and other cyclical current trends adequately and have a typical duration of 12 or 18 months if previous data are not available.

- Stratification. Spatial profiling (salinity, temperature, depth) should be undertaken at regular intervals to coincide with the current measurements. A thermistor string is to be deployed together with the continuously recording current meters.

In estuaries, longitudinal profiles of salinity and temperature variations at high and low water, both at springtide and at neap tide, are required. Simultaneously gauging of the river flow, and of water level variations near the mouth, need to be undertaken.

The following outputs are required as part of a detailed investigation:

- Geophysical investigation.

  The following are required:

  - Detailed bathymetric charts and contour maps
  - Profile of the seabed along the pipeline route
  - Map of seabed features (sand, rock, etc.)
  - Sub-bottom profile (seismic interpretation supported by diver investigations)
  - 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)
  - Sediment transport rates (together with potential scour/accretion probabilities) in the surf zone

- Nearshore circulation, wind, tides and stratification. For a detailed investigation, a 2-D or preferably a 3-D numerical model for the simulation of the composite hydrodynamic processes over the entire project area needs to be applied. This assessment also forms the basis for other process models such as a water quality model for detailed assessments of waste fields for the optimisation of the design of a marine outfall or the impact from an existing outfall(s).

  A state-of-art numerical model will include equations for the simulation of the majority of driving forces:

  - Tidal forcing
  - Surface wind shear stress
  - Seabed shear stress
  - Coriolis force (effect of earth's rotation)
  - Barotropic effects (free surface gradients)
  - Baroclinic effects (horizontal pressure gradients)
  - Water with variable density
  - Turbulence-induced mass and momentum fluxes
  - Thermocline dynamics
  - Insolation and air-sea interactions
  - Drying and flooding in shallow areas.

To assess advection-diffusion, the typical hydrodynamic differential equations for numerical applications (finite difference or finite element methods) are:

For the conservation of momentum (equation of motion) in the x- and y-planes:

$$\partial u/\partial t + u.\ \partial u/\partial x + v.\ \partial u/\partial y + g.\ \partial \eta/\ \partial x - f.v + g.u|U|/c^2 - F_x/(\rho(d+\eta)) - \upsilon(\partial^2 u/\partial^2 x + \partial^2 u/\partial^2 y) = 0 \text{..... in x-direction}$$

$$\partial v/\partial t + u.\ \partial v/\partial x + v.\ \partial v/\partial y + g.\ \partial \eta/\ \partial y - f.u + g.v|U|/c^2 - F_y/(\rho(d+\eta)) - \upsilon(\partial^2 v/\partial^2 x + \partial^2 v/\partial^2 y) = 0 \text{...... in x-direction}$$

For the conservation of mass (continuity of flow):

$$\partial \eta/\ \partial t + \partial[(d+\eta)u]/\ \partial x + \partial[(d+\eta)v]/\ \partial y = 0$$

The advection-diffusion equation is:

$$\partial C/\partial t - \partial/\partial x[D_x.\ \partial C/\partial x - u.C] - \partial/\partial y[D_y.\ \partial C/\partial y - v.C] - \partial/\partial z[D_z.\ \partial C/\partial z - w.C] = S$$

Where

η	= water level elevation
d	= water depth
u,v,w	= velocity in 3 planes
U	= total current velocity
$F_{x,y}$	= external forces
f	= Coriolis parameter
g	= acceleration due to gravity
ρ	= water density
υ	= eddy viscosity
c	= Chezy coefficient
D_{xyz}	= dispersion coefficient
C	= concentration of constituent
S	= source term

The hydrodynamic model is used to calculate (predict) the water levels and current velocities over the model grid. The model provides the hydrodynamic and dispersion data for further application of water quality models, which simulate the chemical behaviour of ambient as well as introduced (from waste streams) constituents.

The required temporal investigations (the period for which conditions are simulated), the total area to be investigated and the complexity of the bathymetry will determine the dimensions (spatial extent and the grid size) of the model.

The hydrodynamic model should be calibrated with measured Eulerian as well as Lagrangian current measurements and a stratification dataset. For the verification of the model results, a separate dataset should be used. A sensitivity test should be undertaken to determine the sensitivity of the model outputs to uncertainties in input parameters and model assumptions. Examples of spatial outputs of current velocities and temperature distribution from a 3-D model are shown in Figures 6.24a and 6.24b.

The output of the numerical model, as well as the statistical analysis of the data, is used to determine ambient current velocities for the structural design of a marine outfall.

Numerical modelling of the surf zone hydrodynamics is complex and it is not easy to calibrate and verify the model because of the continuous physical changes (beach profiles) and continuously varying shallow water flows, driven mainly by the approaching waves. Surf zone modelling provides results/outputs that tend to be qualitative rather than quantitative.

Conditions in estuaries are complex and are dependent largely on tidal variations, wind shear, and river inflow. Longitudinal and lateral variations in salinity, and hence in water density, can have a significant effect on estuarine dynamics, mixing and subsequent water quality (SEPA, 2002). Selection of an appropriate numerical model with the capability of reproducing these features (if present) is essential.

For a well-mixed ‘narrow’ estuary, the components of acceleration and velocity in the transverse and vertical directions are considered small enough to be neglected and a 1-D model can be used to predict the flows/water exchange in the estuary, assuming average cross-sectional flows. For wider well-mixed estuaries, a 2-D depth-averaged model can be applied. For partially mixed estuaries (vertical salinity variations), a 3-D hydrodynamic model is essential and the water quality model must be capable of simulating the complex chemical processes (Van Ballegooyen *et al.*, in press).

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FIGURE 6.24 a: Example: Spatial output from a 3-D numerical model, showing current velocities and direction

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FIGURE 6.24 b: Example: Spatial output from a 3-D numerical model, showing temperature distribution

A theoretical schematisation for a 1-D model for estuaries, with motion in the horizontal plane, can be expressed in the following differential equations:

Along the estuary, choosing the x-axis in the upstream direction, the equation for motion at time t is:

$\partial h/\partial x \quad = 1/(g.A).\ \partial Q/\partial t - |Q|Q/(C^2.A^2.R) + 2b.Q/(g.A^2).\ \partial h/\partial t + W_x/(\rho.g.R)$

The equation for continuity of flow is:

$\partial Q/\partial x \quad = -b.\ \partial h/\partial t$

Where:

h	= water level (m)
x	= Distance upstream (m)
Q	= Flow (m^3/s)
A	=Cross-sectional area (m^2)
b	= Stream width (m)
t	= Time (s)
C	= Chezy coefficient for friction
R	= Hydraulic radius (m)
W_x	=Wind factor = τ_W Cos θ
τ_W	= Wind shear stress = $\rho_{air}.\ C_D.\ V_{10}^2$
C_D	= Drag coefficient = $0.5.V_{10}^{1/2}.10^{-3}$
V_{10}	= Wind velocity, 10 m above water surface (m/s)
θ	= Angle between the wind and the channel direction
ρ	= Water density (kg/m^3)

All the differential quotients (example $\partial h/\partial x$) can be replaced with finite difference quotients for example:

$\partial h/\partial x \quad = (h(x + \Delta x,t) – h(x – \Delta x,t))/2\Delta x$ (a central difference approximation)

The two equations can be solved using explicit numerical methods (unknown values of h and Q at a certain time are expressed directly in terms of the known values at previous time steps) or implicitly (solving of the unknown values of h and Q over the entire model area).

For the computation of the concentration of water quality constituents (e.g. nutrients or trace metals), the change in the load (volume *x* concentration) with time can be expressed as the diffusive and advective transport in the equation below:

$\partial(V.C_C)/\partial t \quad = \partial(A.k.\ \partial C_C/\partial x)/\partial t.dx - \partial(A.u.\ C_C/\partial x)/\partial\ x.dx$

Where:

V	= Volume (m^3)
C_C	= Concentration (kg/m^3)
k	= Diffusion coefficient (m^2s)
u	= mean velocity (m/s)

Terms to represent microbiological decay or point source loads can be added to the model as required.

A 1-D numerical model is a fairly simple technique, easy to apply, and if the estuary can be classified as 1-dimensional, provides valuable information with regard to the hydrodynamics and the subsequent mixing and transport of a point source. An example of the outputs (water levels, flows and velocities) of a calibrated 1-D model at three locations for the Swartkops River Estuary (Figure 6.25) is provided in Figure 6.26. The differences in flow and stream velocities at the three locations clearly indicate the importance of the spatial selection of an outfall location with regard to the mixing and transport of a wastewater plume.

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FIGURE 6.25: A map of the Swartkops Estuary, Port Elizabeth

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FIGURE 6.26: Water level simulations, flow rates and average stream velocities simulated at different locations in the Swartkops River Estuary under zero river inflow

Where a 2-D numerical model is not available, the 1-D model schematisation approach can be expanded to simulate the hydrodynamics of a more complex 2-D case by creating 1-D branches for all the streams, as illustrated for the Knysna Estuary in Figure 6.27.

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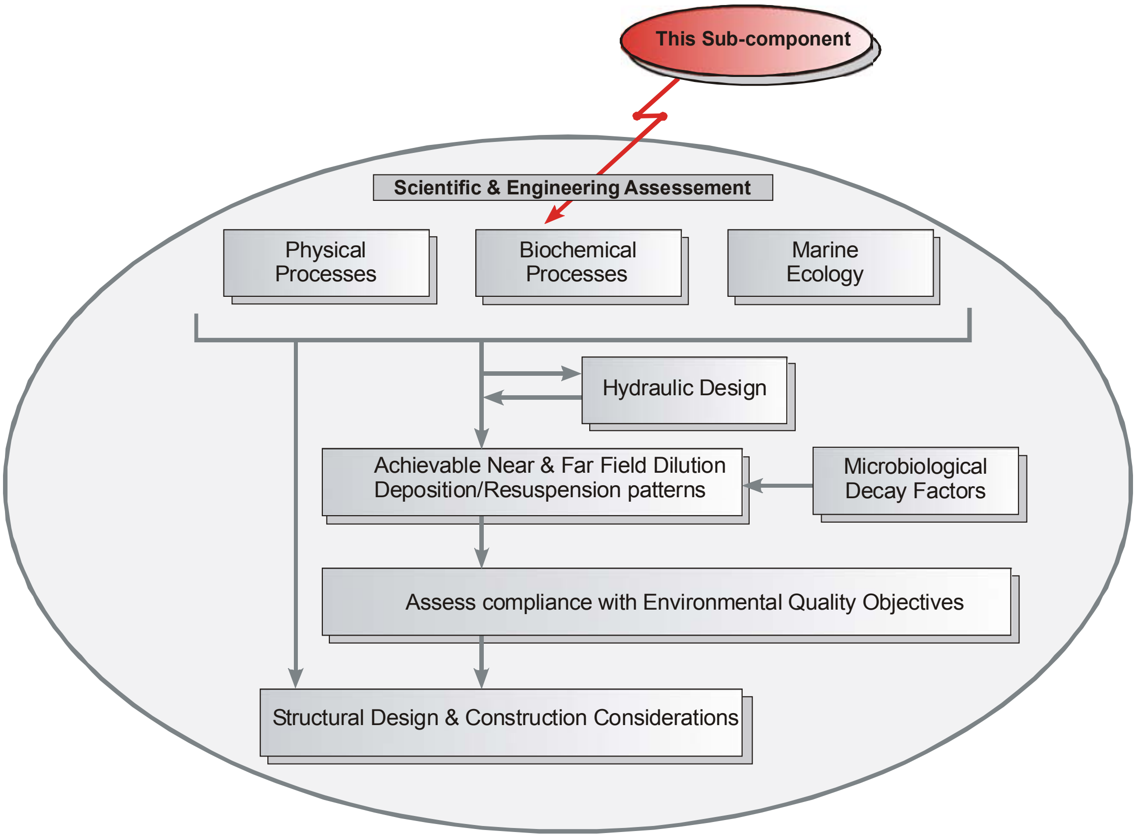
FIGURE 6.27: 1-D schematisation for the Knysna Estuary

6.2 BIOGEOCHEMICAL PROCESSES (WATER COLUMN AND SEDIMENT)



PURPOSE:

The purpose of this component is to gain an understanding of those key biogeochemical characteristics and processes in the study area that may influence, or will have an influence on, the transport and fate of the wastewater plume. Any existing human interferences/activities in the study area, e.g. existing waste disposal or coastal structures, should also be taken into account.

Because of the site-specific nature of these types of investigations, this section is not intended to be prescriptive. Rather, it sets out the approach to follow when formulating a biogeochemical measurement programme as part of the scientific and engineering assessment process for marine disposal of land-derived wastewater. In particular, it highlights important factors to be taken into account when designing such measurement programmes, as well as the type of output that is required to provide information with sufficient confidence to allow for sound management decisions.

NOTE:

Methods for the Determination of the preliminary Ecological Reserve for Estuaries *(RSA DWAF, 2004), issued under the National Water Act, through the Directorate: Resource Directed Measures, provide guidance on the design of baseline data collection programmes. To ensure alignment with existing initiatives on estuaries, those methods (or future updates thereof) need to be consulted when designing baseline monitoring programmes for estuaries as part of this operational policy (proposed refinements to the design of baseline data collection programmes for estuaries are also provided in a WRC report entitled:* Resource Monitoring Procedures for Estuaries for Application in the Ecological Reserve Determination and Implementation Process *[Taljaard et al., 2003]).*

6.2.1 Overview

Biogeochemical characterisation of the marine environment requires data on the spatial and temporal variability of biogeochemical parameters, both in the water column and in the sediments, as well as an understanding of the key processes that govern such variability. 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 the physical processes study programme 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.

In addition to assisting in understanding the biogeochemical processes characteristic of the receiving marine environment, biogeochemical data are also used to calibrate and test the validity of model predictions (where applicable), as well as to provide a benchmark (baseline) for future monitoring programmes. It is important, therefore, that the manner in which biogeochemical data are collected is appropriate, e.g. model calibration and validation of water column parameters usually require time series data collected over a pre-determined time-scale.

i. Receiving marine environment

The selection of measurement parameters to be used in the receiving environment is site-specific. A key determining factor in the selection of such parameters is the composition of the proposed wastewater discharges as well as the anticipated effects on the biogeochemical characteristics of, and processes in the receiving environment. Essential, therefore, to the design of the biogeochemical measurement programme is the preparation of a preliminary conceptual model of the key biogeochemical processes governing the ‘cause-and-effect’ linkages between the wastewater discharge and the receiving environment.

Biogeochemical parameters (e.g. pH, dissolved oxygen, turbidity, particulate organic carbon and nitrogen, dissolved nutrients, toxin concentrations and microbiological parameters) can be measured in the water column and/or the sediments, including interstitial waters.

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 inter-tidal sediments is particularly relevant where, for example, a wastewater discharge to the surf zone is under investigation.

Spatial scales at which data need to be collected 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 about the locations of, for example, short- and long-term deposition sites, in the case of sediment sampling. This typically requires a high resolution unbiased grid.

The temporal scale at which biogeochemical data need to be collected, as part of the measurement programme, largely depends on:

- The variability in the load of contaminants from waste inputs
- The variability in processes driving transport and fate of the wastewater plume in the receiving environment
- The temporal sensitivity of the ecosystem to contaminant loading, i.e. exposure time versus negative impact.

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, for example, to separate an anthropogenic impact from a natural water quality anomaly.

EXAMPLE…

A time series plot, showing the natural variability of dissolved oxygen concentrations (mℓ/ℓ) at a depth of 10 m in Small Bay (Saldanha Bay, South Africa) is provided in Figure 6.28 (Monteiro *et al.*, 1999). It shows regular intrusion of cold, low oxygen (< 2mℓ/ℓ) coastal waters into the bay (mℓ/ℓ multiplied by density of O_2 = mg/ℓ).

Weekly sampling would indicate that there is an apparently random variability of high and low oxygen concentrations. Hourly sampling (automated) shows that this variability is linked to variability in upwelling, and the low oxygen concentrations are brought into the system by those upwelled waters rather than by any localised eutrophication effects. Weekly sampling would result in an apparently random variability of high and low concentrations.

The results of the monitoring show that natural variability needs to be well characterised prior to interpreting the impacts of effluents on oxygen concentrations in the receiving water body.

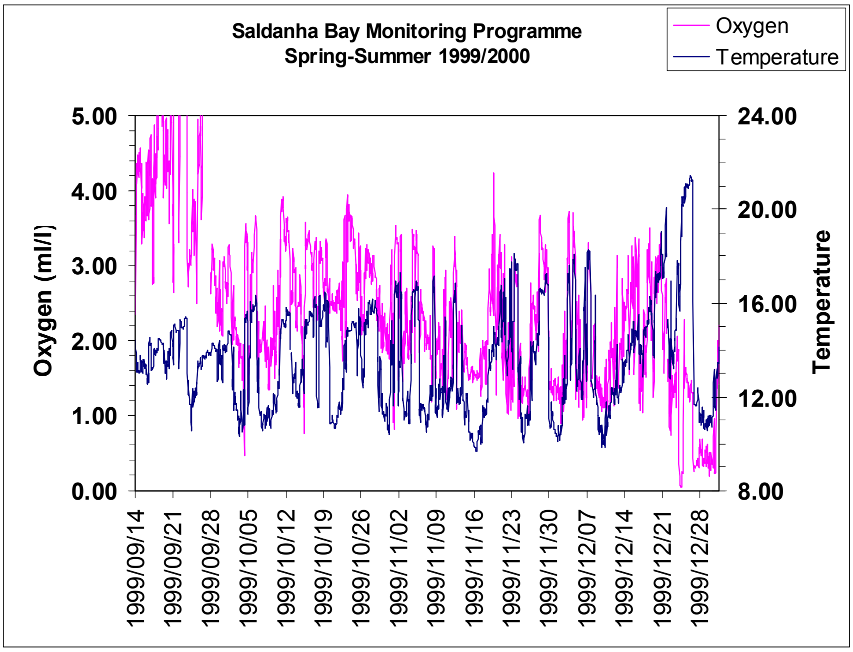


FIGURE 6.28: Dissolved oxygen variability in the bottom water layer in Saldanha Bay, South Africa (from Monteiro et al., 1999)

EXAMPLES…

I. A proposed wastewater discharge containing trace metals is considered for disposal to a marine environment receiving turbid (muddy) river inflow. For such a case, the likely fate of trace metals will be to adsorb onto the fine particles and to be deposited at some location, usually in the far field. The measurement programme, therefore, needs to be designed to enable the characterisation of the variability in river inflow and turbidity, the processes governing such variability, as well as the potential depositional sites in the study area. This will require:

- Time series data on the variability of salinity, temperature and turbidity at pre-selected position/s in the study area (e.g. intensive sampling over a period of two weeks to a month, during periods of high river inflow)
- A spatial survey of the particle size distribution, particulate organic carbon and nitrogen, and trace metal distribution patterns in sediments within the study area.

II. A proposed wastewater discharge contains relatively high dissolved inorganic nitrogen concentrations. In such, a case the processes driving nutrient distribution and primary production and the subsequent degradation of organic matter, need to be characterised. Measurement parameters need to include:

- Time series data on the variability of salinity, temperature, pH, dissolved oxygen, dissolved inorganic nitrogen and phosphate at pre-selected position/s in the study area (e.g. intensive sampling over a period of two weeks to a month, during periods of high river inflow)
- A spatial survey of the particle size distribution, particulate organic carbon and nitrogen distribution patterns in sediments within the study area.

EXAMPLE…

Plots showing the modelled and measured distribution of low turbulence (bed shear stress) zones in Saldanha Bay, South Africa are provided in Figure 6.29 (Monteiro, *et al.*, 1999). These plots show that long-term deposition of contaminant carrying fine particles will only occur at certain locations (blue: model and red in observations). The modelled results show that the wave climate as well as the currents governs the distribution of long-term and short-term depositional zones. The long-term depositional zones are the most vulnerable to contaminant accumulation.

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FIGURE 6.29 ***Plots showing the measured particle size distribution in Saldanha Bay, as well as the modelled distribution of low turbulence (bed shear stress) zones in Saldanha Bay, South Africa (Monteiro et al., 1999).***

ii. Behaviour of constituents

Immediately after entering the marine environment, constituents present in a wastewater discharge can either (WHO, 1982):

- Remain in solution (i.e. remain in the 'dissolved phase')
- Adsorb onto solid phase particles
- Precipitate from the water column.

Another type of transformation is that of certain poly-aromatic hydrocarbons, in particular volatile organics (e.g. benzene, toluene, naphthlalene and xylene). On entering marine waters, such compounds do not follow the conventional 'dilution' behaviour. It is thought that these substances are actually extracted out of the aqueous phase and into the buoyant hydrophobic fraction that results in concentration as a film at the water's surface (referred to as the surface micro-layer), which subsequently evaporates to the atmosphere, rather than diluting. It will be extremely difficult to predict the transport and fate of such volatile substances in the receiving environment. Removing such compounds from the wastewater before discharging to sea best mitigates their potential risk to the marine ecosystem and other beneficial uses.

It is important, therefore, as part of the biogeochemical assessment process, to assess possible biogeochemical transformations of the wastewater (i.e. immediately after it enters the marine environment) that could have a major influence on the predicted transport and fate of the specific constituents in the wastewater plume.

Dissolved phase. Constituents associated with 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 that in the wastewater).

Although changes in concentration of constituents behaving non-conservatively are difficult to quantify without sophisticated tools such as numerical models, the concentration after a given dilution of a constituent behaving conservatively can be calculated as follows:

$C_{AE} \,.\, (Q_A + Q_E) = C_E.Q_E + C_A.Q_A$

Where
Q_A = Receiving water flow rate
Q_E = Effluent flow rate
C_E = Effluent concentration
C_A = Ambient concentration in the receiving water
C_{AE} = Concentration after mixing

The physical dilution (S) of the effluent can be expressed as the following dimensionless parameter:

$S = (Q_E + Q_A)/Q_E$ or $Q_A = Q_E(S - 1)$

Substituting Q_A in the mass balance equation, the concentration after mixing is:

$C_{AE} = (C_E + S.C_A - C_A)/ S$

Adsorption. On entering the marine environment, toxic compounds such as trace metals and poly-aromatic hydrocarbons, poly-nuclear aromatics and pesticides, tend to adsorb onto 'solid' phase particles present either in the wastewater or in the receiving environment. '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, which are different for each 'solid' phase particle. Partition coefficients, in this context, are defined as (US-EPA, 1999):

For a given pH and assuming that concentration of the 'solid' phase particles is in excess with respect to C_d:

$K_d \sim C_p/C_d$

where

K_d = Partition coefficient (in ml/g)
C_p = Concentration of trace metal adsorbed onto the 'solid' phase particle at equilibrium (in µg/g)
C_d = Concentration of trace metal remaining in solution at equilibrium (in µg/mℓ)

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 (Luger *et al.,* 1999; Monteiro, 1999).

Precipitation. A rise in pH and oxygen content 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 and which are specific to the metal/anion complex, need to be sourced from the literature in order to quantify such transformations (Stumm & Morgan, 1970; Faust & Aly, 1984). 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, which are much higher than those occurring naturally (Solomons & Förstner, 1984; WHO, 1982).

EXAMPLE…

An iron (Fe)-rich, strongly acid effluent (Fe will be in the dissolved phase) will be neutralised on contact with seawater (releasing CO_2). The change in pH will result in the precipitation of the Fe (i.e. Fe will be in the solid phase). This modification in constituent characteristics needs to be taken into account when quantifying the transport and fate of the wastewater plume in the far field.

6.2.2 Data requirements for pre-assessment and detailed investigation

i. Pre-assessment

A pre-assessment is usually based on published or archived information and data, either from the study area or comparable sites. As much data and information as possible, as described in Section 6.2.1, need to be collated. For the pre-assessment, conceptual and analytical assessment techniques (rather than far field numerical modelling), are used to produce:

- An initial quantitative description of the biogeochemical characteristics of and processes in the study area
- An estimate of the ambient concentrations of relevant biogeochemical parameters
- An identification of the potential depositional areas and estimate of the extent of contamination as a result of existing waste inputs (where data are available, prepare a contour map showing the distribution of toxic compounds). The sediment grain size and particulate organic matter distribution patterns are crucial for the interpretation of results.
- A quantitative assessment of the chemical behaviour of constituents in the wastewater immediately after being discharged to the marine environment.

As part of the pre-assessment, it is also necessary to estimate required dilutions since such information is used as an input parameter in the hydraulic design of offshore marine outfalls, i.e. to provide a first indication of the initial dilution that needs to be achieved in the design of the outfall.

Required dilutions are defined as the dilution necessary to ensure compliance with the environmental quality objective recommended for a particular constituent, taking into account the present concentration in the receiving marine environment as well as the proposed concentration in the wastewater. The required dilution is calculated as follows:

Referring to the mass-balance equation…

$$S = (C_E - C_A) / (C_G - C_A)$$

Where
C_E = Effluent concentration
C_A = Ambient concentration in the receiving water
C_G = Environmental quality objective (target value)
S = Required dilution

EXAMPLE…

The dissolved ammonia concentration is about 30 mg/ℓ after preliminary treatment of sewage:

Concentration of the effluent (C_E):	30 mg/ℓ
Ambient concentration in the sea (C_A):	Low, assume 0.001 mg/ℓ
Guideline (C_G):	0.600 mg/ℓ

The required dilution (S) is:

$$S = (30 – 0.001)/(0.600 – 0.001) = 50$$

ii. Detailed investigation

A detailed investigation requires an intensive data collection programme to acquire the data and information on the relevant physical processes, as described in Section 6.2.1

In a detailed assessment of the biogeochemical characteristics and processes, numerical modelling tools such as water quality models in association with hydrodynamic models need to be applied. These models are particularly useful in the interpretation of existing knowledge of the key processes and thus help to define the temporal and spatial variability of the biogeochemical characteristics of the receiving marine environment.

Outputs required for the characterisation of biogeochemical processes, as part of a detailed investigation, include:

- A contour map showing the distribution of relevant chemical constituents in the marine sediments of the study area, including details on sediment particle size distribution and particulate organic carbon and nitrogen. Expected variability, both temporally and spatially, need to be addressed.

  NOTE:

  Geochemical ratios of trace metals can be used to determine whether the trace metals are of natural or anthropogenic origin. It is possible for conditions to arise in which the total trace metal concentration in the sediment is high (particularly in depositional areas) but completely linked to the natural structure of clay minerals, in which case the trace metals will not be bio-available. This condition would be characterised by geochemical ratios very similar to those of unpolluted sediments typical of the area. The geochemical ratio of each trace metal relative to aluminium (TM [µg/g]: Al [%]) is used, usually allowing a conservative 2-fold natural variation in the geochemical ratios. Natural geochemcial ratios are site specific for different geographical regions and need to be sourced from the literature (Monteiro & Scott, 2000).

- Graphs showing the temporal (and, where applicable, spatial) variability of system variables (temperature, salinity, dissolved oxygen and suspended solids/turbidity), inorganic nutrients (nitrate, ammonia, reactive phosphate and reactive silicate), and organic nutrients (dissolved organic carbon, particulate organic carbon and particulate organic nitrogen) in the water column.

- Description of the expected interaction of the constituents of waste inputs with biogeochemical processes in the receiving marine environment, e.g. whether the constituents are in the 'dissolved' phase (i.e. remain in solution), will precipitate from the water column, or whether they are in the 'solid' phase (e.g. adsorbed to solid phase particles).

As part of a detailed investigation, numerical modelling should be used to refine the required dilutions that were estimated during the pre-assessment stage (refer to Section 6.2.2).

Numerical modelling techniques have proven to be powerful tools 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 existing understanding of the key processes

- Modelling assists in defining the most critical spatial and time scales of potential negative impacts in the receiving system

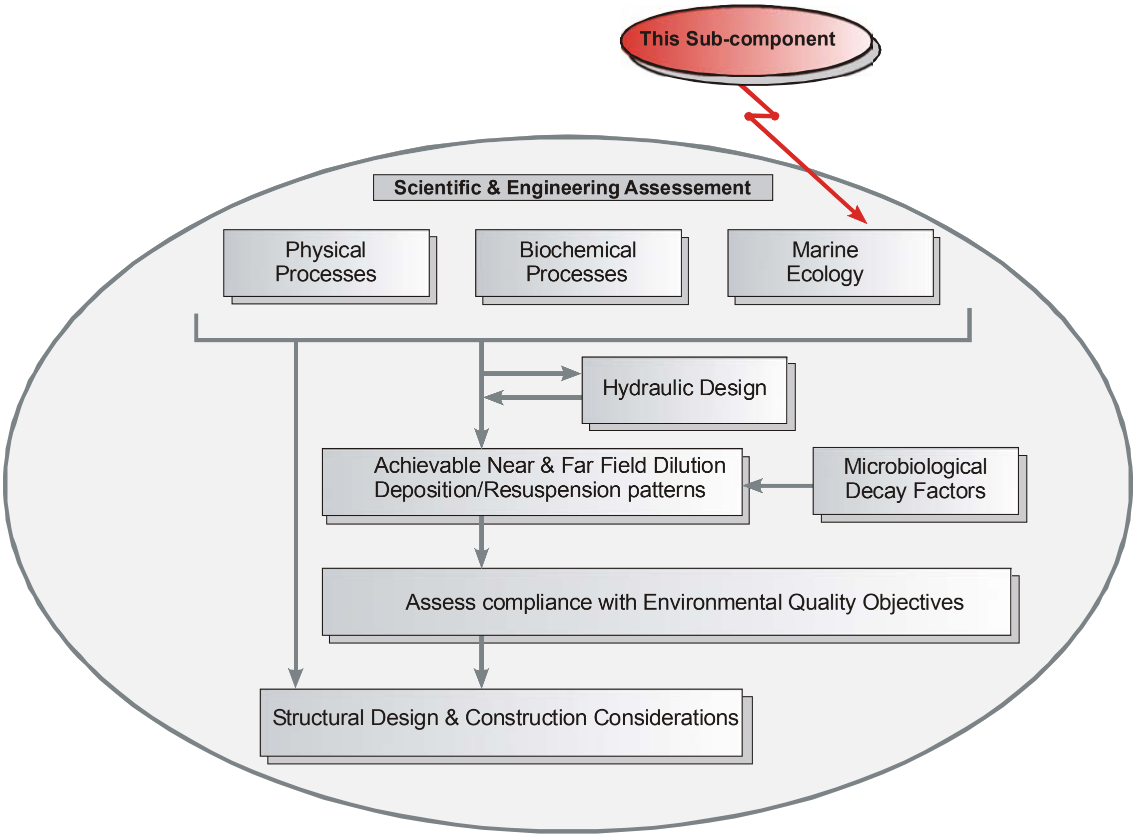
- Model outputs provide quantitative results which can be used, together with field data, to check the quality of assumptions and insights.

However, in the application of numerical modelling techniques, the following must be complied with:

- The model chosen 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 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.

A basic overview of statistical techniques that are typically applied in the evaluation of environmental data, where and when appropriate, is provided in Section 7.4.2. It highlights important factors that need to be taken into account when applying statistical analyses to data sets and is by no means exhaustive.

6.3 MARINE ECOLOGY



PURPOSE:

The purpose of the ecological component, as part of the scientific and engineering assessment, is to:

- ***Establish the biological resources within the study area***
- ***Identify biological resources that are of high conservation value***
- ***Establish which biological resources have already been lost or are stressed by anthropogenic influences, including existing waste inputs***
- ***Identify biological resources that are particularly sensitive to anthropogenic influences in the area (both existing and proposed)***
- ***Refine the ecological objectives for the study area (e.g. the description of the balanced indigenous population [US-EPA, 1994]) and related objectives pertaining to water quality***
- ***Assist in determining a suitable pipeline route so as to minimise damage to the marine ecology***
- ***Provide ecological baseline data for future monitoring programmes.***

6.3.1 Overview

To characterise the ecology of a particular marine environment, data on the following are required:

- Identification of habitat types, e.g. reefs, kelp beds, sandy and rocky bottoms
- Community structure within each of the habitat types
- Community composition and list of species (and abundance) associated with the different 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. It is important, therefore, to ensure such information is collected simultaneously and is taken into account when interpreting the ecological data.

Ecological data should be adequate to perform valid statistical and community analyses as proposed below.

NOTE:

For estuaries, guidelines on baseline data requirements are provided in the* Methodology for the Determination of the Preliminary Ecological Reserve for Estuaries *(RSA DWAF, 2004) issued under the National Water Act. Proposed refinements to these methods are provided in a WRC report entitled:* 'Resource Monitoring Procedures for Estuaries for Application in the Ecological Reserve Determination and Implementation Process' *(Taljaard et al., 2003).

6.3.2 Data requirements for pre-assessment and detailed investigation

i. Pre-assessment

A pre-assessment is based on published or archived information and data from the study area or comparable sites. As much data and information as possible, as described in Section 6.3.1, need to be collated.

As part of a pre-assessment it is important to provide the following:

- A map showing, at least conceptually, the distribution of the various habitat types and the associated biological resources (i.e. to refine the beneficial use map in terms of the distribution of marine ecosystems), and 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.

  (Site photography and video recordings have been used effectively to assist in providing information on the above.)

- Identification of the dominant species, species of particular conservation importance and species targeted for exploitation, providing best estimates of spatial and temporal variability.

- Identification of biological resources that are potentially sensitive to anthropogenic influences already present in the area and/or that may be sensitive to constituents present in the proposed wastewater discharge, and quantification of cause-and-effect relationships as best as possible (i.e. to refine the ecological quality objectives).

ii. Detailed investigation

A detailed investigation requires an intensive data collection programme to acquire the data and information on the relevant ecological processes, as described in Section 6.3.1. In a detailed assessment of the ecological characteristics and processes, ecological modelling tools can be applied. These models are particularly useful in interpreting existing understanding of the key processes in order to improve quantitative predictions with respect to cause-and-effect relationships.

For a detailed investigation, the ecological component should include:

- A geo-referenced map showing the distribution of the various habitat types and their associated biological resources (i.e. to refine the beneficial use map in terms of the distribution of marine 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.

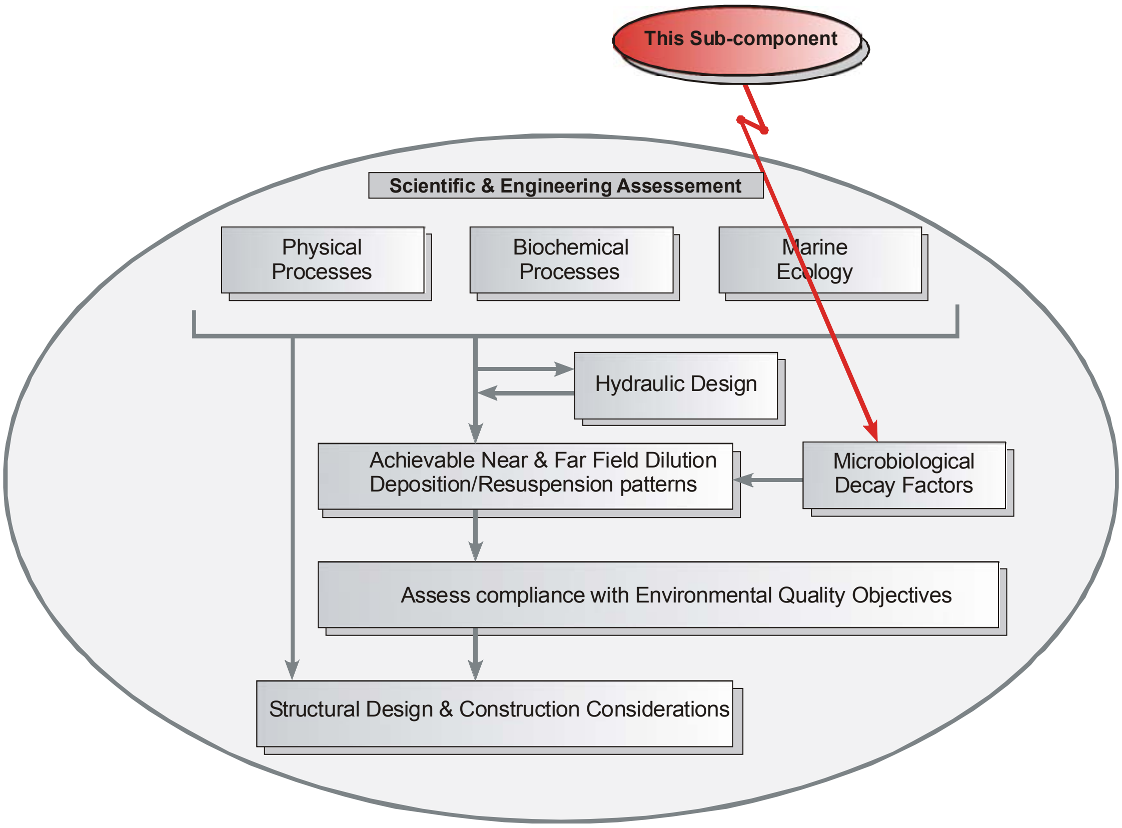
- For each of the habitat types, a listing of the key species and their abundance and community composition, as well as expected temporal and spatial variability (this may be expensive to obtain and it may therefore be more realistic to focus on selected indicator species and community structure)

- Confirmation of the presence of biological resources that are potentially sensitive to anthropogenic influences already present in the area and/or that may be sensitive to constituents present in the proposed wastewater discharge, and also provision of a quantitative assessment of cause-and-effect relationships (i.e. to refine the ecological quality objectives)

- Refinement of the ecological objectives (e.g. described in terms of a *balanced indigenous population*) for the study area (refer to Section 4.2.1 for more details) that can be used as the baseline or reference for future monitoring.

A basic overview of statistical techniques that are typically applied in the evaluation of environmental data, where and when appropriate, is provided in Section 7.4.2. It highlights important factors that need to be taken into account when applying statistical analyses to data sets and is by no means exhaustive.

6.4 MICROBIOLOGICAL FACTORS



PURPOSE:

The purpose of this component is to determine the relevant microbiological indicator and associated decay coefficients to use in predicting microbiological die-off in the far field for a specific study area. These decay coefficients for the selected microbiological indicator, for example, depend on exposure to solar radiation (i.e. whether its day or night time) and water salinity of receiving environment.

6.4.1 Overview

The types and numbers of various pathogens in sewage depend on the incidence of disease in the population of an area and the seasonal variation of infections (WHO, 1999). Numbers and types, therefore, will vary throughout the world and between seasons. A general indication of pathogenic numbers in sewage is provided in Table 6.6 (WHO, 1999).

TABLE 6.6: A general indication of pathogens found in sewage, the associated diseases and typical counts (WHO 1999)

PATHOGEN/INDICATOR	*DISEASE/ROLE*	*COUNTS PER LITRE*
Bacteria		
Campylobacter spp.	*Gastro-enteritus*	*37 000*
Clostridium perfringens	*Indicator*	$6 \times 10^5 – 8 \times 10^5$
E.coli	*Indicator*	$10^7 – 10^8$
Salmonella spp.	*Gastro-enteritus*	*20 – 80 000*
Shigella	*Bacillary dysentery*	*10 – 10 000*
Viruses		
Polioviruses	*Indicator*	*1 800 – 5 000 000*
Rotaviruses	*Diarrhoea, vomiting*	*4 000 – 850 000*
Parasitic protozoa		
Cryptosporidium parvum oocysts	*Diarrhoea*	*1 – 390*
Entamoeba histolytica	*Amoebic dysentery*	*4*
Giardia lamblia cysts	*Diarrhoea*	*125 – 200 000*
Helminths		
Ascaris spp.	*Ascariasis*	*5 – 110*
Ancylostoma spp.	*Anaemia*	*6 - 190*
Trichuris spp.	*Diarrhoea*	*10 - 40*

Methods to detect and identify infectious viruses and parasites are very expensive and do not exist for some. The use of indicator organisms to indicate the potential presence of harmful organisms has been used for a long time and the faecal indicator bacteria most commonly used today are thermotolerant coliforms, *E.coli* and Enterococci or faecal streptococci. The advantages and disadvantages of these bacteria as indicators are listed in Table 6.7 (WHO, 1999).

TABLE 6.7: Advantages and disadvantages of different microbiological indicators

INDICATOR	ADVANTAGES	DISADVANTAGES
Faecal streptococci/ enterococci	*Marine and potentially freshwater human health indicator.* *More persistent in water and sediments than coliforms.*	*May not be valid for tropical waters due to growth in soils.*
Thermotolerant coliforms	*Indicator of recent faecal contamination.*	*Possibly not suitable for tropical waters due to growth in soils and water.* *Confounded by non-sewage sources (eg. Klebsiella spp. in pulp and paper wastewater)*
E. coli	*Potentially a freshwater human health indicator.* *Indicator of recent faecal contamination.* *Rapid identification possible if defined as b-glucuronidase producing bacteria.*	*Possibly not suitable for tropical waters due to growth in soils and water.*

The effect of conventional sewage treatment on the removal of the major pathogen groups is illustrated in Table 6.8.

TABLE 6.8: Effect of conventional sewage treatment on the removal of the major pathogen groups (adapted from WHO, 1999)

TREATMENT	Enteric viruses	Salmonella	C. perfringens	Giardia
Raw sewage	*100 000 – 1 000 000*	*5 000 – 80 000*	*100 000*	*9 000 - 200 000*
Primary treatment				
% removal	*50 - 98,3*	*99,5 – 99,8*	*30*	*27 – 64*
Counts remaining	*1 700 – 500 000*	*160 – 3 360*	*70 000*	*7 200 – 146 000*
Secondary treatment				
% removal	*53 – 99,92*	*98,65 – 99,996*	*98*	
Counts remaining	*80 – 470 000*	*3 – 1 075*	*2 000*	
Tertiary treatment				
% removal	*99,983 – 99,999998*	*99,99 – 99,9999995*	*99,9*	*98,5 – 99,99995*
Countsremaining	*0 - 170*	*0 - 7*	*100*	*0 – 2 951*

Potential risks associated with different levels of treatment and disposal location in the marine environment is indicated in Table 6.9 (WHO, 1999).

TABLE 6.9: Potential risks associated with different levels of treatment and disposal location in the marine environment

TREATMENT	DISCHARGE TYPE		
	Surf zone or estuarine discharge	Marine outfall (less than 10 m water depth)	Marine outfall* (greater than 10 m water depth)
None	*Very high*	*High*	*NA*
Preliminary	*Very high*	*High*	*Low*
Primary	*Very high*	*High*	*Low*
Secondary	*High*	*High*	*Low*
Secondary and disinfection	*Medium*	*Medium*	*Very low*
Tertiary	*Medium*	*Medium*	*Very low*
Tertiary and disinfection	*Very low*	*Very low*	*Very low*

* *Assuming that the design capacity is not exceeded and that extreme climatic and oceanic conditions were considered in the design (i.e. the wastewater plume will not reach the beach).*

In 1999, the WHO (1999) concluded that the data available on T_{90} values were inadequate for use in model predictions, especially in the near-shore zone. At that stage, the WHO referred to Chamberlain and Mitchell (1978), who gave a mean T_{90} value of 2.2 hours for marine waters and a T_{90} value of 58 hours for freshwaters. These numbers were obtained from *in situ* tests at wastewater outfalls. From these data numbers it can be assumed that the mean daytime T_{90} value will be less than 2.2 hours. A summary of T_{90} values provided by Gunnerson (1988) for a number of coastal areas is listed in Table 6.10

TABLE 6.10: Summary of T_{90} values for a number of coastal areas (Gunnerson, 1988)

LOCATION	*DATE*	*T_{90} (hours)*
Raw sewage		
Honolulu	*1970*	*$\leq$ 0.75*
Titahi Bay, New Zealand	*1959 – 1960*	*0.65*
Rio de Janeiro	*1963*	*1.0 – 1.2*
Israel	-	*< 1.0*
Istanbul	*1968*	*0.8 – 1.7*
Genofte, Denmark	-	*1.2*
Tema, Ghana	*1964*	*1.3*
Nice, France	-	*1.1*
England	*1965*	*0.78 – 3.5*
Manila, Philippines	*1968 – 1969*	*1.8 – 3.4*
England	*1969 – 1973*	*1.4 – 5.3*
Mayaquez Bay, Puerto Rico	-	*0.7*
Montevideo, Uruguay	-	*1.5*
Santos, Brazil	-	*0.8 – 1.7*
Porlaleza, Brazil	-	*1.1 – 1.5*
Maceio, Brazil	-	*1.2 – 1.5*
Primary Treated Wastewater		
Ventura, California	*1966*	*1.7*
Seaside, New Jersey	*1966*	*1.8*
Orange County, California	*1954 – 1956*	*1.8 – 2.1*
Santa Barbara, California	*1967*	*2.4*
Los Angeles, California	*1954 - 1956*	*4.1*

Typically, pathogenic organisms are modelled using faecal coliforms as the proxy with appropriate die-off responses to changes in ultraviolet light intensity linked to time of day and penetration of the water column. Night-time values for T_{90} will be higher.

The variability of the T_{90} value, as part of detailed investigations, is normally simulated using numerical models. For a pre-assessment, a value of 10 hours can be used.

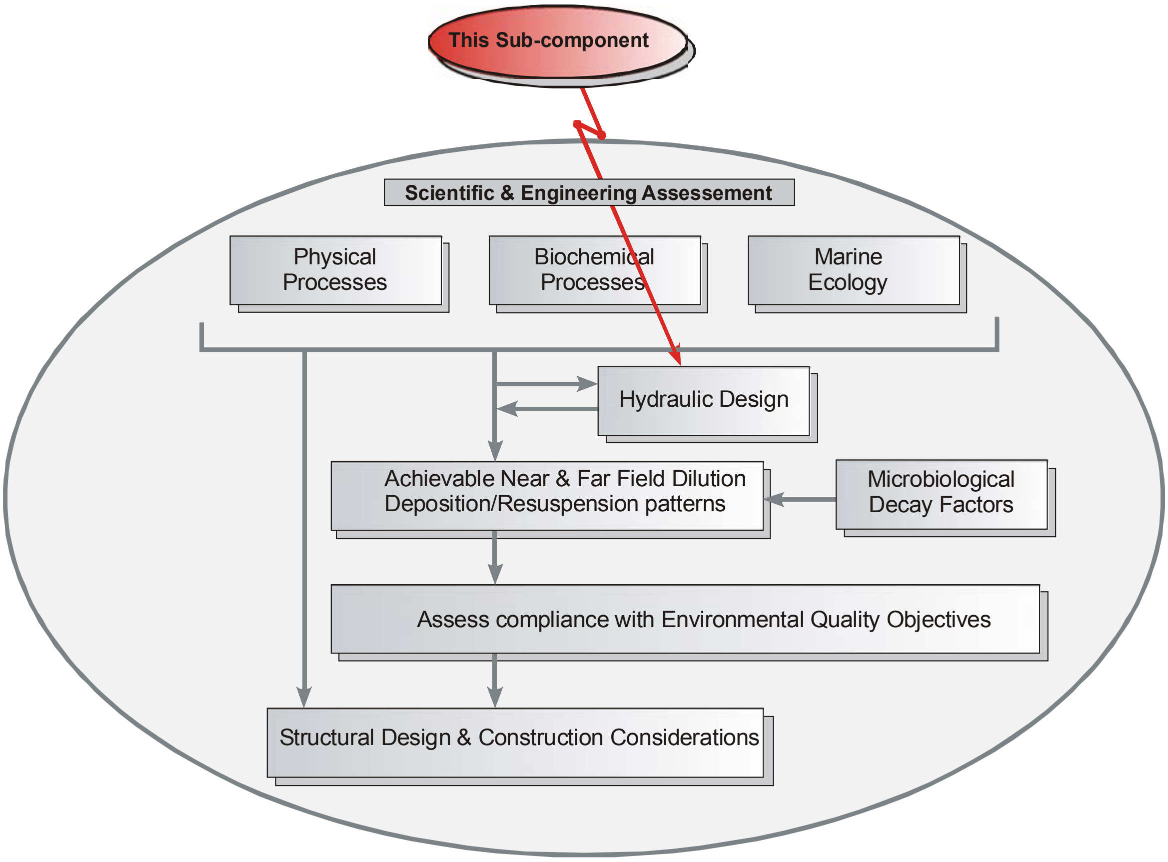
6.4.2 Data requirements for pre-assessment and detailed investigation

For a pre-assessment conservative die-off coefficient, for both daytime and night-time, considered to be representative of conditions at the study area, can be applied.

For a detailed investigation, the above needs to be refined, by using diurnal variations of daytime and night-time die-off coefficients in conjunction with variation in wastewater flow patterns. For large projects it may be required to measure actual die-off coefficients in the study area.

A basic overview of statistical techniques that are typically applied in the evaluation of environmental data, where and when appropriate, is provided in Section 7.4.2. It highlights important factors that need to be taken into account when applying statistical analyses to data sets and is by no means exhaustive.

6.5 HYDRAULIC DESIGN



PURPOSE:

A sound hydraulic design for a wastewater discharge system includes the following main functional components:

- ***The head works, to discharge the wastewater***
- ***The main outfall pipe, to convey the wastewater to the discharge location***
- ***The diffuser, to release the wastewater into the receiving environment.***

6.5.1 Outfall site selection

Prior to commencing with the scientific and engineering assessment process, it is important to conduct a preliminary on-site assessment of the possible location of a wastewater discharge system.

A well-designed wastewater discharge system consists of the following main components:

- Head works to discharge the wastewater
- Main outfall pipe to convey the wastewater to the discharge location
- Diffuser to release the wastewater into the receiving environment.

An illustration of the different components is provided Figure 6.30. The 'diffuser' component is specific to marine outfalls (i.e. wastewater discharges to the offshore marine environment).

CLICK TO VIEW GRAPHIC

FIGURE 6.30: An illustration of the components of a well-designed wastewater discharge system

The location of the head works is the onshore end of the wastewater discharge system and will control the route of the outfall. Typically, the head works will be on the site where the wastewater is generated (e.g. the WWTW). For a new development, the following aspects have to be taken into account during the selection of the optimum site for the head works:

- The natural drainage of the area
- The existing or future planned reticulation system
- A suitable location for the land-based section of the system with regard to the area available, considering possible future extensions of the treatment processes as well as the existing or future development plans for the area.

In the selection of the discharge/diffuser location, the following needs to be taken into account:

- Delineated beneficial use areas along the coastline
- The bathymetry of the marine environment, keeping in mind the quality of the wastewater and the maximum required initial dilutions
- The coastline configuration and bathymetry, considering the route for the pipeline
- The typical physical processes that can be expected.

Link the onshore end (head works) to the offshore end (diffuser) via the shortest possible route for pipeline (length), considering the following basic requirements and restrictions:

- A shore crossing which will create the minimum interference to the physical characteristics of the coastline, ecology and the existing infrastructure, taking into account the most likely method of construction
- An onshore route (head works to shoreline) with regard to construction impacts on the existing and planned onshore infrastructure
- A gradually sloping seabed without, or with the minimum of, natural or manmade obstacles such as rock outcrops, underwater cables or shipwrecks.

6.5.2 Discharging of wastewater

Wastewater can be discharged using a gravity (potential) head, if available, or by using a pressure head provided by pumps. Where gravity flows are used, these will vary according to the diurnal flow patterns. Where pumps provide the pressure head, wastewater can be discharged intermittently at a specific flow rate from a storage tank.

NOTE:

Energy (potential or gravity, kinetic and pressure) or energy losses (e.g. friction loss) per unit weight is expressed as 'head' (in meters water of specific gravity).

There are a number of factors that need to be taken into account when planning the discharge of wastewater:

- ***Surge effects***. The most common pressure transient (or momentary) effect affecting a pumping system is the switching off of pumps or the uncontrolled loss of the power supply. Operation of valves can also cause large transient effects and, subsequently, pressure surges. Variations in discharge rates normally do not result in significant transient effects. Pressure surge analyses should be conducted for all marine outfalls that use pumps. This is to ensure that no structural damage occurs to any component of the outfall during any flow scenario as a result of possible transient effects that may occur during operations. Gravity surge, related to sudden pressure changes and subsequent rapid flow changes in a marine outfall, should also be carefully examined for both pumped systems and those using gravity flow.

- ***Air entrainment***. Air entrainment may occur during high flows in the drop shaft of an outfall, resulting in flow reduction and an increase in pressure.

- ***Saline intrusion***. Seawater intrusion into outfall diffusers can cause higher pumping heads, reduce the initial dilutions and result in sedimentation (Charlton *et al* 1987). As it is not practical to prevent saline intrusion completely without the use of non-return valves, the hydraulic design must be such that salt water can be purged from the pipeline and diffusers.

6.5.3 Main pipe diameter

The optimisation of the main pipe diameter, a key component in determining the cost and hydraulic performance of a marine outfall, depends on:

- Flow scenarios (present flow as well as the ultimate flow conditions)
- Available or practical head to discharge the wastewater (gravity or pumps)

In the case of small diameter outfall, scouring velocities can be maintained more easily and the capital investment will be lower. However headlosses resulting from friction will require higher pressure/gravity heads and subsequent higher running costs if a gravity head is not available. The design criteria for a first assessment are:

- Maintain a main pipe velocity of greater or equal to 0,7 m/s during low flows to prevent deposition of solids.
- Discharge maximum flows with available gravity head or by cost-effective pumping, taking into account the increase in roughness during the lifetime of the outfall as well as all losses at fittings (entrances, exits, bends, contractions, expansions, valves) in the main pipe and the diffuser.

Headloss (h_f) resulting from friction can be calculated using the Darcy-Weisbach equation (Shand, 1993):

$$h_f = \lambda L V^2/(2gD)$$

Where

λ = friction factor
L = length of the pipe (m)
D = pipe diameter (m)
V = velocity in the main pipe (m/s)

The Colebrook-White formula can be applied to determine the friction coefficient (λ), as it correctly models the laws for smooth and rough pipes as well as for the transition zones (Shand, 1993). The Moody diagram for pipe friction (Shand, 1993) is given in Figure 6.31.

$$\lambda = 0.25[\log_{10}\{k_s/3.7D + 2.51/(R_e\lambda^{1/2})\}]^{-2}$$

Where

k_s = roughness height (mm)
R_e = Reynolds number

Typical roughness heights (i.e. the characteristic size of surface roughness) for pipe materials are (Shand, 1993):

PIPE MATERIAL	*SMOOTH*	*AVERAGE*	*ROUGH*
Plastic (PVC)	*0.015*	*0.03*	*0.06*
Coated steel	*0.03*	*0.06*	*0.15*
Cast iron or cement mortar lined	*0.15*	*0.3*	*0.6*
Spun concrete	*0.3*	*0.6*	*1.5*
Rough concrete or riveted steel	*1.5*	*3*	*6*

CLICK TO VIEW GRAPHIC

FIGURE 6.31: Moody diagram for pipe friction (Shand, 1993)

It is important to investigate the maximum friction losses that may occur during the lifetime of an outfall. These losses need to be determined for the maximum possible flows and for an expected pipe roughness after 20 to 30 years in operation.

Entrance, exit, bend and contraction losses (h_e) are defined as:

$$h_{e,b,c} = K_{e,b,c}V^2/2g$$

where
$K_{e,b,c}$ = Loss coefficient for entrance, exit, bend and contraction losses.

Shand (1993) summarised typical fitting loss coefficients as follows:

PIPE DIMENSION	***TYPE***	$\boldsymbol{K_e}$	
Pipe entrance	*Projecting*	*0.80*	
	Sharp cornered	*0.50*	
	Slightly rounded	*0.25*	
	Bellmouth	*0.05*	
Pipe exit	*Projecting*	*1.0*	
	Sharp cornered	*1.0*	
	Slightly rounded	*0.5*	
	Bellmouth	*0.2*	
Pipe bends	R_b/D	K_b *for 45°*	K_b *for 90°*
	1	*0.15*	*0.20*
	2	*0.09*	*0.13*
	3	*0.07*	*0.10*
	4	*0.06*	*0.08*
	6	*0.05*	*0.07*
	8	*0.05*	*0.07*
	Where R_b *= bend radius*		
Contractions	D_1/D_2	K_c	
	1.1	*0.05*	
	1.2	*0.11*	
	1.4	*0.20*	
	1.6	*0.26*	
	1.8	*0.34*	
	2.0	*0.38*	
	2.5	*0.42*	
	3.0	*0.44*	
	4.0	*0.47*	
	D_1*: Upstream diameter,* D_2*: downstream diameter*		

6.5.4 Diffuser design

For the optimisation of the diffuser, the following criteria must be met:

- Design flows must be discharged satisfactorily through the ports. A rule of thumb for the continuity of flow is that the total cross-sectional areas of the ports should not be less than 0.7 times the cross-sectional area of the main pipe at any point in the diffuser. A port diameter of less than 75 mm is not recommended because it will be more susceptible to blockage (from particulates in the wastewater as well as from outside).

- Maintain sufficient flow in each port to prevent the intrusion of seawater. This flow can be achieved by the gradual increasing of the sizes of the ports towards the end of the pipe. To prevent the intrusion of seawater, the port exit velocities must be such that the densimetric Froude Number for each port is greater than unity (i.e. 1).

  The densimetric Froude Number of the jet at exit is expressed as follows:

$$F_r = v_p/[g.d_p(\Delta\rho/\rho_s)]^{1/2}$$

Where

v_p	=	port velocity (m/s)
$\Delta\rho$	=	$\rho_s - \rho_e$
ρ_s	=	seawater density (kg/m^3)
ρ_e	=	density of wastewater (kg/m^3)
d_p	=	port diameter (m)

- Ensure an even distribution of flows, through all the diffuser ports, because the flow is directly related to the achievable initial dilution, and the worst performing port (highest flow and lowest dilution) will be considered as representative of the performance of the diffuser. Even distribution can be achieved by the gradual increase of the port sizes.

- Maintain scouring flows within the diffuser section: this can be achieved by introducing tapers in the diffuser section together with increasing port sizes towards the seaward end of the diffuser.

- Optimum dilution will be obtained with diffusers discharging horizontally and with alternate ports directed in opposite directions.

- The distance between any two ports must be such that the plumes do not merge during the rise of the buoyant plumes. This can be achieved by ensuring that the distance between any two adjacent ports is greater than one third of the water depth.

EXAMPLE…

As a first assessment, outfall configuration can be obtained as follows:

For a population of 100 000 and an average flow of 250 ℓ/day per person, the total daily flow is:

Q_d = 100 000 x 0.25 m^3/day = 25 Mℓ/day or 25 million ℓ/day

resulting in an average discharge rate of:

Q_{ave} = 25 000/(3600 x 24) m^3/s = 0.289 m^3/s

Referring to Chapter 2 of this Section, this discharge rate will result in a peak diurnal flow of approximately:

Q_{peak} = 0.289 x 2 = 0.578 m^3/s

In order to maintain velocities (V) in the main pipe and to prevent deposition of solids in the main pipeline during average flow conditions, the diameter of the main pipe is:

$V > 0.7$ m/s as $V = Q/A$

$\therefore \quad A = Q/V$ or $\pi D^2/4 = Q/V$

$\therefore \quad D = [4QV/\pi]^{1/2}$

$\therefore \quad D \geq [(4 \times 0.289) / (0.7 \times \pi)]^{1/2} \geq 0.72$ m

where

A = cross-sectional area of the main pipe = $\pi D^2/4$

Therefore, a main pipe diameter of 0,72 m will be required. For the estimation of the number (n) of ports required, apply the rule for continuity of flow:

Σ (port cross-sectional areas) < 0.7 x cross-sectional area of the main pipe (A)

Using a port diameter (d_p) of 100 mm:

$n.[\pi d_p^2/4] < 0.7 \times \pi D^2/4$

$n \times d_p^2 < 0.7 \times D^2$

$n < 0.7 \times 0.72^2/0,1^2$

n (number of ports) < 36

Thus for a water depth of 20 m a main outfall pipe with an inside diameter of 0.72 m and a diffuser with 35 ports with a diameter of 0.1 m, spaced at 7 m intervals, will be a first estimate. The average discharge (q_p) per port (port flow rate) is:

q_p = 289/35 = 8.25 ℓ/s and for a peak diurnal flow rate q_p = 16.5 ℓ/s

The port exit velocity (vp) for average flows is:

$v_p = q_p/a_p = 0.00825/[\pi d_p^2/4] = 1.08$ m/s

Check if the Froude No > 1 for a seawater density (ρ_s) of 1026 kg/m^3 and an effluent density (ρ_e) of 1000 kg/m^3

$F_r = v_p/[g.d_p((\rho_s-\rho_e)/\rho_s)]^{1/2} = 1.08/[9.81 \mathrm{x} 1((1026-1000)/1026)]^{1/2} = 6.85 > 1$

A detailed hydraulic analysis will have to be conducted to optimise the diffuser in order to maintain the main pipe velocity throughout the diffuser (introduce tapers) and the port diameters will have to be increased to ensure that the discharge is uniform along the diffuser.

6.5.5 Hydraulic analysis

The hydraulic analysis is based on the hydraulic energy balance for the complete system by comparing the specific energy between any two points in the system, taking into account all friction and fitting losses between two adjacent points. This balance ensures continuity of flow.

The flow (discharge) from a single port is given in Figure 6.32 (Rawn *et al*, 1960):

$q = C_D.a(2g.E)^{1/2}$ where $q = v_p.a$

thus

$v_p = C_D(2g.E)^{1/2}$

$E = V^2/2g + P/\rho_e - H.\ \rho_s/\rho_e$

Where

q	=	port discharge (m^3/s)
C_D	=	port discharge coefficient which is a function of the main pipe velocity and the entrance configuration (smooth, rounded edges, elbow-port, etc.). For an elbow port a value of 0.75 can be assumed for a first assessment.
a	=	port cross-sectional area (m^2)
E	=	Total energy head in the outfall line (m)
v_p	=	port velocity (m/s)
ρ_s	=	seawater density (kg/m^3)
ρ_e	=	effluent density (kg/m^3)
V	=	main pipe velocity (m/s)
H	=	water depth (m)
P	=	pressure in the pipe (kg/m^2)

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FIGURE 6.32: Energy balance for flow from a single port

As the flow from each port is a function of the total energy head (E), the energy increases from the offshore port inshore. This is a result of the friction loss between adjacent ports and the increase in head resulting from the increase in the slope of the seabed (Refer to the definition sketch for head losses in the main pipe in Figure 6.33 taken from Williams [1985]):

$$E = E_1 + \sum_{j=1 \text{ to } n}[(f.s/2g.D)V_j^2] + \sum_{j=1 \text{ to } n}[\beta(H_1-H_j)]$$

and for continuity of flow at each port

$$Q_j = Q_{j-1} + q_j$$

Where

f	=	friction factor
s	=	distance between ports (m)
V_j	=	Velocity in the diffuser pipe between ports j and (j+1) (m/s)
Q	=	Flow in the diffuser pipe (m^3/s)
q	=	Port flow (m^3/s)
β	=	ρ_s/ρ_e - 1

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FIGURE 6.33: Head losses in a multi-port diffuser (Williams, 1985)

The equations presented above can be solved manually. However because hydraulic analysis is an iterative procedure, hydraulic engineers should use an existing computer programme, or write their own, to optimise a multi-port diffuser, because numerous runs may be required to comply with the requirements (ensure even port flow distribution along the diffuser, maintain main pipe velocities to prevent deposition, ensure that Froude numbers for all ports are greater than one, achieve the required initial dilutions). Typical outputs required to evaluate the functionality of a diffuser configuration are:

- Total headloss (friction and fitting losses in the main pipe as well as the diffuser)
- Minimum velocity in the main pipe at any point in the diffuser
- Minimum Froude Number.

A typical diffuser layout is shown in Figure 6.34 and the graphical outputs required to evaluate the hydraulic functionality of the outfall system in Figures 6.35a and 6.35b.

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FIGURE 6.34: Typical diffuser layout

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FIGURE 6.35 a: Example of graphical output required to evaluate hydraulic functionality: Main pipe velocities in the diffuser section (top) and port flow rates (bottom)

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FIGURE 6.35 b: Example of graphical output required to evaluate hydraulic functionality: Port Froude Numbers (top) and port exit velocities (bottom)

6.5.6 Data requirements for pre-assessment and detailed investigation

The procedures described in Section 6.5.1 to 6.5.5 need to followed, in both the pre-assessment and detailed investigation stages, albeit to different levels of detail.

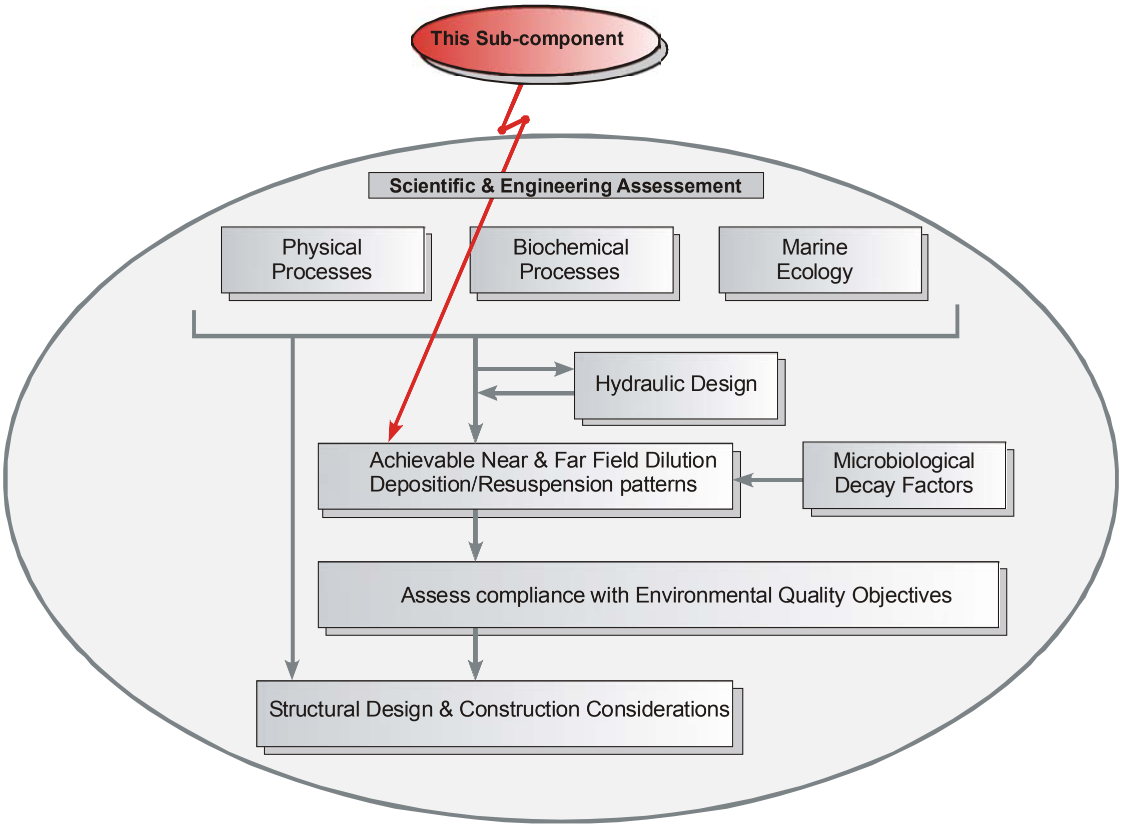
For the pre-assessment, the level of detail that would typically be required includes:

- A range of friction factors (e.g. average to maximum) for possible pipe material types
- Main friction components, e.g. taking into account only the friction in the main pipeline and the diffuser section (excluding detailed components such as bends, contractions and valves)
- Single (rather than detailed dynamic) hydraulic calculations to assess typical discharge patterns for the average to worst case wastewater flow scenarios
- Available geophysical data and information to estimate the pipeline profile and physical conditions at the discharge location.

For a detailed investigation, a much higher confidence is required and typical requirements include:

- Refinement of friction factors according to the manufacturer's specification for the selected pipe material, also taking into account detailed components such as bends, contractions and valves
- Detailed transient pressure calculations of the entire outfall system
- Detailed modelling of dynamic hydraulic processes, taking into account realistic wastewater discharge patterns
- Determining the actual pipeline profile and physical conditions at the discharge location, using detailed geophysical measurements.

6.6 ACHIEVABLE DILUTION



PURPOSE:

The purpose of this section is to determine the achievable dilution of a wastewater plume on entering the receiving marine environment, through:

- ***The initial dilution process (S_i), in which a buoyant plume rises from the diffuser or an open end pipeline to the surface of the sea***
- ***The secondary dilution (S_d) or subsequent dilution process (after dissipation of the energy during the initial dilution phase), in which the plume (waste field) is transported to distant locations by ocean currents.***

The concentrations of non-conservative substances, such as microbial organisms, will be further reduced by 'decay', that is the die-off of the organisms. This reduction is discussed in the following section.

6.6.1 Overview

When a buoyant wastewater plume is discharged into the sea, various physical, chemical and biological processes bring about the reduction in concentration of the constituents.

The physical dilution of a wastewater plume consists of two distinct processes:

- The initial dilution is the process (S_i) in which a buoyant plume rises from the diffuser or an open ended pipeline to the surface of the sea. The dilution is brought about by the entrainment of seawater during the rise of the plume. The influencing parameters are the buoyant and momentum flux of the jet, the ambient currents and the density structure of the receiving water column. Adapting the diffuser design for a certain ambient environment can optimise the dilution obtained from this process. The physical extent (i.e. height above the diffuser and distance from the diffuser) of the initial dilution process can be described as the **Initial Mixing Zone**.

  The entire concept of achievable initial dilution is based on the assumption that the receiving water is continuously moving and that 'clean' water is always available for entrainment and subsequent dilution of the wastewater plume. In estuaries and the surf zone this is not the case.

- The secondary dilution (S_e) or subsequent dilution (after dissipation of the energy during the initial dilution phase) occurs when the plume (waste field) is transported to distant locations by ocean currents. During the transport of the waste field, mixing occurs as a result of eddies that arise from various physical processes, also referred to as eddy diffusion. In contrast to the initial dilution process, secondary dilution cannot be influenced by the design of the outfall and is primarily dependent on the near-shore oceanographic conditions.

The concentrations of non-conservative substances, such as microbial organisms, will be further reduced by 'decay', that is, the die-off of the organisms. A predominant factor determining the rate of die-off is solar radiation. Other factors such as osmotic shock (caused by rapid salinity changes) and sedimentation can also contribute to the decay rate, although to a lesser degree.

Because of the differences in the physical processes operating in the offshore environment, the surf zone and in estuaries, different prediction techniques for secondary dilution and dispersion need to be applied in each of these environments.

The physical processes in the offshore environment are less complex than, for example those in the surf zone and estuaries. As a result, offshore processes can usually be described more accurately by applying standard numerical statistical analyses to data records representative of conditions in a particular study area. Because of the complex hydrodynamic processes in the surf zone, the prediction of the behaviour of an injected water source is less exact for the surf zone than for the offshore environment, and analytical prediction methods thus have to be based on model and prototype observations.

In the case of offshore marine outfall, the total achievable dilution of a conservative substance at a distant location will be the initial dilution (S_i) multiplied by the secondary dilution (S_e); for microbiological substances, the decay 'die-off' (S_d) of the organisms will further contribute to the total dilution. The process is illustrated in Figure 6.36.

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FIGURE 6.36: ***Illustration of the different dilution components making up the total achievable dilution for an offshore marine outfall***

Normally the magnitude of the dilution for a deep-sea outfall in > 20 m water depth is:

- Initial dilution (S_i): > 200 times under calm conditions
  > 1000 under fairly moderate conditions (e.g. currents of greater than 0.2 m/s)

- Secondary dilution (S_e): 2 to 10 times after 1000 m

- Decay (S_d) will vary according to the current speed and distance (travelling time) and the value of the decay rate T_{90} (see Section 6.4) - Example: T_{90} value of 2 hours (daytime) and a current speed of 0.2 m/s will result in:

  Decay (S_d): 5 times after 1 km.

Thus for calm conditions, the total dilution can range from 400 to 2000 for conservative substances and from 2000 to 10000 for microbiological organisms. It is clear that the main contribution to the total dilution is the initial dilution process (S_i).

In considering discharges to the surf zone, the key factors in determining dilution are long-shore dispersion ('secondary dilution') and microbial decay (i.e. the processes resulting in 'initial dilution' are not relevant). Thus total dilutions are two to three orders of magnitude less than those that can be achieved with outfalls in the offshore environment.

The complex hydrodynamic processes affecting dilution in the surf zone are illustrated Figure 6.37.

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FIGURE 6.37: Illustration of the total dilution process for a surf zone discharge

Estuaries with permanently open mouths can be considered as semi-enclosed water bodies in which the exchange of water between the estuary and the sea is dependent on a source flow (river inflow), the diurnal and semi-diurnal tidal differences in water levels in the estuary and in the sea, and the 'size' (cross-sectional area) of the estuary mouth. The exchange of water results in dynamic conditions (currents) with a periodic velocity variation, changing direction approximately every 12 hours if the net source flow is less than the tidal flow. Theoretically, a volume of water, equal to the surface area of the estuary multiplied by the tidal height (the tidal 'prism'), will be exchanged between the sea and the estuary over a tidal cycle. Thus, if a wastewater plume is mixed uniformly with the water in an estuary, the dilution will be proportional to the tidal prism. However, there are many factors that inhibit the advection and dispersion of the wastewater stream within an estuary and prevent the wastewater from being uniformly mixed with the estuarine waters.

In the case of estuaries in which the mouth is closed, dilution (mixing) is limited to dispersion of the wastewater plume into adjacent waters in which concentrations are lower.

The different dilution processes are discussed in more detail in the following sections.

6.6.2 Initial dilution (only offshore)

Numerous field studies have provided a basis for the verification of theories that predict the hydraulic behaviour of an 'injected' water source into a dynamic water body. Numerical solutions were derived from analytical techniques and sophisticated models were developed for the accurate prediction of the behaviour of 'jets' (e.g. wastewater plume) released in 'deeper' waters.

The behaviour of a wastewater stream jetted into a water body with a density greater than that of the wastewater stream (generally referred to as a buoyant wastewater plume) depends on the dynamics and stratification of the receiving water body. Initial dilution is brought about by the entrainment of surrounding 'clean' seawater into the wastewater jet as it leaves the diffuser port and the further entrainment which occurs as the buoyant plume rises to the surface. Laboratory experiments and field measurements yielded a normal (bell-shaped) distribution of concentrations in a rising wastewater plume with the maximum concentrations at any point in the plume being 1.74 times the average concentration across the plume (Roberts, 1977).

The typical receiving water conditions and the subsequent behaviour of a wastewater plume are:

- *Stagnant unstratified water* (no currents and no stratification), in which the wastewater plume will rise vertically to the surface and laterally dispersed in a surface field.

- *Stagnant stratified water* (no current with a density gradient between the surface and the bottom), in which the rising of the wastewater plume can be inhibited and a submerged waste field can be formed below the surface (this is not considered to reflect a 'real' situation in the marine environment, as stagnant stratified conditions in an open marine environment rarely occur)

- *Moving, unstratified water* (currents and no stratification), in which the current component will lengthen the time and the path of the rising plume, thereby enabling it to entrain seawater and resulting in increased initial dilutions

- *Moving, stratified water* (currents and stratification), in which the current component will lengthen the time and the path of the rising plume, but the wastewater plume will become trapped below the surface because of the inhibitory effect which stratification has on the rising of the plume.

Examples of typical behaviour patterns are illustrated in Figure 6.38.

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FIGURE 6.38: ***Buoyant plume in (a) stagnant, unstratified water, (b) stagnant, stratified water, (c) moving (weak currents) stratified water and (d) in moving (moderate currents), stratified water***

An overview of all possible sea conditions at a certain area can be estimated or determined from available data and the worst-case initial dilution scenario (lowest dilutions) determined. However, the most exact and realistic method is to use a site-specific real-time current/stratification data record as input to a diffuser hydraulic program in order to obtain the extreme dilutions and plume rise heights together with a statistical output (occurrences/exceedances) of achievable initial dilutions.

The theories of dilutions put forward by Roberts (1977) are well-known and are widely applied in the theoretical prediction of dilutions. These theories form the basis of many analytical and numerical models. Roberts shows, by dimensionless analysis, that the minimum dilution, S_{min}, in stagnant uniform sea conditions, on the centre line of a buoyant plume of wastewater rising from a single round port in a diffuser on the seabed, depends on two dimensionless groupings:

$S_{min}/F_r = [y/d_p.F_r , 1/F_r]$

Where

y	=	height above the jet exit where S_{min} is determined (m)
d_p	=	port diameter (m)
F_r	=	Froude number
	=	$v_p/[g.d_p(\Delta\rho/\rho_s)]^{1/2}$

and

v_p	=	port velocity (m/s)
$\Delta\rho$	=	$\rho_s - \rho_e$
ρ_s	=	seawater density (kg/m^3)
ρ_e	=	effluent density (kg/m^3)
d_p	=	port diameter (m)

Roberts (1977) also summarised initial dilution prediction methods (Cederwall, 1967; Abraham *et al.*, 1983; Fan & Brooks, 1969) and compared these with laboratory experiments (Hansen & Schroder, 1968; Cederwall, 1967; Liseth, 1970). Fan and Brooks (1969), for example developed theoretical procedures solving simultaneous differential expressions for conservation of continuity, momentum, density difference and concentration (these are solved by numerical integration). Taking all of the above into account, Roberts proposed the following equation, valid for all ratios of $y/d_p.F_r$:

$$S_{min} = 0.107.\ F_r\ [1.6 + 5(y/d_p.F_r) + (y/d_p.F_r)^2]^{5/6}$$

and for $y/d_p.F_r > 20$ reduces to:

$$S_{min} = 0.107.\ F_r\ (y/d_p.F_r)^{5/3}$$

Average dilution ($S_{av} = 1.74 S_{min}$)

EXAMPLE…

Dilution in an ambient current according to Roberts (1977):

The port flow (q_p) for peak diurnal flows: 16.5 ℓ/s
Water depth: 20 m
Seawater density: 1026 kg/m^3
Effluent density: 1000 kg/m^3
Port diameter: 0.1 m

$\Delta\rho = \rho_s - \rho_e$ = 1026 – 1000 = 26 kg/m^3

Port exit velocity (v_p) = q_p/a_p = 0.0165/[$\pi d_p^2/4$] = 0.0165/[$\pi\ 0.1^2/4$] = 2.1 m/s

F_r = $v_p/[g.d_p(\Delta\rho/\rho_s)]^{1/2}$
= $2.1/[9.81x.1(26/1026)]^{1/2}$ = 13.32 < 20

For the dilution at the surface, 18,5 m (y) above the port (take the port exit at 1,5 m above the seabed):

S_{min} = $0.107 \times F_r\ [1.6 + 5(y/d_p.F_r) + (y/d_p.F_r)^2]^{5/6}$
= $0.107\ x13.32\ [1.6 + 5(19.5/0.1 \times 13.32) + (19.5/0.1 \times 3.32)^2]^{5/6}$
= 160

S_{av} = 278

For dilutions in an ambient current, Roberts (1977) used laboratory testing to provide empirically derived coefficients for relationships based mainly on dimensional analysis. The relationships relate to 'slot plumes' that are equivalent to a curtain of buoyant wastewater plume rising in a homogeneous sea. Such a curtain would be formed by closely spaced diffusers which would cause merging of plumes close to the seabed. He used a dimensionless Froude number F_a to describe the relative strength of the ambient current:

F_a = u_a^3/b

where
u_a = average ambient current (m/s)
b = buoyancy flux per unit length of the diffuser
= $g\ (\Delta\rho/\rho_s).(Q/L)$
Q = Total discharge (m^3/s)
L = Total length of the diffuser (m)

Where $F_a > 0.1$ (for $F_a < 0.1$ the increased dilution is negligible), the following expression for initial dilution in a current perpendicular to a diffuser can be used:

S_{av} = $0.58(u_a.H)/(Q.L)$

where
H = water depth (m)

This is a conservative approach to obtain a rapid estimate of the achievable dilutions.

EXAMPLE…

Dilution in moving water according to Roberts (1977):

The total peak diurnal discharge (Q_{peak})	0.578 m^3/s
Water depth:	20 m
Seawater density:	1026 kg/m^3
Effluent density:	1000 kg/m^3

Length of the diffuser (L): 7 x 34 m = 238 m

$\Delta\rho = \rho_s - \rho_e = 1026 - 1000 = 26\ kg/m^3$
Buoyancy flux per unit length of the diffuser (B):
$B = = g\ (\Delta\rho/\rho_s).(Q/L) = 9.81(26/1026)(0.578 \times 238) = 34.2$

The current velocity that will have an effect on the achievable initial dilution when:

$F_a = u_a^3/b > 0.1$
$u_a > (0.1 \times 34.2)^{1/3}$ thus if $u_a > 1.5$ m/s

For normal inshore conditions along the South African coastline, the net current speed rarely exceeds 1.5 m/s. Thus the increase in dilution is negligible.

Wright's (1984) theory refers to individual rising plumes in an average ambient current and makes provision for a linear, stratified environment. The vertical density profile present in the ambient seawater causes the plume to entrain denser water close to the bottom so that the density of the diluted plume could equal that of the surrounding sea water at some intermediate height before reaching the sea surface. The height above the port at which the plume ceases to rise is:

$z_m = 2.3(g_1.q_p/u_a)^{1/3}.G^{-1/3}$

where

q_p	= port discharge (m^3/s)	
G	$=g/\rho_{sb}.(\rho_{ss}-\rho_{sb})/H$	(density gradient parameter)
ρ_{sb}	= density of the seawater at the seabed (kg/m^3)	
ρ_{ss}	= density of the seawater at the sea surface (kg/m^3)	
g_1	$= g[(\rho_a-\rho_e)/\rho_a]$	(relative density parameter)
ρ_a	$= (\rho_{sb}+\rho_{ss})/2$	(average density of the water column)

After computing the rise height (z_m) the average dilution is determined as follows (Wright, 1984, Chu, 1979, Roberts, 1977):

$S_{av} = 0.71.u_a.z_m^2/q_p$

EXAMPLE…

Initial dilution for linear stratification and an ambient current:

The port flow (q_p) for peak diurnal flows: 16,5 ℓ/s
Water depth: 20 m
Effluent density: 1000 kg/m^3
Seawater density at the surface (ρ_{ss}) : 1025 kg/m^3
Seawater density at the bottom (ρ_{sb}) : 1026 kg/m^3

$G = g/\rho_{sb}.(\rho_{ss}-\rho_{sb})/H = 9.81/1026\ (1/20) = 0.000478$
$\rho_a = (\rho_{sb}+\rho_{ss})/2 = (1026 + 1025)/2 = 1025,5$
$g_1 = g[(\rho_a-\rho_e)/\rho_a] = 9.81[(1025.5 - 1000)/1025,5] = 0.2439$

For a current velocity (u_a) of 0,2 m/s, the rise height of the plume (z_m) is:

$$z_m = 2.3(g_1.q_p/u_a)^{1/3}.G^{-1/3}$$
$$= 2.3(0,2439 \times 0.0165/0.2)^{1/3} \times 0.000478^{-1/3}$$
$$= 8.0 \text{ m}$$

The average initial dilution at a height of 8.0 m is:

$$S_{av} = 0.71u_a.z_m^2/q_p = 0.71 \times 0.2 \times 8^2/0.0165$$
$$= 550$$

For a current velocity (u_a) of 0,1 m/s, the rise height of the plume (z_m) is:

$$z_m = 2.3(g_1.q_p/u_a)^{1/3}.G^{-1/3}$$
$$= 2.3(0.2439 \times 0.0165/0.1)^{1/3} \times 0.000478^{-1/3}$$
$$= 10.1 \text{ m}$$

The average initial dilution at a height of 10,1 m is:

$$S_{av} = 0.71u_a.z_m^2/q_p = 0.71 \times 0.1 \times (10.1)^2/0.0165$$
$$= 439$$

After an analysis of laboratory and field data, the WRc (1990) suggested an approach for horizontal round buoyant jets in stagnant water. Two regimes for round buoyant jets should be considered: (a) the buoyant-dominant condition (BDC), when the buoyancy flux of the rising plume is the controlling parameter for achievable dilutions, and (b) a current-dominant condition (CDC), in which the dilution is influenced less by buoyancy and more by ambient currents.

For discharge into a cross-flowing current a CDC exits when:

$$y < 5.B/u_a^3$$

where
y = height above port exit (m)
u_a = ambient current velocity (m/s)
B = $g\ (\Delta\rho/\rho_s).q_p$ (buoyancy flux)

For a buoyant-dominant condition (BDC) the initial dilution is given as:

$$S = C_w(B^{1/3}.H^{5/3})/q_p$$

And for a current -dominant condition:

$$S = C_w(u_a.H^2)/q_p$$

C_w was derived from actual measurements to provide statistical probabilities of exceedance for the minimum dilution:

	Cw - VALUES	
	Buoyant-dominant condition (BDC)	***Current-dominant condition (CDC)***
95 percentile	*0.16*	*0.11*
Median	*0.27*	*0.27*
Mean	*0.34*	*0.32*

EXAMPLE…

Initial dilution in an ambient current according to WRc (1991):

The port flow (q_p) for peak diurnal flows:	16,5 ℓ/s
Water depth:	20 m
Effluent density:	1000 kg/m^3
Seawater density:	1026 kg/m^3

The buoyancy flux (B) is:

B = g ($\Delta\rho/\rho_s$).q_p = 9.81(26/1026) x 0.0165 = 0.0041018

For a current velocity (u_a) of 0,2 m/s:

$5.B/u_a^3$ = 2.564 which is < 20 m (water depth) thus a CDC exists and the mean initial dilution is:

S_{mean} = $C_w(u_a.H^2)/q_p$ = 0.32(0.2 x 202)/0.0165
= 1551

For a current velocity (u_a) of 0,1 m/s:

$5.B/u_a^3$ = 20.5 which is > 20 m (water depth) thus a BDC exists and the mean initial dilution is:

S_{mean} = $C_w(B^{1/3}.H^{5/3})/q_p$ = $0.34(0.0041018^{1/3} \times 20^{5/3})/0.0165$
= 486

The United States Environmental Protection Agency (US-EPA, 1985) developed methods for dilution estimates for various ambient and diffuser conditions and published standard computer programmes that are recommended for use in the evaluation of initial dilution in a standard way in the design stage. Original programmes published by Baumgartner *et al.* (1971) were updated in US-EPA (1985). One program, UOUTPLM, computes rise heights and initial dilutions for stagnant and moving water, non-uniform sea states. The computations are based on tracking a plume element as it gains mass due to ambient fluid entrainment. Horizontal momentum, energy, density, buoyancy and dilution are computed as the element rises through the water column. The computation ends when either the vertical velocity reaches zero or the water surface is reached. The input parameters include the density of the wastewater, port discharge angle, port discharge rate besides the surface, and seabed current velocities and water densities.

The UOUTPLM programme has been coupled to a multi-port diffuser hydraulic model to facilitate the optimisation of the diffuser with regard to the achievable dilutions, and applied to numerous outfall projects. The model output includes interactive visual trajectories of the plumes for all the ports of the diffuser and standard graphical outputs of the entire range of diffuser characteristics. A far field dilution prediction technique (based on the Brooks method) for conservative and non-conservative substances has also been linked to the model for an assessment of achievable dilutions for compliance with environmental quality objectives at distant locations (WAMTechnology 1996, WAMTechnology 1997, Van Ballegooyen et al., 2003, Van Ballegooyen & Botes 2003, GIBB Eastern Africa, 1997).

The procedure was further refined to provide dilutions and plume rise heights as input data to 3-dimensional and 2-dimensional far field numerical models for time series (current velocities, seawater densities and wastewater flows) in sections which correspond to the grid of the far field numerical models (CSIR 1996, CSIR 1998, HR Wallingford 1997).

6.6.3 Secondary dilution

i. Offshore

A standard analytical prediction method for secondary dilution for a current perpendicular to the diffuser is based on a method developed by Brooks (1960). This method defines the horizontal diffusion coefficient, a controlling parameter in the determination of secondary dilutions, as follows:

$K_o = \alpha L^n$

Where L refers to a length scale (waste field width – 10 to 10 000 m) and a value of 4/3 for n is recommended for offshore outfalls. In calmer waters the spreading of the waste field is curtailed as a result of limited eddies and n values < 1 will be more applicable. Where the lateral spreading of an effluent plume is restricted by the shoreline or estuary banks, the value for n =0.

A general α-value (dissipation parameter) of 0.0005 $m^{3/2}/s$ is used. However, due to the diversity of the coastal processes along the 3 000 km South African coastline, the application of a 'general diffusion' coefficient has caused some concern over the last few years and, therefore, warranted investigation. Botes and Taljaard (1996) assessed all available data (data included the Lagrangian recording of currents, using pairs of surface and sub-surface drogues and tracer (i.e. Rhodamine B) measurements) measured at existing and proposed outfall sites in South Africa between 1982 and 1994, applying techniques relevant to each data type for determining the magnitude of eddy diffusivity at various locations along the South African coastline (i.e. diffusion coefficients). Botes and Taljaard (1996) found that the α-value of 0.0005 $m^{3/2}/s$ represents the average for seven locations along the South African coastline (data from 1881 to 1994). However, the α-value may vary from 0.0003 $m^{3/2}/s$ at the West Coast to $\pm$ 0.002 on the East Coast at Richards Bay.

Referring to Figure 6.39, it is assumed that the concentration across a wastewater plume at a distance x from the discharge location, resembles a Gaussian distribution in which the average concentration is:

$C_x = C_{max}/1.5$

The surface plume at the diffuser is taken as a steady line source of a width b and transported by a steady uniform current. The minimum secondary dilution can then be expressed as:

$S_{e(min)} = C_o/C_{max}$

For the 4/3 'law' Brooks (1960) expressed C_{max} as:

$C_{max} = C_o.\ \mathrm{erf}[3/2/\{(1 + 2/3\beta.x/b)^3-1\}$

where

$\beta = 12K_o/u_a b$
$\beta = 12K_o t/xb$
K_o = initial horizontal diffusion coefficient (m^2s)
b = initial plume width (m) if the current is perpendicular to the outfall
b = (b + 2H)Sinθ
θ = angle between the wave and the diffuser
u_a = current speed (ms^{-1})
x = distance from the diffuser (m)

Determine a dimensionless distance (T)

$T = \beta.x/b$
$T = 12K_o x/u_a b^2$

Note: There are doubts about the accuracy when applying this theory to the direct onshore case (θ = 0: current parallel to the diffuser). Although such a condition is likely to be rare for a long marine outfall, it must be kept in mind that the method will tend to an under-prediction of dilutions.

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FIGURE 6.39: An illustration of Brooks's surface plume model

For a desktop assessment, the parameter β can be calculated and the secondary dilution obtained from the graph in Figure 6.40. The plume width at distance x can be determined from:

$$L_x = b[1 + 2/3(12K_o t/b^2)]^{3/2}$$
$$= b[\ 1 + 2T/3]^{3/2}$$

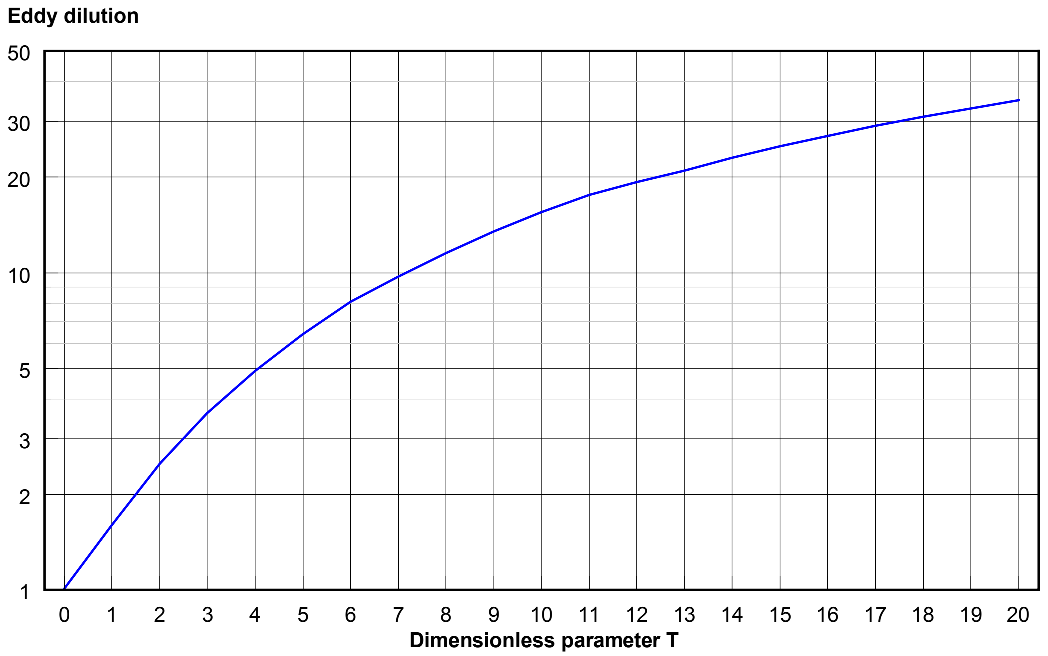

***FIGURE 6.40: Graph from which to calculate secondary dilution using the dimensional parameter* (T)**

EXAMPLE…

Diffuser length (b): 238 m (no. of ports x port spacing)
α-value: 0,0005 $m^{3/2}/s$
Current speed (u_a): 0,2 ms^{-1}
K_o $\alpha.b^{4/3}$ = 0.0005 x $238^{4/3}$ = 0.7374

The value of b, distance (x), time (t) and the secondary dilution from Figure 6.40 are shown below and illustrated graphically in Figure 6.41:

Distance (x) (m)	T ($12K_ox/u_ab^2$ = 0.00078x)	Time (h) (3600.x/u_a)	Se	Plume width = $b[1 + 2T/3]^{3/2}$ (m)
500	0.39	0.69	1.1	256
1000	0.78	1.39	1.4	446
2000	1.56	2.77	2.3	693
3000	2.34	4.17	2.8	974
4000	3.12	5.56	3.6	1286
5000	3.91	6.94	4.7	1630

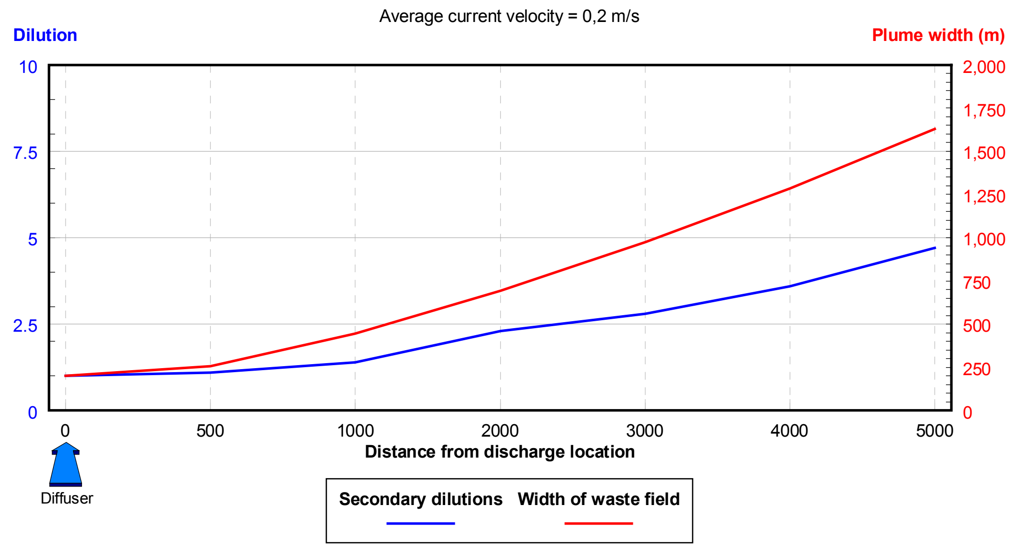

FIGURE 6.41: Secondary dilutions and plume widths versus distance

An illustration of a waste field along a straight coastline, using Brooks's surface plume model, is illustrated in Figure 6.42. In reality, the situation is far more complex because of the horizontal and vertical 'meandering' of nearshore currents. The more complex the physical configuration of the coastline, the more complex the circulation patterns in time and space. Therefore, the first principle when selecting an outfall site should be to search for the straightest stretch of coastline and an evenly sloping bottom topography. In Figure 6.43, the behaviour of a waste field along a rugged coastline is schematised. Currents behind promontories form complex eddies with direct onshore components and lower current velocities that will result in possible deposition of suspended solids.

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FIGURE 6.42: Illustration of a waste field along a straight coastline using Brooks's surface plume model

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FIGURE 6.43: Illustration of a waste field along a coastline with promontories

Brooks's method is a highly parameterised method as evidenced by the wide range of dissipation parameters and values applicable to the South African coast. A more robust method for assessing secondary dilution is through the use of a 3-D numerical modelling, albeit a significantly greater effort and cost.

An illustration of the output of a 3-D far field numerical model on a waste field at a specific time, utilising the hydrodynamic data (illustrated in Figures 6.42 and 6.43), is in Figure 6.44.

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FIGURE 6.44: 3-dimensional simulation of an outfall plume

ii. Surf zone

Currents in the surf zone (littoral zone) are wave-dominated, and initial mixing is rapid due to the vigorous processes of which the longshore and cross-shelf transport are the most dominant. Longshore transport is driven by the momentum flux of shoaling waves approaching the shoreline at an angle while cross-shelf transport is driven by the shoaling waves. Water is transported out of the surf zone by rip currents which results in the diffusion of surf zone water into the offshore waters. Some of the water expelled beyond the surf zone may be transported back into the surf zone with the next set of waves. It is important to note that onshore winds and an incoming tide will tend to keep water in the surf zone, where offshore winds and an outgoing tide will contribute to the transport of water away from the shoreline.

Normally stratification in the surf zone area will be insignificant because of vigorous processes and the subsequent high degree of mixing. Horizontal density differences may occur as a result of solar heating in sheltered shallow waters.

There are periods of meandering flow along a shore, and other times when the flow is more uniform. Some periods exhibit clear indications of rip currents, others not. It is difficult to predict the fate of a waste field in this non-linear surf zone regime and it is not easy to provide quantitative answers on the degree of mixing or transport that can be expected, even for a specific day. During field exercises in False Bay, the behaviour of a waste field changed drastically within hours (meandering of the flow, change in direction along the shore, change of rip currents, etc.) without observable changes in the weather or sea state.

The major mechanisms that contribute to the dispersion of surf zone discharges include:

- Breaking waves, which cause 'rapid' mixing normal to the shoreline within the breaker zone.
- Rip currents, which result in the longshore advection of the waste field.

Inman *et al.* (1971) describe the mixing process in the surf zone as the transport of water between 'nearshore circulation' cells, formed between adjacent rip currents, as well as the exchange of water from the surf zone to the offshore region.

According to Inman *et al*. (1971), a wastewater stream that is introduced into surf zone will be diffused by the turbulence in the breaking waves until it has a uniform distribution over the width of the breaker zone. Further dilution will then be brought about by the longshore advection related to the longshore current and the strength and spacing of the rip currents. Inman *et al*. (1971) expressed the change in concentration in terms of the concentration and a vector distance as:

$$\partial C/\partial t = \partial/\partial r\ (\upsilon\ .\ \partial C/\partial r) - \partial/\partial r(C.u) + R_s$$

where
$\partial C/\partial t$ = change in concentration in time
υ = kinematic coefficient of diffusion
u = velocity
R_s = change in concentration in time due to a source

<u>Initial mixing.</u> The concentration (C_o) of a substance after initial mixing of the concentration (C_e) in the wastewater is:

$$C_o = C_e/v_x$$

where v_x is the cross-shore mixing coefficient. Prototype tests yielded the following semi-empirical relation (Inman, 1971):

$$v_x = H_{brms}.X_b/T$$

where
H_{brms} = rms breaker height (m)
X_b = surf zone width (m)
T = incident wave period (s)

The following equation was derived after further prototype dilution experiments:

$$v_x = 5.22.\ c_2.H_b.X_b/T$$

where c_2 is a dimensionless friction coefficient and determined as 0,1 for steeper beach slopes (1 in 10) and 0.2 for less steep slopes.

Referring to CSIR (1995), surf zone widths determined from wave data for 1990/1991 for the northern beaches at Richards Bay (South Africa) ranged between 75 m and 325 m, with an average of approximately 120 m. CSIR (1995) provided a mean breaker height of 1.55 m and mean peak wave period of 11.1 s for the area. These average values yield a cross-shore mixing coefficient of approximately 13. Measurements at two surf zone discharges (for flow rates varying from less than 0,2 m^3/s to 3 m^3/s) in False Bay indicated that dilutions rarely exceeded 10 within 100 m from the discharge location.

Longshore dispersion. After initial dispersion, the plume is transported by the longshore currents and separated by the rip currents where part of it is transported to the offshore region by the rip current and part of it leaks to the next circulation cell (Figures 6.45). Inman *et al.* (1971) describe the effect of the rip current as:

$R_R = Q_m/Q_{m-1}$

where
Q_m = Total longshore flow in cell m
Q_{m-1} = Total longshore flow in cell (m – 1)

Thus the rip current flow is:

$Q_R = Q_m - Q_{m-1}$

From field data it was found that R_R is in the range 0 to 0.5, where R_R approaches 0.5 when the longshore current velocity > 0,4 m/s.

The concentration in the m-th cell is:

$C_m = C_{m-1}.(R_R)$
$C_m = C_0.(R_R)^n$

An approximation in terms of the distance from the discharge location and the length of the circulation cells yielded:

$C_m = C_0.(R_R)^{y/Y}$

where
y = distance from the discharge location (m)
Y = length of the circulation cells (m)

The length of circulation cells (Y) related to the surf-zone width was extensively investigated theoretically and by assessing prototype data. Most investigations yielded a factor between 2 and 5. Analysis of aerial photos at Richards Bay over a period of 11 years yielded an average of 3.5 (range 2.3 to 5.3).

Longshore current velocities at Richards Bay (CSIR, 1995) were determined theoretically and were correlated with field measurements, using Rhodamine B. These yielded a maximum of 0.8 m/s with peak occurrences at about 0.3 to 0.4 m/s.

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FIGURE 6.45: Illustration of the longshore transport and dispersion processes in the surf zone under normal and oblique wave direction

In order to obtain an idea of the magnitude of the dilutions along the beach according to the above theory, conditions along the northern beach at Richards Bay (South Africa) is used as an example (CSIR, 1995). Based 1990/1991 wave data collected in 1990/1991, surf zone widths along the beach ranged between 75 m and 325 m with an average of approximately 120 m, resulting in a predicted average length of the circulation cell of 420 m. Using a R_R value of 0.5 (longshore current velocity equalled 0.4 m/s) the achievable dilutions versus distance were estimated as:

DISTANCE (m)	*DILUTION*
500	*1*
1000	*5*
1500	*11*

This process is further illustrated by an example of the dye dispersion patterns observed in the surf zone in False Bay (Cape Town) during a continuous release (CSIR, 1991a) (Figure 6.46).

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FIGURE 6.46: Example of a dye dispersion test during a continuous release to the surf zone in False Bay (Cape Town)

Where appropriate data are available (e.g. high resolution wave time series data), a combination of wave and hydrodynamic modelling of the nearshore can be used to predict dilutions in the surf zone in greater detail.

iii. Estuaries

An open estuary can be considered as a water body with a 'pumping mechanism' due to the gravitational in- and outflow of the tide, which in theory can result in the flushing of the estuarine waters. A simplistic approach is to assume that wastewater is mixed uniformly with the estuarine waters, transported to sea during the outgoing tide and that uncontaminated water will flow to the estuary during the incoming tide. Theoretically a volume of water, equal to the area of the estuary times the tide height (the tidal 'prism'), will be exchanged between the sea and the estuary over a tidal cycle. Thus, if wastewater is mixed uniformly with the water of an estuary, there will be a 'dilution' proportional to the 'tidal prism'.

EXAMPLE…

The tidal prism (V_t) for an estuary 5 km long and on average 100 m wide during a tidal variation of 1 m is:

V_t = 5000 x 100 x 1 = 500 000 m^3

For a settlement with a population of 50 000, there will be a diurnal (24 hr) effluent volume of:

V_e = 50 000 x 0,25 = 12 500 m^3 (250 ℓ/day per capita)

The ratio V_t/V_e = 40, which is theoretically the best overall 'dilution' that can be achieved. During neap tides, with smaller tidal variations, this dilution will be further reduced.

For a point source (along the bank of an estuary), numerous factors contribute to the inhibition of the spreading and mixing of the wastewater plume. The process of mixing relates to the transport of a plume with the tidal current (advection) and the mixing with the adjacent estuary water with concentrations lower than the concentrations in the plume (dispersion). In shallow water areas where the bed resistance is high, flow velocities will be reduced and the wastewater can at times be trapped, in which the strong velocity shear between fast-moving channel flows and the slow moving waters in shallow areas, in which the bed resistance is high, will enhance the mixing process.

For a surface discharge, mixing will also occur vertically, because of the velocity shear between the different vertical layers. An illustration of the complex mixing processes associated with a fresh wastewater discharge into an estuary is illustrated in Figure 6.47.

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FIGURE 6.47: Illustration of the mixing of a wastewater plume in a partially stratified estuary

Because a discharge point is normally at the high-water mark at the estuary bank, the mixing will be site dependant, depending on the hydrodynamics at the discharge point. Tidal currents (ebb and flow) will provide some longitudinal advection dispersion. The estuary banks and cross-stream flow profile will limit lateral dispersion. The current velocity will change from a maximum to zero in six hours (as will the advection and dispersion). When changing direction, the past 6-hour plume will move with the new wastewater in the opposite direction – thus the 'mixing' will be less effective, because of mixing with the contaminated 'old' plume. Theoretically, the result will be that after a period, if the discharge is continuous, a wastewater plume will exist on both sides of the discharge location, with the maximum concentration of constituents potentially being the same as that in the wastewater. The fresh wastewater inflow will also result in reduced salinities, which in turn will increase the T_{90} value for microbiological organisms, thus reducing the die-off rate and increasing the possibility of contamination with regard to microbiological organisms.

Without elaborate field measurements, the ultimate behaviour of a wastewater plume in a stratified estuary can only be predicted by a verified 3-D numerical model.

In the case of a closed estuary, dilution (mixing) is limited to dispersion of the wastewater plume into adjacent waters, in which concentrations are lower.

EXAMPLE…

For an estuary 5 km long and on average 100 m wide, the surface area is:

$A = 5000 \times 100 \times 1 = 500\ 000\ m^3$

A settlement with a population of 50 000, there will be a diurnal (24 hours) effluent volume of:

$V_e = 50000 \times 0.25 = 12\ 500\ m^3$ (250 ℓ/day per capita)

The increase in level (Δh) over 24 hours is:

$\Delta h = V_e/A = 12\ 500/500\ 000 = 0.025\ m$

However, the mixing processes in an estuary are complex and change continuously according to the river inflow, tidal flow and the associated density structure. Figures 6.48 and 6.49 illustrate some of the complexities in the behaviour of a wastewater plume in an estuary, using actual simulations in the Swartkops River Estuary as an example. This example does not take vertical mixing processes, which is even more complex, into consideration (Figure 6.47). Figure 6.48 illustrates the difference in average flow velocities at three locations in the estuary (4 km, 10 km and 15 km from the mouth) under zero river inflow. Figure 6.49 illustrates the difference in the extent to which a wastewater plume is transported over a 12-hour tidal cycle, after wastewater has been released at the three locations. These differences clearly indicate the importance of considering transport and dispersion characteristics in the selection of an outfall location, where these are considered in estuaries.

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FIGURE 6.48: Difference in average flows at three locations in the Swartkops River Estuary (river inflow is zero)

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FIGURE 6.49: A simulation showing the difference in spatial behaviour of a wastewater plume released at different locations simulated in the Swartkops River Estuary

Apart from the dispersion and transport of a wastewater stream, discharges in estuaries can affect the physical dynamic processes of such systems, as discussed below:

- *Changes to mouth conditions*. Discharges can result in a significant increase in base flow and, as a result, can alter the pattern of mouth closure. For example, in small, temporarily open/closed estuaries, unstable conditions, resulting from almost complete draining of these systems during the open phase, prevent optimal biological production and, consequently a period of mouth closure is required for such systems to reach their optimal biological production.

EXAMPLE…

The Eerste River Estuary (in False Bay, South Africa) is a small estuary of approximately 10.2 ha draining a catchment of approximately 660 km^2 (CSIR, 2001b). Historically this was a temporally open/closed estuary, i.e. closing during summer and breaching again after the first winter rains. Now, as a result of numerous WWTW discharges, both directly to the estuary and in the catchment, elevated base flows have modified the system to a permanently open estuary.

Preliminary estimation of the correlation between river inflows and different states for the estuary is provided below:

PHASE	***ESTIMATED RIVER FLOW***
Mouth closed, but overwash of the berm by seawater occurs occasionally	*May occur at flows less than 0.1 m^3/s*
Mouth semi-open, where the mouth is open, but normally only outflow occurs. Some seawater intrusion takes place at spring high tides	*May occur at flows between 0.1 m^3/s and 3 m^3/s*
Mouth open with seawater intrusion (i.e. normal estuarine function)	*This state may occur only for brief periods after a freshette*
Mouth wide open with the estuary being completely fresh	*May occur at flows greater than 3 m^3/s*

- *Changes in salinity distributions*. Base flows into the estuaries of South Africa are often relatively low, between 0 and 0.2 m^3/s. This results in specific distributions of salinities and temperatures, which are important for the ecological processes. Even a small disposal of waste water of 0.01 to 0.2 m^3/s can have a significant effect on these distributions and in turn also on the ecological processes in those estuaries.

EXAMPLE…

Increase in the base flow to the Eerste River, as a result of wastewater discharges in the catchment, has resulted in a strong reduction in the intrusion of saline seawater into the system, which now occurs only for short periods. This has markedly modified the ecology of the estuary (CSIR, 2001b).

6.6.4 Microbiological decay

Universally, microbiological organisms, such as *E.coli* and *Enterococci*, are used as indicators of the likely presence of human pathogens and viruses of concern. Environmental quality objectives for beneficial uses where human health is an issue, such as recreation and mariculture, therefore, are typically set in terms of 'allowable counts' of these organisms.

Solar radiation is the most important factor for decay of these organisms in saline waters. The decay process is commonly described by the first order decay equation:

$C = C_o e^{-kt}$

where:

C	= Concentration at a distant location
C_o	= concentration after initial dilution
t	= travel time (h)
k	= $2.303/T_{90}$

Where T_{90} is the time it takes for 90% of the organisms to die

The dilution due to decay (S_d) can then be expressed as:

$$S_d = C_o/C = e^{kt}$$

T_{90} values are different for daytime and night time and also for summer and winter conditions.

The influence of current velocities on the dilutions due to decay at distant locations from the discharge, is illustrated in Figures 6.50 and 6.51.

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FIGURE 6.50: Dilutions due to decay versus distance under stronger current conditions. T_{90} = 2 hrs (daytime).

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FIGURE 6.51 Dilutions due to decay versus distance under weaker current conditions. T_{90} = 2 hrs (daytime)

EXAMPLE…

T_{90} (daytime) 2 hrs
T_{90} (night-time) 10 hrs
Current velocity (u_a) 0.2 m/s
Substitute t in e^{kt} with x/u_a as $u_a = x/t$ and k with $2.303/T_{90}$

$$S_d = e^{2.303.x/T_{90}.u_a}$$

The dilutions due to decay at distances from the outfall are:

DISTANCE (m)	***S_d ($e^{2303.x/T_{90}.u_a}$)***	
	Daytime	***Night-time***
500	*2.22*	*1.17*
1000	*4.95*	*1.38*
2000	*24.5*	*1.90*
3000	*121*	*2.61*
4000	*600*	*3.60*
5000	*2970*	*4.95*

NOTE: T_{90} values can vary widely, depending on the oceanographic and atmospheric conditions at a study area. The values used in the above example are considered typical values, based on measurements taken at different location across the world.

6.6.5 Total dilution

The total dilutions at distant locations for a wastewater discharge to the marine environment can be defined as:

S_T = Initial dilution x Secondary dilution x Decay
= S_i . S_e . S_d

EXAMPLE…

Refer to Section 6.6.3 and the example using Wright's theory (1984): for an ambient current (u_a) of 0.2 m/s the achievable initial dilution for a peak flow rate is:

S_i = 550

The total dilutions for conservative substances and for microbiological organisms at 500, 1000, 2000, 3000, 4000 and 5000 m distances from the outfall are:

DISTANCE (x in m)	***S_e***	***S_d***		***S_T (conservative substances)***	***S_T (Microbiological substances)***	
		Day time	***Night time***		***Day time***	***Night time***
500	*1,1*	*2.22*	*1.17*	*605*	*1343*	*710*
1000	*1,4*	*4.95*	*1.38*	*770*	*3811*	*1060*
2000	*2,3*	*24.5*	*1.90*	*1265*	*30992*	*2398*
3000	*2,8*	*121*	*2.61*	*1540*	*186340*	*4020*
4000	*3,6*	*600*	*3.60*	*1980*	*1188000*	*7117*
5000	*4,7*	*2970*	*4.95*	*2585*	*7677450*	*12794*

Figure 6.52 presents a graphical illustration of the achievable dilutions versus distance. This output provides the first overview/assessment of the environmental performance of the system while optimising the outfall

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FIGURE 6.52: A graphical illustration of the achievable total dilutions versus distance

6.6.6 Data requirements for pre-assessment and detailed investigation

The procedures described in Section 6.6.2 to 6.5.5 need to be followed in both the pre-assessment and detailed investigation stages, albeit to different levels of detail.

i. Pre-assessment

In computing the initial dilutions for offshore marine outfall as part of a pre-assessment, only average and worst-case scenarios related to descriptive statistical parameters of physical conditions (currents and stratification) need be used, in combination with the outputs from the hydraulic design.

For the analytical/statistical estimation of the achievable secondary dilutions for offshore, surf zone and estuarine waste water discharges as part of a pre-assessment, only average/typical and worst-case scenarios related to descriptive statistical parameters of physical conditions (currents and stratification) will be used. Typical values for day and night-time micro-biological decay rates will be used in conjunction with the analytical determination of the secondary dilutions in time and distance.

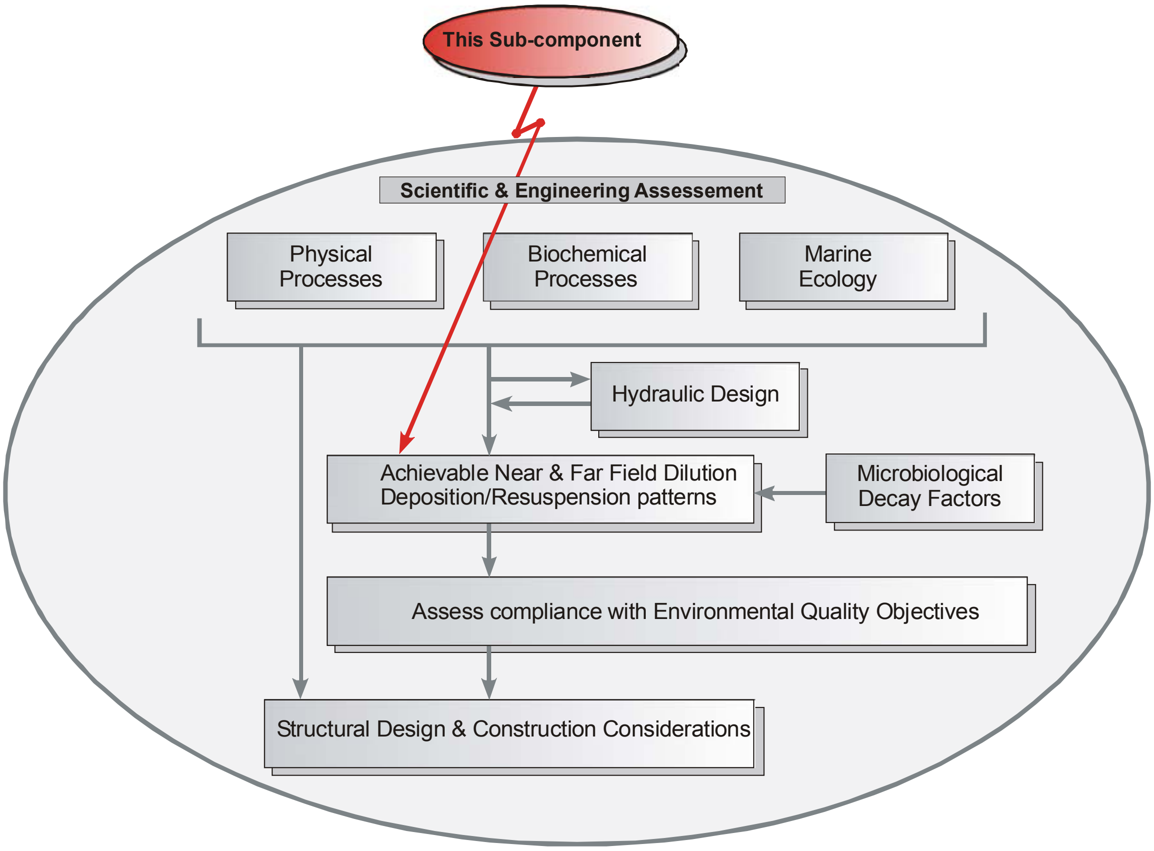
ii. Detailed investigation

In the case of a detailed investigation, initial dilution needs to be modelled using measured or simulated real-time data on the physical conditions (e.g. stratification and currents) at the location of the proposed discharge in the study area, in combination with the proposed wastewater flow scenarios (including diurnal and seasonal cycles). The output needs to be presented as a time-series (i.e. dilution and plume geometry) for the determination of frequency distributions of achievable dilutions.

Depending on the volume of the wastewater discharge, the sensitivity of the receiving marine environment and the complexity of natural processes, refined analytical/statistical estimations of the achievable secondary dilutions for offshore, surf zone and estuarine waste water discharges can be conducted, using measured physical conditions such as currents and stratification. Diurnal (and seasonal) variations for day and night-time microbiological decay rates will be used in conjunction with the analytical determination of the secondary dilutions in time and distance.

Normally (especially with deep sea outfall), a 3-D numerical model (in some cases it may be justified to use a 2-D model) will be 'constructed', calibrated, verified and applied for the prediction of far field dilutions and subsequent reduction of the concentrations of the wastewater constituents. Real-time measured (or simulated) nearshore data, as well as diurnal microbiological die-off rates, will be used in conjunction with the time-series data (i.e. dilution and plume geometry) from an initial dilution model.

6.7 SEDIMENTATION/RE-SUSPENSION OF SOLID PHASE PARTICLES



PURPOSE:

The purpose of this component is to establish the physical fate of suspended material with regard to transport, deposition and possible re-suspension after deposition. The aim is to identify possible depositional areas which could act as a sink for harmful chemical constituents (originating from wastewater inputs) when adsorbing onto suspended material.

6.7.1 Overview

Sediments are generally classified according to grain size as clay, silt, sand, gravel and boulders, ranging from very fine to coarse. Suspended and deposited particles in the marine environment are not only of lithogenous origin but can also be of organic nature (breakdown of marine fauna and flora or introduced from land sources such as rivers, stormwater and wastewater streams). Temporal changes to sediments and suspended particles, such as flocculation and chemical interactions (adsorption of certain constituents onto sediment, dissolution of certain constituents in sediment particles), can occur. Sewage effluents contain organic particles, varying in density and size and mostly with low settling velocities (Gunnerson, 1988). The settling speed of the suspended particles depends on the specific gravity, size and shape of the particles as well as the specific gravity and viscosity of the receiving water.

The physical fate of the suspended material with regard to transport, deposition and possible re-suspension after deposition is primarily related to the current and wave dynamics. The effect of current velocities on sediments is illustrated in Figure 6.53 (Gunnerson, 1988).

CLICK TO VIEW GRAPHIC

FIGURE 6.53: The effect of current velocities on the erosion, transport and deposition of sediments (Gunnerson, 1988)

Gunnerson (1988) also related the solids in sewage wastewater to settling velocities and velocities required for re-suspension as shown in Table 6.11. However, it should be noted that velocities are not fully representative of what occurs in terms of sedimentation and re-suspension, as it does not take into account all wave effects/turbulence. Where numerical modelling is used to predict deposition and re-suspension it is thresholds of bed shear stress that is typically the determining factor.

TABLE 6.11: Settling velocities and velocities required for re-suspension of solids in sewage wastewater (Gunnerson, 1988)

PARTICLE SETTLING VELOCITY (cm/s)	*PERCENTAGE OF SETTLING PARTICLES WITH SETTLING VELOCITIES > THAN INDICATED*	
	RAW SEWAGE	*PRIMARY TREATED WASTEWATER*
1.0	*5*	*-*
0.5	*20*	*-*
0.1	*40*	*5*
0.05	*-*	*-*
0.01	*60*	*20*
0.005	*-*	*30*
0.001	*85*	*50*
BOTTOM CURRENT VELOCITY (cm/s) FOR RE-SUSPENSION		
Re-suspension unlikely	*0 – 6*	*0 – 6*
Re-suspension possible	*6 - 30*	*6 - 20*

Suspended particles (or 'solid' phase particles) comprise cohesive (non-biological) particles and organic particles, to be referred to as *solid phase particles*. Cohesive (non-biological) particles represent very fine sediment particles (< 60 µm) where adsorption phases such as Al(OH)x, Mn(OH)x and Fe(OH)x are common. The origin of the organic particles can be natural (e.g. algal blooms) or introduced through anthropogenic activities (e.g. sewage disposal). The transport and fate of chemical constituents associated with the 'solid' phase are therefore largely determined by the flux and sedimentation/re-suspension behaviour of these particles. The sedimentation/re-suspension behaviour of solid phase particles is therefore required in order to determine the fate of adsorbed chemical compounds in the receiving marine environment (Luger *et al*., 1999; Monteiro, 1999).

EXAMPLE…

A plot of the distribution of Copper in Saldanha Bay (South Africa) showing the strong correlation between predicted, observed depositional areas, is provided in Figure 6.54 (Monteiro, *et al*., 1999). The long-term depositional zones, characterised by the smaller sediment particle size fractions, are the most vulnerable to contaminant accumulation.

CLICK TO VIEW GRAPHIC

FIGURE 6.54: Plot of the distribution of copper and particle size in Saldanha Bay (South Africa), showing the strong correlation between depositional areas and trace metals deposition

6.7.2 Data requirements for pre-assessment and detailed investigation

As part of a pre-assessment, the following has to be assessed, based on available information:

- The proximity of potential depositional areas in the study area, typically characterised by weak currents and low wave energy, e.g. in sheltered bay areas.

- The percentage occurrence of currents that are likely to transport a wastewater plume to depositional areas

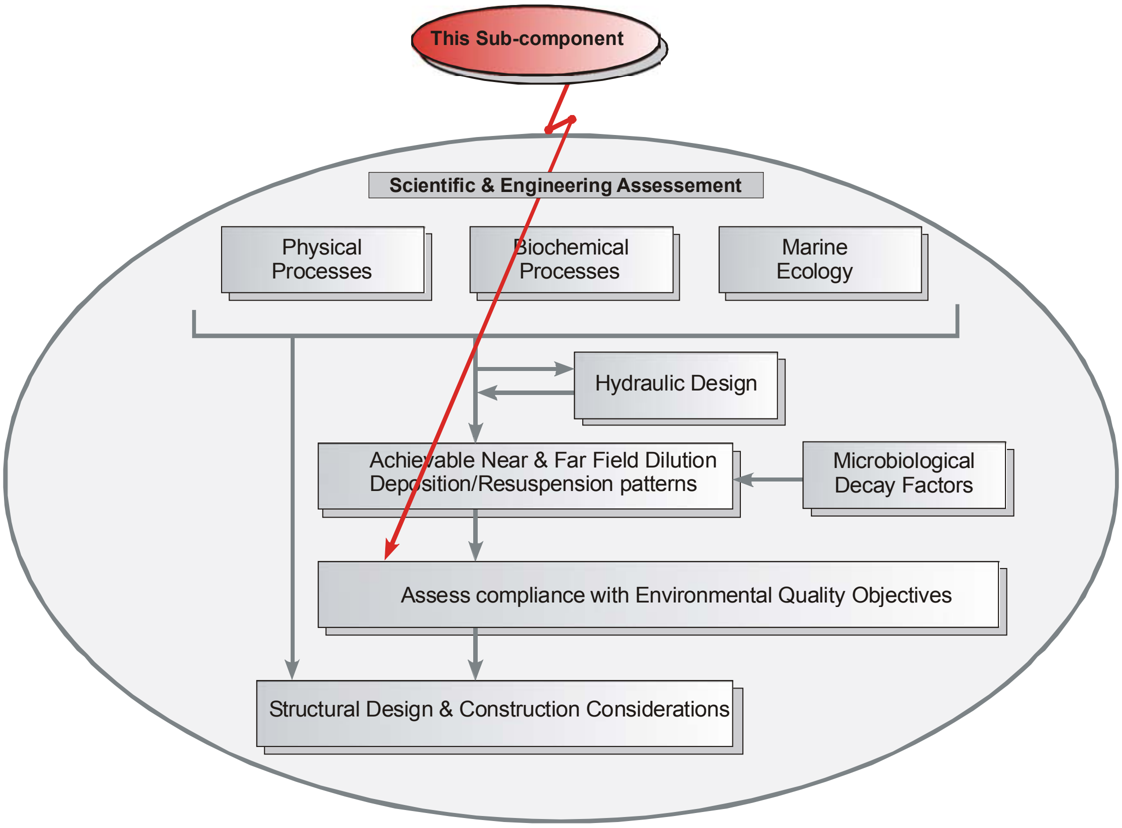
- Concentration and loads of suspended matter in the wastewater plume after initial dilution, as well as the estimated concentration when arriving at the depositional areas

- Concentration and load of constituents in the wastewater (e.g. trace metals) that, through adsorption to organic or cohesive sediment particles, can be transported to the depositional areas

- The possibility that re-suspension will occur, based on the percentage of time within which wave and current velocities are sufficient to re-suspend deposited material.

As part of a detailed investigation, the complex physical and biogeochemical processes associated with the deposition and re-suspension of solid particles are best assessed using properly calibrated and verified numerical models.

6.8 Compliance with Environmental Quality Objectives



PURPOSE:

The purpose of this step is to:

- ***Verify whether the environmental quality objectives will be adhered to, both in the near and far fields***
- ***Refine critical limits set for a wastewater discharge in terms of volume and/or composition.***

6.8.1 Overview

Compliance with environmental quality objectives, in essence, requires that the concentration of chemical constituents, after initial dilution or on reaching specific (beneficial use) areas in the receiving marine environment, comply with the environmental quality objectives specified for the study areas or for a particular use. In order to determine this compliance, the following needs to be taken into account:

- Beneficial use map of the study area and the environmental quality objectives associated with each use

- Behaviour of constituents in wastewater, taking into account interaction with the biogeochemical characteristics and processes in the receiving environment, as well as waste inputs from other activities into the defined water body (this is necessary to quantify potential synergistic effects and to assess cumulative impacts)

- Processes affecting the achievable dilution, i.e. to determine the dilution and transport of constituents in the 'dissolved phase', both in the near and far fields

- Processes affecting the sedimentation/re-suspension of solid phase particles, i.e. to determine the transport and fate of biogeochemical constituents associated with the 'solid' phase, both in the near and far fields.

Based on the above, the spatial and temporal concentrations of biogeochemical constituents in the receiving environment are predicted. These outputs are then superimposed on the beneficial use map (and associated environmental quality objectives) to establish if there is compliance with the environmental quality objectives.

6.8.2 Data requirements for pre-assessment and detailed investigation

i. Pre-assessment

The typical output to show compliance/non-compliance with environmental quality objectives, as part of a pre-assessment study, is as follows:

- Statistical presentations of the concentrations of the constituents in the wastewater plume after initial dilution. It is normally required that all the biogeochemical constituents in wastewater, except for microbiological indicators, comply with the environmental quality objectives within the initial mixing zone (this will be attained if the required dilution is less or equal to the initial achievable dilution). A precautionary (conservative) approach must be followed, i.e. taking into account the worst-case scenarios, such as:

  - Maximum concentrations in the wastewater and maximum discharge rates for the full range of scenarios
  - Physical conditions which will result in the minimum achievable dilutions (both for the near and far fields)
  - Using the achievable initial dilution for the worst performing port in the diffuser.

- Spatial and statistical presentations of the concentrations of constituents in the wastewater (remaining in the 'dissolved phase') in the waste field at the time of being transported away from the discharge location (i.e. outside the initial mixing zone).

For microbiological organisms, typical daytime and night-time decay coefficients must be used and compliance to environmental quality objectives at specific (beneficial use) areas must be determined for the full range of current velocities. For example, the variation in the distance from the discharge location at which faecal coliform counts comply with environmental quality objectives (or water quality guidelines) under a range of current velocities, irrespective of the current direction, is illustrated in Figure 6.55.

CLICK TO VIEW GRAPHIC

***FIGURE 6.55: Example: Variation in** distance from the discharge location at which faecal coliform counts comply with environmental quality objectives (or water quality guidelines) under a range of current velocities*

- Identification of the percentage of occurrence of currents, as well as average velocities on route to sheltered areas within the study area, where stagnant conditions are likely to occur. Referring to Figure 6.53, a conservative assumption is that deposition for fine material may occur in current velocities of less than 3 cm/s (considering that only preliminary treatment was applied and that a degree of flocculation will occur).

  For an ‘open’ coastline, current velocities in the upper layers of the water column rarely drop below 5 cm/s and, if this occurs it is normally for a very short time, for example, when currents change direction on account of the tide. An estimate of the percentage occurrence of current velocities less than 5 cm/s (stagnant conditions) will provide a conservative estimate of the time at which deposition can be expected.

- Spatial and statistical estimates of deposition/re-suspension of constituents in the wastewater (i.e. associated with solid phase particles) in the far field. A conservative approach to follow for a pre-assessment would be, for example, to assume that all trace metals present in the wastewater will adsorb onto solid phase particles and, thus, be transported to the depositional areas identified above.

ii. Detailed investigation

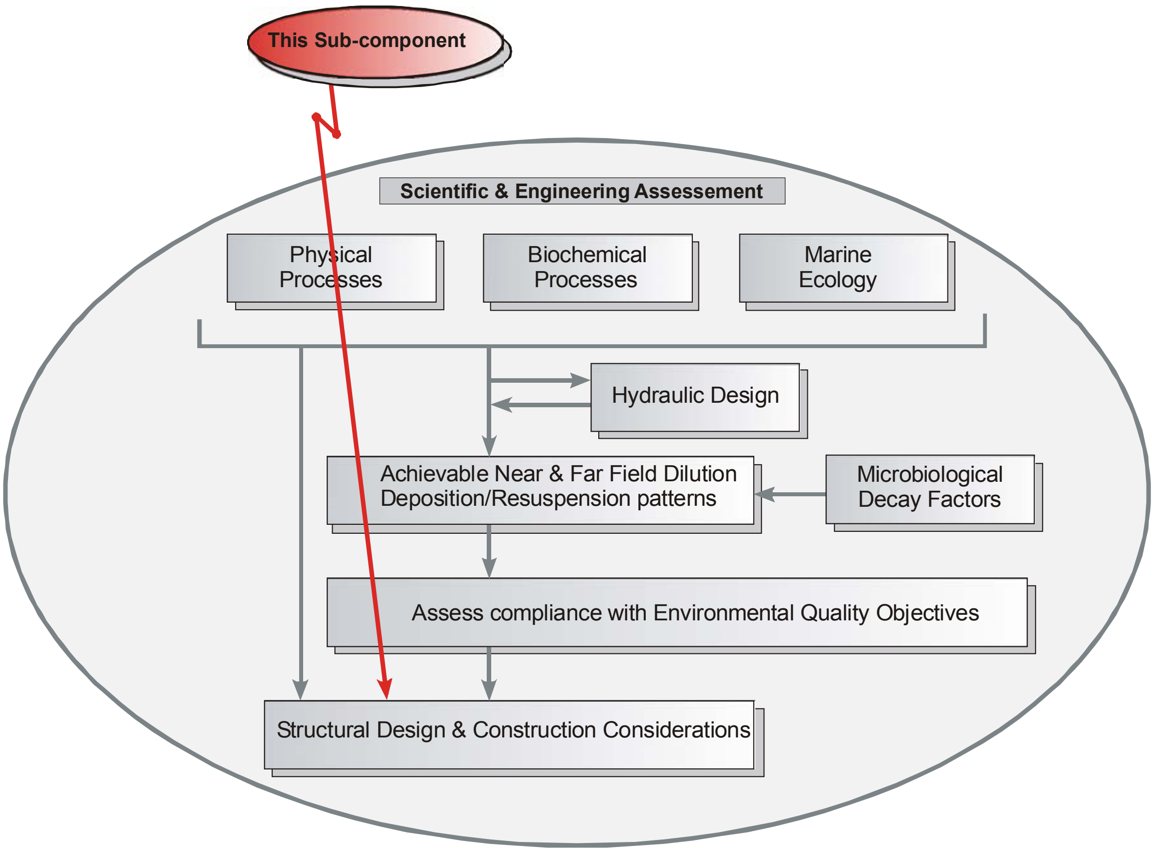
For a detailed investigation, a water quality model, using output from the hydrodynamic model, is used to predict more realistically the fate of constituents in the wastewater, taking into account the influence of all existing waste inputs together with the proposed discharge and variability in ambient biogeochemical conditions. In particular, the water quality model is used to predict (quantitatively and dynamically) (Luger *et al*., 1999; Monteiro, 1999) the:

- transport and fate of constituents in the wastewater that remain in the dissolved phase (e.g. Figure 6.44)

- deposition/re-suspension of constituents in the wastewater associated with the ‘solid’ phase (e.g. Figure 6.54)

Water quality modelling can also be applied to simulate different scenarios (e.g. variations in wastewater composition and flows) to determine the effects of these on the environmental quality objectives.

6.9 CONSTRUCTION CONSIDERATIONS AND STRUCTURAL DESIGN



PURPOSE:

The purpose of this component is to provide specifications for the structural design and construction of a marine wastewater discharge system. Sub-components that need to be specified include:

- ***Pipeline material***
- ***Construction methods***
- ***Detailed design of the structure***
- ***Contractual aspects***
- ***Decommissioning.***

6.9.1 Pipeline Material

WRc (1990) grouped materials for pipelines in three categories (main materials):

- Ferrous (Steel and cast-iron)
- Polymetric (Polyethylene, PVC, Glass-reinforced plastic)
- Cementitious (Steel reinforced concrete)

The most commonly used pipe material for ocean outfalls is steel or plastic (HDPE). Other pipeline materials are:

i. Ferrous materials

<u>Coated Steel</u>. Steel pipe has been used extensively by the oil and gas industry for underwater works because it allows a great degree of flexibility in construction techniques. Steel pipe has also been used in numerous outfalls. It is ideal for bottom-tow construction and also suitable for float-and-lower as well as the lay barge method.

Large diameter pipes (up to 3000 mm diameter) can be manufactured by rolling and welding as well as by spiral fusion welding. Both methods are flexible and allow for any diameter or wall thickness. Lengths can be specified, but usually pipes with a diameter > 500 mm are supplied in 9 m lengths.

Weld seam inspection and defect identification are of the utmost importance and detailed inspection clauses should be included in the specifications. Steel pipes for marine use are usually joined by welding, although flanged connections are sometimes used at the ends of an outfall to permit extension of the line or to add a diffuser at a later time. Welded joints are usually checked by X-ray radiography.

Steel is susceptible to corrosion in seawater. However, it has been proved that a well-coated pipeline with cathodic protection has a reasonably long life. The initial costs of steel pipe and cathodic protection may be higher than for plastic pipe. The advantages of steel pipe include its adaptability to rapid fabrication and installation, its joint tightness, inherent structural integrity, and its higher head capacity. This ability to operate at higher pressures allows the flexibility of conversion from a gravity outfall to a pumped or pressured outfall in the future.

<u>Cast-Iron</u>. Although historically a popular material, cast-iron has not been used for marine outfalls in South Africa. Its strength is comparable to steel pipe and it has corrosion-resistant properties that are superior to unprotected steel pipe (Gunnerson, 1988). However, it has poor flexibility and impact resistance and it is more expensive than other types of pipe. It is seldom used as an outfall pipe material today.

ii. Polymetric materials

<u>Polyethylene</u>. Polyethelyne pipes are categorised by the density of the constituent material, that is, low density (LDPE– 0.915 to 0.924 g/cm^3), medium density (MDPE– 0.925 to 0.944 g/cm^3) and high density (HDPE – 0.945 to 0.965 g/cm^3). The HDPE pipes are the most commonly used for marine outfalls. With regard to corrosion resistance (wastewater and seawater), polyethylene pipes have great advantages over ferrous and cementious materials. Polyethylene is not affected by acidic conditions, (sewage wastewater) or corrosive chloride and sulphate ions in seawater. Disadvantages are that solvents (e.g. petrol) may affect the strength of the pipe and, like all thermoplastic materials, the mechanical properties are time and temperature dependent.

Polyethylene pipes are manufactured from pre-compound granules, which contain the polymer as well as additives such as anti-oxidants, pigments, etc. Manufacturing is by extrusion, under pressure, (heated granular material) through a die to provide the required diameter (up to 1200 mm diameter) and wall thickness. The extrusion plant can be at the construction site, eliminating the transport of pipes.

Polyethylene pipes can be fusion welded into continuous pipe strings to be installed by lay-barge or the float-and-sink-method. Because the density of the pipes is less than that of seawater, the pipeline must be stabilised on the seabed by additional weights. Adding concrete collars before the pipe is towed out to sea is a possible solution.

During backfilling, care must be taken to ensure that the backfill weight is within limits with regard to possible deformation of the pipe. Low longitudinal bending stiffness makes polyethylene pipes ideal for undulating trench profiles as they can conform to the seabed profile. Continuous concrete weighting can be used to keep the bending characteristics.

Glass-reinforced plastic (GRP). Although not used at present in marine outfalls in South Africa, GRP as a material for large pipe diameters recently has been used in other countries. The advantages are its strength to weight ratio, corrosive resistance and the ability to be moulded to any shape or dimension for specific requirements. Filled with water, GRP pipes have a slight negative buoyancy and can be installed by the pipe-by-pipe method, with concrete collars for additional weight and stability. A disadvantage is its susceptibility to impact damage (brittleness) during installation and backfill. Care must also be exercised when concrete collars are fitted and appropriate packing material must be used between collars and the pipeline.

Other thermoplastic materials. Other materials such as uPVC (unplasticised polyvinal chloride) and polypropylene have been used before in other countries but, in general, will not be considered at present for long sea outfalls.

iii. Cementious materials

Steel reinforced concrete. Overseas, marine outfalls greater than 215 cm in diameter have been built of reinforced concrete pipe. Installation costs can be quite high. Concrete pipe is highly resistant to corrosion and to attack by seawater or marine organisms.

6.9.2 Construction methods

i. Outfall construction

Bottom-pull method. This is the most frequently used method of outfall construction due to it's suitability for exposed as well as sheltered areas. According to WRc (1990), the limiting wave height for construction is between 2 and 3 m.

Weldable steel is the most suitable material. The high bending/tensile strength of steel can withstand the installation loads. Care must be taken not to exceed the allowable stresses of the concrete protection.

The bottom-pull method can only be considered if the outfall has a straight route alignment. This method requires a relatively large construction site at the shore crossing for pipe storage, assembling and launchway. A minimum construction area of 100 m x 80 m will be required. A typical construction-launching site for the bottom-pull method is shown in Figure 6.56.

CLICK TO VIEW GRAPHIC

FIGURE 6.56: A typical construction-launching site for the bottom-pull method

Pulling sections of corrosive pre-coated steel pipe with concrete cover are assembled onshore in at least 80 m lengths. Field welds are non-destructively tested, and corrosion-resistant protective coating is applied to the field joints. Each pulling section is stored on rollers parallel to the launching ramp to be tied in as the pipe is pulled out to the sea.

The pulling barge is anchored offshore, directly in line with the launchway (route of the outfall line). Before initiating the pulling operation, one end of a cable or wire rope is connected to a pulling head welded to the leading section of pipe. Depending on the length of the pulling sections and the total pipeline length, the pulling operation can be completed within 2 weeks. If the submerged weight of the pipe is more than 50 kg/m, it may be necessary to add buoyancy to the pipe to prevent damage to the external concrete coating.

Surface-pull (float-and-lower-method). Normally, this method is more suitable for outfall construction in sheltered areas. Even under moderate wave conditions, the pipe can start to oscillate and a lateral current can force the pipe off-line. The handling of a long floating pipeline requires specialised equipment and expertise.

For the construction of the pipe, a sheltered area in close proximity to the proposed route is required, where the pipeline can be left (floating or submerged) until being towed out to the site. Horizontal bending during the towing operation and vertical bending during the lowering operation require a high degree of flexibility, and plastic material such as HDPE is the most suitable for this method. Pipe lengths can be fusion welded into a continuous line or can be manufactured on site by extrusion, in which case a relatively small onshore construction site is required with minimum onshore traffic. Required weight collars are installed onto the air-filled pipeline before the tow-in operation. After flooding the pipe along the proposed route, care must be taken that no air pockets remain in the pipe.

Pipe-by-pipe method. This method is suitable for shorter marine outfalls. The pipe sections are manufactured off-site (most pipeline materials can be used), transported to a barge and lowered into position to be tied up to the existing line.

Pipes can be joined by bolted flanges, or spigot and socket joints with 'O' rings can be used. Installation can take a long time, because the underwater jointing can be delayed by adverse weather. Completed sections can be protected as the installation proceeds, leaving no long unprotected sections that can be damaged during adverse sea conditions. Thus, apart from possible delays, the risks during construction are relatively small, compared to other methods.

For larger diameter pipes in deeper water, alignment with the existing line can be a problem. This can be overcome by using a pipe handling frame to provide vertical and longitudinal alignment for the tie-up of a 'new' pipe to the existing line. Alignment frames also contain a chamber that enables a diver-welder to join the sections.

***Reel-barge and lay-barge methods*.** These methods require small onshore construction sites. The pipe is pulled from the sea to the high-water mark and is then lowered in the offshore direction from the barge. For the reel-barge method, only smaller diameter (300 mm) plastic pipes can be used, while large diameter pipelines of weldable steel or HDPE can be installed by the lay-barge method. These methods are suitable for long lengths of pipelines (oil and gas) and are normally not used for 'short' sea outfalls.

ii. Trenching

Trench widths relate to the type of dredger that is used. Typically the width ranges from 5 m to 10 m and the side slopes will depend on the seabed material. When the seabed consists of hard material and blasting or the use of special cutter suction dredgers is required, a trial trench will facilitate the cost estimation and provide more clearly defined tender specifications. Detailed specifications are required for measures that ensure that the side slopes for the entire length of the trench remain stable until backfilling is completed and that the level and line of the trench are accurately controlled.

Normally a pipe will be buried below the lowest possible seabed profile in the surf zone area. It may also be a requirement for the offshore region that the seabed has to be restored to the original level, which will require a deep trench. The trench depth and the degree of protection will depend on:

- natural characteristics of the seabed (rock, sand, clay).
- impact of an artificial protrusion above the seabed on the natural processes and ecology
- possible threats (ship anchors, fishing gear, direct contact with a ship).

Trenching and rock protection are the most effective and secure method for protecting a marine outfall. However, in some cases (undulated rocky seabed), it is not practical or economically viable to provide a trench below the seabed along the entire route of the pipeline. The aim then will be to provide a level bed for the pipeline with protection that at some places will be above the seabed.

Land-based machinery (e.g. backhoe) on a pontoon (loading the dredged material on barges) can be used in shallow water. Two types of dredgers are normally used for outfall trenching, namely cutter suction dredgers, which can also cope with harder type material such as soft rocks (e.g. coral and 'soft' sandstone), and bucket dredgers. The dredged material is discharged to hopper barges.

A pipe can also be jetted into the seabed, using a sledge with water jets, suction pumps, etc. This method can also be used when a trench has become filled with sediment before the installation of a pipe. Similarly, fluidisation, which involves the forcing of large quantities of water into the soil surrounding the pipeline, can be used.

iii. Backfilling

Backfill material for outfalls can be placed from barges by side dumping in shallow water or by a fall pipe in deeper water for more accurate control.

Normally, dredged material (if not rock) is not suitable for backfill. When a pipe has to be protected by rock armour, a filter material must be used for the protection of the pipe against the larger rocks. If a trench is in a rocky seabed, a stable bed has to be provided for the installation of the pipe and remains stable enough to provide a permanent foundation. It is important to ensure that the 'composite' structure of pipe and rock layers is stable and that the grading of the layers is such that finer underlayers do not 'escape' through the upper layers. Specialist advice will be required to ensure that the selected material is stable under the expected extreme conditions for the site. If the trench is in hard material (rocks), tremie concrete can be used for protection instead of rock armour. For the contract specifications, it is important to specify the minimum thickness of each layer after settlement of the material.

Examples of backfill cross-sections are shown in Figure 6.57.

CLICK TO VIEW GRAPHIC

FIGURE 6.57: Examples of backfill cross-sections

6.9.3 Structural design

In general, there are three main areas to be considered in the structural design of outfall pipelines:

- **Stability –** bottom stability is a critical aspect in the design of an outfall. The pipeline must remain stable during installation (construction) and throughout its design life. Other aspects related to the ultimate stability of the pipeline that have to be investigated are trench stability, seabed stability, sediment transport and required rock armour for protection of the pipeline.

- **Stress –** stresses in the pipeline must at all times be within acceptable limits

- **Accidental damage –** the risk of accidental damage must be acceptably low.

NOTE:

Under-design:	***Leading to risk during operation***
Over-design:	***Leading to excessive costs.***

The purpose of this section is not to serve as a detailed design procedure (tool) but, with regard to the physical environment at the proposed outfall site, to provide the following:

- A checklist of the critical and important aspects to be addressed regarding the detailed structural design of an outfall

- Some basic/empirical methods for obtaining estimations of the magnitude of forces that can be expected, for a pre-assessment of suitable materials to be used, construction methods to be considered, and whether the pipeline needs to be protected or not.

Because of the specialised construction techniques for a marine outfall, the choice of material, construction technique/method and specialised equipment form a ‘package’ developed by recognised contractors. The preferred option should be designed in detail for the Tender Specifications and Bill of Quantities. However, due to specific contractor expertise, for major outfall projects during the past 8 years, an option has been included in the Tender for alternatives, providing that the Contractor must provide a structural design together with his bid, to be reviewed in detail by the client’s engineer.

i. Hydrodynamic Forces

When water flows around and over a structure, hydrodynamic forces will be exerted on the structure, resulting from pressure differences in the flow field. Buried pipelines are usually not directly subjected to such hydrodynamic forces after installation, except for the diffuser section.

***Currents (steady flow)*.** For an exposed pipeline or partially-buried pipeline, the vertical lift force (normal to the current because of low pressure on the downstream side of the pipe) and drag forces (perpendicular or normal to the pipeline) in an ambient flow (quasi-steady currents are caused by factors such as tides, continental circulation, storm surges and wind stress interacting with the wave orbital oscillations and result in net particle velocities and accelerations) can be estimated as follows WRc (1990) (Figure 6.58):

$$F_D = 0.5\ \rho.C_D D.u^2$$
$$F_L = 0.5\ \rho.C_L D.u^2$$

where

F_D, F_L	= Horizontal and vertical drag forces
C_D	= Drag coefficient (typically 0.5 to 2.0)
C_L	= Lift coefficient (typically 0.9 to 2.0)
ρ	= ambient water density (kg/m^3)

The drag and lift coefficients are functions of the Reynolds number and also depend on factors such as wall roughness of the exposed outfall, the velocity profile over the height of the pipe, and the roughness of the seabed.

CLICK TO VIEW GRAPHIC

FIGURE 6.58: Drag and lift forces on a pipeline in steady flow

Gunnerson (1988) provided a guideline (Figure 6.59) for drag and lift coefficients for an exposed pipeline on the seabed and recommended that these be used as an upper range, as higher values result in over-design and excessive costs. The Reynolds Number (R_e) is defined as:

R_e = uD/μ

Where:

u	= Current velocity (m/s)
D	= External pipeline diameter (m)
μ	= Kinematic viscosity of seawater (m^2/s)

CLICK TO VIEW GRAPHIC

FIGURE 6.59: Drag and lift coefficients for an exposed pipeline on the seabed (Gunnerson, 1984)

Waves (unsteady flow). Unsteady flow occurs under waves, where an outfall is subjected to an oscillatory wave-induced current (superimposed on a steady current component).

With reference to WRc (1990), most analysis methods are based on the Morison method, which is almost universally used in the submarine pipeline industry, because of its reasonable representation of prototype measured forces in unsteady flow.

The drag (F_D), inertia (F_M) and lift forces (F_L), according to the semi-empirical Morison equation (WRc, 1990), are:

$F_D = 0.5\ \rho.C_D D.u|u|$
$F_M = [\pi\ \rho.C_M D^2/4]du/dt$
$F_L = 0.5\ \rho.C_L D.u^2$

where
C_D = Drag coefficient (typically 1.0 to 2.0)
C_L = Lift coefficient (typically 1.25 to 1.5)
C_M = Inertia coefficient (typically 1.65 to 3.29)
du/dt = water particle acceleration normal to the pipe
ρ = ambient water density (kg/m^3)

The choice of coefficients is controversial and careful consideration must be given to published values with regard to the approaches and assumptions followed for the determination of these coefficients. (WRc, 1990).

An alternative approach, as proposed by Grace (1978), is based on force coefficients, and the extreme horizontal and vertical forces during a wave cycle are determined.

To combine wave and current forces, the simplest approach is to vectorially add the velocity components and use the result for calculating the forces.

ii. Stability

The design philosophy for outfall pipelines is to ensure complete stability under the maximum hydrodynamic forces. This stability can be achieved by complete burial of the outfall. However, in many cases, the pipeline is partially buried or fully exposed, conditions which may also occur temporarily during construction prior to backfilling. The pipeline weight or anchoring system must be adequate to resist the expected hydrodynamic forces during and after construction.

If an outfall is exposed on the seabed, it must resist lateral movement under the hydrodynamic forces induced by waves and currents. The forces on a cross-section of an unburied outfall (WRc, 1990), which resists lateral movement by its own weight (W_S), are:

$W_S \geq (F_D + F_M)/f + F_L$

Where
f = seabed friction factor

The seabed friction factor for a threshold of large movements on a sandy seabed according to WRc (1990), can be taken as approximately 0.7. For a partially buried pipeline, the seabed friction factor (f) will increase considerably. Due to the characteristics of clay in a dynamic environment, the determination of a constant factor is much more complicated.

Sediment transport is an important aspect regarding the stability of a pipeline. Erosion of the seabed can result in full exposure of a buried pipeline and can even cause a length of pipeline to become unsupported. The theory of sediment transport is extensive and will not be discussed here.

The biggest change in seabed profile is caused by onshore-offshore transport in the breaker zone which can vary in meters. Typically winter and summer profiles are predetermined, but major short-term variations during storm conditions may be encountered.

Long-shore sediment transport is caused by waves approaching the shoreline at an angle. If an outfall pipe is near the seabed in the surf zone, the transport of sediment will be interrupted, resulting in accretion upstream of the outfall and erosion in the lee of the pipe. It is therefore important that the depth of burial in the surf zone is below the lowest possible level of a sandy beach. The transport rate can be calculated analytically for known wave conditions. There are also numerous numerical models available which can be used to predict the longshore transport.

The best approach is to obtain information on the history of the beach/near-shore profile at the proposed outfall site. Envelopes of sufficient long-term data will provide a good estimate for the depth of burial of a pipeline.

The transport of sediment is of particular importance during the construction of a pipeline, because a trench acts as a sediment trap and, under certain conditions, can be filled in a very short time. Normally the trench will be protected by sheet piles in the surf zone area. Sufficient information on the sediment movement should be available to determine the depth and distance offshore for protecting the trench, because temporary protection is expensive. However if a trench becomes filled up during the installation of the pipeline, the consequences will be disastrous. For a bottom-pull method, the buried section can make it impossible to move the pipe.

Depending on the seabed properties, an outfall can also settle below the seabed under its own weight. Geotechnical investigations on the bearing capacity of the seabed material must be conducted. Gunnerson (1988) refers to the relation between the ultimate seabed bearing capacity (Q) and the pipe diameter (D):

$$Q \quad \alpha \; k.\, c_s D$$

where
c_s = soil cohesive shear strength
k = variable which is a linear function increasing to a constant when the depth is 4x pipe diameter

Attention must also be given to the possibility that a pipeline will start to float out of a trench. This floating will occur when the pipeline is lighter than the backfill material, a condition that ensues when the trench is filled naturally with soft material or where use is made of dredged material, which after handling becomes a liquid-mud with little or no shear strength.

The possibility of seabed liquefaction by wave action must also be determined.

The stability of the slopes of a trench will depend on bed material (clay or sand). In consolidated (stiff) clays, the slopes of the trench will be fairly stable. For sandy sea bottoms, the trench slopes will be between 1:3 and 1:6.

iii. Pipeline protection and stabilisation

Protection of the pipeline against external forces, such as dragging anchors, can only be achieved by rock armouring. The design of rock armour as well as the filter material required between the rock armour and the pipeline/seabed, will depend on the geotechnical properties of the seabed and the hydrodynamic forces.

For stabilisation and protection against external and hydrodynamic forces above the seabed, burial in the seabed is the most economic method. It must be ensured that the depth of burial is below the extreme lowest seabed level, especially in areas where the seabed is unstable.

The pipeline can also be stabilised by increasing its weight. For steel pipes the concrete weight coat or/and the pipe wall thickness can be increased. For plastic pipes the weight of the weight collars or the number of collars can be increased. Although not general practice, pipelines can be anchored to the seabed, using piles in sandy areas or screw and rock anchors in rocky areas.

iv. Stress analysis

The construction method and the pipeline material will determine the approach to follow for the stress analysis of an outfall. The total loading on an outfall will include a number of structural effects and consideration must be given to possible combined effects of superimposed stress components.

For the detailed design of long submarine pipelines, the stress analysis of the pipeline normally involves the application of a sophisticated structural numerical model. For sea outfalls, which are relatively short and rigid, analytical techniques can be applied without a loss of accuracy.

It is important to review existing outfalls with regard to the construction method, pipe materials, structural design approach and the structural behaviour and performance. These constitute the best guidelines and know-how for the optimum design of a new outfall.

v. Stresses arising from individual forces

Stress may arise from the following:

- pulling forces during construction
- forces produced by pipeline curvature and spanning
- internal and external pressures
- hydrodynamic forces
- backfill forces
- thermal expansion forces.

Forces and stresses related to the construction phase,are discussed below. Compressive stresses are shown as negative and tensile stresses as positive.

Pulling forces. For the bottom-pull method of construction, the pull force is taken as the weight of the pipe times a longitudinal friction factor which will depend on the bed characteristics of the trench, taking into account the submerged and above ground sections. Referring to WRc (1990), the pulling force (P) is:

$$P = L_a W_a f_a + L_s W_s f$$

where
- L_a = Length of the pipe in air
- W_a = Weight per unit length in air
- f_a = friction factor of the launch way
- L_s = Length of the submerged section of the pipe
- W_s = Weight per unit length of the submerged pipe
- f = seabed friction factor

The longitudinal stress (S_L) induced by the pulling force is at its maximum at the seaward end, reducing to null at the landward end.

$$S_L = P/A$$

where
- A = cross-sectional area of the pipe, excluding all non-structural components

Forces resulting from curvature and spanning. For the bottom-pull method of construction, curvature and spanning can occur as a result of an undulating seabed profile, a horizontal curve along the route, the profile of the launchway, and/or the spacing of the rollers on the launch way. Longitudinal bending will occur as the pipe axis is deflected from a straight line. For float-and-sink-methods horizontal and vertical bending will all the time during construction until the pipeline is on the seabed. Referring to WRc (1990), the longitudinal bending stress (S_{LB}) is:

$$S_{LB} = \pm\ 0.5ED/r$$

where
- E = elastic modulus of the pipe material (200 GPa for steel)
- D = external diameter of the pipe
- r = radius of curvature (of bend)

To analyse the spanning lengths to which a pipeline may be subjected (between rollers during construction or unsupported sections due to scouring) the pipeline is considered as a continuous beam and the bending stress, according to WRc (1990), is given by:

$$S_{LB} = \pm\ 0.5.k\ [WL^2D]/I$$

where
- k = bending factor (0.08 to 0.125)
- W = weight of the pipe per unit length
- L = length of the span
- I = second moment of area of the pipe = $(\pi/64)(D^4 - d_i^4)$
- d_i = internal diameter of the pipe

Internal and external pressure. Large differences between external and internal hydrostatic pressures may result in buckling of a pipeline and the subsequent failure of the pipeline is referred to as 'collapse'. Air-filled thin-walled pipes are subjected to buckling when being installed in deep water; or for large diameter pipes with insufficient wall-thickness, buckling can occur in shallower water depths. Buckling can also occur during operation when the internal pressure falls below the external pressure, as a result of transient flow effects.

According to Gunnerson (1988), the physical properties of a steel pipe are characterised by its D/t ratio and the elastic limit is approached when the D/t ratio is approximately 250.

The compressive hoop stress (S_H) due to a net external pressure (P_e), according to WRc (1990), is:

$S_H = - P_e D/2t$

and the hoop tensile stress for a net internal pressure (P_i):

$S_H = P_i D/2t$

where
D = external diameter of the pipe
t = wall thickness

For a concrete coated pipe (proved compressive strength of the concrete), the compressive hoop stress (S_H) can be calculated as follows (WRc, 1990):

$S_H = - 0.5.P_e D_c E/[2(E_c t_c) + E.t]$

where

D_c = overall diameter of the concrete coating
E_c = Elastic modulus for concrete (22 to 29 GPa)
T_c = thickness of the concrete coating

As the tensile strength of the concrete is insignificant, the concrete coating will not have an effect for a net internal pressure (P_i).

An external pressure will result in a circumferential membrane stress, which, when a pipe is not perfectly round, will generate additional stresses with increasing out-of-roundness. Additional out-of-roundness can be caused by the pipe weight or by the pressure from backfill loading. Refer to WRc (1990) for the calculation of increased hoop stresses resulting from the out-of-roundness of the pipe.

External hydrodynamic loading. During construction, a pipeline will be subjected to additional loads and stresses due to the wave and current forces. Depending on the sea and weather conditions which may occur during construction, careful consideration must be given to the construction method to be used.

Other external loadings for a well-designed outfall are generally small. For the detailed design, all possible loadings should be checked.

Other loads. Considering the structural design of an ocean outfall with regard to forces encountered during the installation, additional loads, such as from backfill weights or increased temperature when in operation will be relatively small. However, depending on the pipeline material, wastewater characteristics, etc. all possible additional loadings should be checked.

vi. Allowable stresses

If the design is based on allowable stress, WRc (1990) proposed the calculation of the equivalent stress (S_{eq}), using the von Mises definition for equivalent stress, defined by Norske Veritas (1981) as:

$S_{eq} = [S_L^2 + S_H^2 - S_L.S_H]^{1/2}$

For steel pipes, the maximum allowable stress is equal to the yield stress, applying a factor of 0.72 (WRc, 1990), to allow for stresses which occur during the installation of the pipeline.

Longitudinal elastic buckling of a pipe under axial compression will occur when the longitudinal stress (S_{Lc}) is equal to (WRc, 1990):

For outfalls with composite pipeline sections (e.g. a steel pipe with internal and external coatings and

$$S_{Lc} = 1.E.t/[D(3(1\text{-}\mu 2))^{1/2}]$$

where
T = pipe wall thickness
μ = Poissons ratio (0.32 for steel)
E = Elastic modulus for steel (~ 200 GPa)

Elastic buckling will occur when the hoop compressive stress (S_{Hc}) is:

$$S_{Hc} = E.t^2/[D^2(1 - \mu^2)]$$

concrete protection), care must be taken regarding the possible behaviour of each component. Components such as the concrete protection, may also contribute to the overall strength of the outfall, therefore the specifications for the protection are important to ensure that the characteristics will not change during the lifetime of the outfall.

vii. Accidental damages

<u>During construction</u>. During construction, the risk of damage to an outfall is high as at this time when the unprotected outfall is exposed to weather/sea conditions as well as floating construction equipment.

Careful design (selection of the most suitable materials for the construction method that is appropriate for the outfall site and environmental conditions) and meticulous planning, scheduling and contingency measures are of the utmost importance. The engineers responsible for the Tender Specifications must ensure that all possible precautions with regard to the installation and protection of the pipeline are specified in detail.

Ship anchors and fishing gear. A pipeline can be damaged by dragging or dropping ship anchors. A pipeline without protection (or sunk into the seabed) is extremely vulnerable to dragging anchors.

Referring to Hoshina and Featherstone (2001), the potential anchor/fishing gear penetration depth into the seabed for different craft/equipment is shown below:

	HARD MATERIAL (clay > 72 kPa and rock)	***SOFT TO FIRM MATERIAL (sand, gravel, clay 18 – 72 kPa)***	***SOFT MATERIAL (mud, silt, clay 2 – 18 kPa)***
Stow net fishing anchors	*N/A*	*2 m*	*> 2 m*
Ships' anchors up to 10 000 DWT (50% of world fleet)	*< 1.5 m*	*2.1 m*	*7.3 m*
Ships' anchors up to 100 000 DWT (95% of world fleet)	*< 2.2 m*	*2.9 m*	*9.2 m*

It is not always feasible to demarcate the area along the route of a pipeline that is close to navigational routes near a harbour.

Protection against dragging anchors can be accomplished by an appropriate backfill. A backfill comprising 1 m of 10 kg to 60 kg rock, followed by 1 m of 60 kg to 300 kg rock armour, with appropriate slopes, will be sufficient protection against most types of anchors with a weight greater than 12 tons. This is only required in a water depth of less than 12 m water as ships with anchors greater than 12 tons will not normally navigate in shallower water.

The possible damage to a diffuser from the impact forces exerted by a dropping anchor can be eliminated by rock protection or pre-cast concrete domes.

Damage resulting from direct impact from a ship is also a possibility in shallower waters. If there is the probability of a direct hit from a ship for a specific outfall site, appropriate protection must be applied to the pipeline.

If an outfall site is within a fish trawling area, precautions must be taken, not only for the protection of the pipeline, but also against possible claims for damage to fishing gear.

6.9.4 Contractual aspects

The calculations in this section provide the baseline information for the actual specifications and detailed plans for cost estimating, tendering and the construction of the pipeline. Standard methods and procedures are normally used for all civil engineering contracts and typically include the following documents:

- Instructions for tenders
- Standard forms of tender, agreement and bond
- General and special conditions of contract
- Detailed design
- Specifications
- Bill of quantities
- Schedule of rates and day works
- Appendices (all other relevant information).

Because of the more hostile nature of the environment of an outfall construction area, the specialised equipment utilised and the complicated methodologies to be used, more detailed and specific information and provisions are required, compared to straightforward on-land civil construction. Many offshore contracts have had a less than satisfactory financial ending for both contractor and client, resulting from disputes over delays caused by unexpected physical and environmental conditions, lack of backup in the event of breakdown of specialised equipment, vague and divided responsibilities, etc. All of these problems could have been prevented by additional clauses in the contract documents, taking into account the unique conditions and circumstances of this type of project.

The following notes are not prescriptive. It merely highlights key points to be taken into account when detailed specifications as provided as part of the preparation of contract documents to ensure the success of this type of construction:

i. General

Due to the specialised nature of offshore engineering works, a contractual split between the onshore and offshore works is recommended. Depending on the pipe material to be used, the supply and testing during fabrication of the pipe material can also be a separate contract.

Special conditions of contract should address the following for the offshore construction:

- Environmental
- Risks.

ii. Specifications

General. In general, the offshore works comprise the following components:

- Manufacturing and supply of pipe and diffuser material, including protection and weighting according to the proposed method of construction
- Trenching (surf zone and offshore)
- Launching of the sea outfall, including the diffuser section
- Protection of the pipeline (filter material and rock armour protection)
- Testing of the entire system and rehabilitation according to the defined environmental guidelines.

Apart from all other standard items, the following need to be specified in detail:

- Availability of all marine surveys (bathymetry, physiography, etc.)

- Contractor's allowance for appropriate marine transport and related equipment for inspections and control by the engineer

- Exchange of information between contractor and engineer

- Temporary site facilities and transport, taking into consideration the sensitivity of the marine environment and subsequent rehabilitation after completion of the contract

- The Contractor's commitment to take all reasonable steps to minimise adverse effects on the environment. Submission of an environmental plan for prevention, as well as for mitigating options for all aspects of the construction of the pipeline

- Pollution restrictions, regulations and reporting procedures.

Materials and workmanship. On account of the inaccessibility to the outfall after installation, it is of the utmost importance that all material and fittings, including all aspects of welding, pipe coating and protection, shall conform to standards (if local standards are not sufficient, then to recognised international standards).

Imported backfill material, including material for the bedding of the pipeline, protection of the pipe against rock armour and the rock armour itself, shall be quarried hard stone, predominantly free of intrusions and unweathered. Rock and stone shall be clean, sound, durable, free from earth or other soft or decomposed or injurious materials and shall show no cracks or fissures caused by the initial processes of decomposition, and shall not break down in the seawater. Generally, dredged material will not be allowed to be used as a substitute for imported fill material. This substitute will be approved only after the examination of representative samples of the dredged material for each fill load.

Marine operations**.** The contractor must comply with all requirements of, and maintain liaison with, the relevant Port Authority and must ensure that all statutory requirements are observed in connection with *Notice to Mariners*.

The contractor is liable for the payment of all dock fees, anchorage charges, pilotage fees, etc. related to all materials and plant/equipment to be utilised. The contractor must provide, maintain and eventually remove temporary moorings for construction craft, according to regulations.

The contractor must provide all navigational signs (lights and marker buoys) required by the Port Authorities, or national and international maritime legislation.

The contractor will be responsible for any damage to his/her own or third party craft and to injuries to any person that may occur during the contract.

The contractor, in cooperation with the engineer, must liaise with organisations/persons which/who may have fishing interests in the area and arrange for temporary agreements during the period of construction.

All operations, both ashore and afloat, must be conducted in accordance with the existing statutory rules and regulations or such as may be issued from time to time. The contractor must list, in a schedule, all the construction plant material he/she proposes to use, complete with relevant rates. Vessels to be used as diving platforms must conform to all national and local diving regulations and provisions for emergencies in terms of standby craft. All vessels must at all times be fully equipped in accordance with the latest safety, fire-fighting and emergency equipment requirements as laid down by the relevant authorities for vessels operating on survey and diving work, or as may be applicable.

The contractor must provide survey vessels with specified equipment for echo-sounding, underwater surveys (photographic and video), as well as transport and communications for the engineer’s staff, for the entire duration of the project.

The contractor must determine the location of underwater hazards (structures, cables or wrecks), take the required precautions to avoid these and liaise with the owners responsible for such items.

The contractor is responsible for removing any plant material (floating or sunken) belonging to him/her or a sub-contractor. He/she is responsible for the prevention of and mitigation measures relating to pollution from any substance which may leak from any craft (afloat or sunken). He/she is liable to all costs with regard to this and are responsible for liaison with the relevant authorities.

The contractor, in cooperation with the engineer, must comply and adhere to environmental practices with reference to international as well as national policies as far as it is practical. Special care must be taken during dredging operations during which elevated concentrations of suspended fine sediments will occur. Mitigation measures must be available, for example, sediment curtains. Monitoring must be conducted in accordance with the construction monitoring programme, which forms part of the contract specifications.

Provision also needs to be made for tide and wind recorders to be installed in close proximity to the site, if they are not already available.

All diving operations must be carried out in accordance with official regulations. Prior to underwater operations, the contractor must submit a copy of the diving rules, a general method statement (or standard operational procedures), a safety policy, etc. For all marine works, during which diving operations may be required, an easily accessible, fully maintained decompression chamber must be provided. During construction, qualified divers provided by the engineer need to carry out routine underwater inspections in accordance with the relevant regulations and the contractor’s procedures. The contractor will be responsible for providing equipment and diving supervision and will control the diving operations related to inspections.

During the contract period, an appropriate closed-circuit television system with operators should be maintained, as well as equipment for still underwater photos.

The sea conditions may vary from the predicted data and estimates obtained from the field survey; allowance must be made for such variations. The contractor will not be entitled to any payment, compensation or allowance for extra expense or loss which may be due to variations, inaccuracies or omissions in the data interpretation report of the field surveys.

***Trenching and dredging operations*.** The 'ownership' of the dredged material and the dumping and handling of dredged material must be stated and defined, taking into account all relevant regulations and legislation and authorities that have to be informed.

If the average Point Load Strength Index of the seabed material exceeds 65 MPa, blasting may be required and all necessary arrangements and protocols required for blasting shall be made by the Contractor with the relevant authorities.

Equipment and the degree of accuracy for position fixing, echo sounding and line control (laser) and tide recording must be specified. A continuous fall towards the diffuser end is a basic requirement.

iii. Bill of Quantities

For marine works, the following are important issues to address in the Preamble to the Bill of Quantities in order to reduce the risk of lengthy and costly disputes:

- With regard to day work rates, the rates for demurrage and charter for the marine plant must include all costs associated with the specific marine operation (personnel, fuels, consumables, etc.) and equipment. The charter rate is for productive hours only. Demurrage is compensation paid to the Contractor for loss of working time caused by naval operations or a suspension of work mutually agreed by the Consultant and Contractor for reasons of safety of staff or plant. Demurrage does not include delays resulting from weather conditions or delays not mutually agreed upon.

- Measurement of dredging of the trench must be specified (e.g. linear meters between chainages) and must be based on the profiles in the Drawings supplied with the Tender Documents. Costs for a pre-dredge survey must be included to adjust for differences between the supplied profile and the actual profile. Inclusive rates must be clearly stated (such as soundings, record keeping, removal of debris, conveying and depositing materials, providing buoys, markers and notices and removing silt deposits). For hard material (strength defined), allowance must be made as a separate item (Provisional Sum) and the measurement must be per m^3.

- The rates for the provision and assembly of the outfall pipeline and diffuser section must include testing of strings and diffuser and the installed outfall pipe, supply of all consumables and equipment, and must also apply to the rates for linings and coatings of the pipe.

6.9.5 Decommissioning

A decommission plan is required to prevent or minimise potentially negative impacts on the environment if it is decided to end the discharge practice after the lifetime of the project or for any other reason. Such planning is required as early as the construction consideration and structural design phase to ensure that decommissioning costs of different construction options are evaluated.

Decommissioning options should describe the plan, management and implementation of the decommissioning process and should, for example, address the following:

- Physical and ecological impact of removing the structure or partially dismantling the structure, including any long-term impact should the structure be abandoned (i.e. not removed)

- Technical aspects and the feasibility thereof (e.g. methods to remove the structure or parts of the structure and the re-using, recycling or disposal thereof)

- Monitoring programme after decommissioning to ensure that any remaining structure does not adversely affect the marine environment or other uses, as well as to monitor the ecological rehabilitation of any impacted area

- Procedures for removing large offshore structures are typically dangerous, lengthy and costly. Therefore, when the construction method is selected, decommissioning aspects must be taken into account. Although the initial cost for a buried pipeline is higher than for an exposed pipeline, removal of most of the offshore section will not be necessary when the structure is decommissioned. Moreover, the removal of a structure could result in a greater environmental impact than leaving it in place.

- Envisaged costs for the different options, considering labour, equipment and any other resource requirements.

Approval to proceed with the recommended decommissioning option will be reviewed and subjected to an EIA (a comparative assessment of all options and the rationale for decommissioning of each component) at such time, taking into account the actual circumstances (environment, costs as well as social aspects) at that stage (prior to decommissioning), and approval will only be given at that stage.

6.9.6 Specific requirements for pre-assessment and detailed investigation

Structural design and construction considerations are typically addressed as part of a detailed investigation. However, as part of a pre-assessment certain, aspects which may influence the route and location of the pipeline have to be taken into account in the assessment, such as:

- Availability of pipeline materials to construct the pipeline in a certain area
- Potential construction constraints (e.g. availability of construction area on land, offshore restrictions).

SECTION 7: MONITORING

SECTION 7: MONITORING

CLICK TO VIEW GRAPHIC

PURPOSE:

In the context of this operational policy, this component refers to the longer-term monitoring programmes that are undertaken once marine disposal activities become operational. Such monitoring programmes typically become part of the licence agreement issued by the DWAF for a particular discharge, under section 21 of the National Water Act. In essence, the purpose of these long-term monitoring programmes is to provide data to continuously evaluate:

- ***The effectiveness of management strategies and actions to ensure compliance with the licence conditions and design criteria (Compliance monitoring and System Performance monitoring)***

- ***The trends and status of changes in the environment in terms of the health of important ecosystems and designated beneficial uses in order to respond. Also, to evaluate whether the actual environmental responses match those predicted during the assessment process (Environmental monitoring).***

Such information is required to provide feedback to management, authorities and other interested and affected parties on the performance of the disposal practice, and to enable informed debate on operations, and operations modifications, where appropriate.

These monitoring programmes are designed and implemented at the cost of the authority or industry responsible for the management of the waste disposal system (following the Polluter Pays Principle).

In order to be useful from a management perspective, monitoring data must be evaluated against pre-determined objectives. Results need to be presented in a clear format, providing the appointed management institution/s with the scientific and engineering information for effective decision making.

Long-term monitoring programmes are typically only designed as part of a Detailed Investigation.

Long-term monitoring programmes related to a systems discharging wastewater to the marine environment consist of two main components, namely:

- *Compliance monitoring*, to determine the effectiveness of management strategies and actions to ensure compliance with licence conditions, e.g. the limits set for the volume and composition of the wastewater

- *System Performance monitoring,* to determine the effectiveness of management strategies and actions to ensure performance in accordance with the design criteria, such as the hydraulic performance of the discharge system

- *Environmental monitoring*, to determine the trends and status of changes in the receiving marine environment, in terms of the health of important ecosystems and designated beneficial uses. Also, to evaluate whether the actual environmental responses, match those predicted during the assessment process. This evaluation is necessary in order to respond, where appropriate, in good time to potentially negative impacts, including cumulative effects.

If compliance monitoring shows non-compliance, the licensee can be prosecuted even if the system performance monitoring and environmental monitoring indicates compliance with the design criteria and environmental quality objectives. If there is compliance with licence conditions and/or the system performs within the design criteria, but the environmental quality objectives are not being met, the licence needs to be reviewed to set stricter limits or the objectives need to be re-evaluated.

7.1 COMPLIANCE MONITORING

Once a wastewater discharge to the marine environment is approved by the DWAF, a licence is issued, which among other aspects, specifies the volume and composition of the wastewater. The aim of this monitoring component is to assess continuously whether these licence requirements are adhered to. Parameters to be monitored include:

- *Flow*: The sampling frequency need to be sufficient to resolve the actual *variability* in the wastewater volume.

- *Composition of wastewater*: The list of constituents to be monitored will depend on the composition of the wastewater, while the frequency of monitoring needs to reflect the actual *variability* in wastewater composition.

  Urban/Municipal wastewater discharges, consisting mainly of domestic sewage have a characteristic wastewater composition. Key constituents that need to be included in the monitoring programme of discharges to the marine environment are:

  - Biochemical oxygen demand/Chemical oxygen demand
  - Total suspended solids
  - Particulate organic carbon and nitrogen
  - Inorganic nitrate and nitrite
  - Total ammonia
  - Dissolved reactive phosphate.

  In the case of industrial wastewater discharges, or where industrial wastewater discharges entering a municipal WWTW, the constituents included in the monitoring programme will depend on the constituents present in the wastewater and their potential to impact negatively on the receiving marine environment and its designated beneficial uses (refer to Section 3).

NOTE:

An industry, discharging to a WWTW or directly to the marine environment (or if applying for a licence to do so), will be required to provide a detailed description of the waste stream both in terms of volume (quantity) and quality (i.e. listing all substances present and their concentrations). Where industries discharge into WWTW, the WWTW authority is responsible for obtaining this information from the industry concerned (in accordance with Ground Rule 20 in the **Operational Policy for the treatment and disposal of land-derived water containing waste to the marine environment of South Africa** ***(RSA DWAF Water Quality Management Sub-Series No. 13.2).***

The sampling frequency of the composition of the wastewater will depend on the actual *variability* in wastewater composition.

Sample analyses must be conducted by an analytical laboratory accredited to analyse of the relevant constituents in the wastewater.

- *Toxicity testing:* It is imperative that wastewater streams are routinely subject to toxicity testing (refer to Section 4.5 for further details). Such tests have been routinely used in South Africa for the past 15 years for monitoring the performance of wastewater discharges to the offshore marine environment. The frequency of toxicity testing of the wastewater will depend on the actual *variability* in the wastewater composition.

7.2 SYSTEM PERFORMANCE MONITORING

Monitoring of the performance of the wastewater disposal system comprises two main components:

- Physical inspections of the outfall system (for marine outfalls)
- Hydraulic performance (this typically applies to marine outfalls, i.e. wastewater discharges to the offshore marine environment).

7.2.1 Physical inspections

<u>*Head works and land line*</u>. The Standard Operating Procedure for the head works and treatment plant should include specified and scheduled monitoring procedures. These include daily routine observations and longer-term mechanical, electrical and hydraulic testing. These records form an integral part of the maintenance programmes and service contracts for the plant and specific components.

<u>*Underwater section*</u>. The stability of the pipeline and the diffuser of a wastewater discharge system should be checked regularly, especially after major storms, to ascertain that no undesired displacements or damage have occurred.

An underwater video recording of exposed sections of the pipeline, the diffusers and ports is used to check the structural/physical condition of an outfall as well as its operational efficiency. These inspections should be conducted annually and after major storms.

7.2.2 Hydraulic performance

After the commissioning of a new marine outfall, the hydraulic/dilution performance should be confirmed. This field test(s) should include:

- Controlled injection of a conservative tracer material, such as Rhodamine-B dye, into the wastewater at the head works
- Continuous sampling downstream of the injection point and at one or more of the ports (depending on the length of the diffuser)
- Spatial sampling in the initial mixing zone ('boil')
- Accurate recording of wastewater flow and physical conditions at the discharge location (currents and seawater density throughout the water column)
- Sample analysis (e.g. by using a calibrated Turner Design Fluorometer or similar device)
- Statistical analysis of the distribution of concentrations in the boil to determine the achievable dilutions
- Comparison of measured achievable dilution with the theoretically predicted dilutions.

The performance test should also be conducted at any stage during the lifetime of the outfall when physical changes or alterations, which may have an effect on the hydraulic characteristics, are introduced or when there is a substantial change to the wastewater quantity or composition.

During this performance test, the sampling can be extended to the far field to confirm the estimated achievable secondary dilutions.

7.3 ENVIRONMENTAL MONITORING

In the context of this operational policy, the purpose of establishing monitoring programmes in the receiving marine environment is to continuously provide data for the evaluation of the status of the receiving environment in terms of the health of important ecosystems and designated beneficial uses. This evaluation enables a response, where appropriate, in good time to potentially negative impacts, including cumulative effects.

The requirements for monitoring in the receiving environment are usually site-specific and depend on the type of wastewater discharge and the variability in its waste loads, as well as the site-specific physical, biogeochemical and ecological characteristics of the receiving environment and the variability thereof. As a result, this section is not intended to be prescriptive, but rather sets out the approach to follow when formulating long-term monitoring programmes associated with wastewater disposal activities to the marine environment.

Key elements of a successful monitoring programme include (ANZECC, 2000b; US-EPA 2003):

- Setting clear monitoring objectives
- Design and implementation of a cost-effective programme.

NOTE:

Useful documents to consult in the design of monitoring programmes are NATIONAL RESEARCH COUNCIL (1990), ANZECC (2000a), ANZECC (2000b), NZWERF (2002), US-EPA (1994) and US-EPA (2003).

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.

NOTE:

The Methodology for the Determination of the Preliminary Ecological Reserve for Estuaries *(RSA DWAF, 2004), issued under the National Water Act, through the Directorate: Resource Directed Measures, also requires that Resource Monitoring Programmes be implemented for estuaries. To ensure alignment with existing initiatives on estuaries, those methods (or future updates thereof) need to be consulted when formulating monitoring programmes for estuaries as part of this operational policy. Proposed procedures for the design of long-term environmental monitoring programmes for estuaries, as part of Resource Directed Measures, are provided in a WRC report entitled:* Resource Monitoring Procedures for Estuaries for Application in the Ecological Reserve Determination and Implementation Process *(Taljaard et al., 2003).*

7.3.1 Monitoring objectives

Measurable site-specific monitoring objectives are a key component of a sound monitoring programme. Such clear objectives make it possible to design a focused and cost-effective monitoring programme. These objectives can also be translated into hypotheses that could be proved statistically.

The monitoring objectives are distilled from the environmental quality objectives previously specified for the study area and, in turn, are based on the requirements of the important marine ecosystems and the designated beneficial uses (refer to Section 3).

NOTE:

Where a monitoring programme is designed for an existing wastewater discharge to the marine environment and where the study area boundaries, as well as the environmental quality objectives of important marine ecosystems and other beneficial uses, have not yet been established, these will have to be addressed prior to setting monitoring objectives.

EXAMPLE…

Monitoring objectives for a discharge from a municipal WWTW typically include:

- Determine whether *E. coli* levels measured at designated recreational beaches exceed the recommended target values for contact recreation, as set out in the *South African Water Quality Guidelines for Coastal Marine Waters*
- Determine whether particulate organic matter discharged from the WWTW accumulates at depositional areas, thus creating a 'sink' for toxins such as trace metals
- Determine whether trace metals are present in the wastewater discharged from the WWTW accumulates at depositional areas and whether these exceed the limits set for such constituents under the London Convention
- Determine whether toxins are accumulating in biological tissue (e.g. that of filter feeders such as mussels and oysters) at concentrations exceeding the environmental quality objectives set, for example, for human consumption of these organisms or the protection of organism health
- Determine whether the composition of the biotic community in the study area is being altered as a result of the wastewater discharge.

Note that monitoring objectives do not specify details on temporal and spatial scales since these are addressed as part of the monitoring programme design (ANZECC, 2000b).

7.3.2 Programme design and implementation

A key component of the design of a focused and cost-effective monitoring programme is an understanding of dominant physical, biogeochemical and ecological processes that govern the 'cause-and-effect' linkages between the receiving environment and the wastewater discharge. This design should also take into account modifications to such processes resulting from existing human activities. Such information is collated as part of the *Scientific and Engineering assessment* component (refer to Section 6).

NOTE:

Where a monitoring programme is designed for an <u>existing</u> wastewater discharge, it is crucial that an understanding of the dominant physical, biogeochemical and ecological processes be obtained prior to implementing any such monitoring initiative, even if a only conceptual model can be formulated. The procedures to be followed in such circumstances will be similar to those described for the characterisation of physical, biogeochemical and ecological processes of the study area as part of the **Scientific and Engineering assessment** ***component (refer to Section 6).***

In areas in which the marine environment receives waste inputs from multiple sources, monitoring programme design efforts need to be combined and integrated to ensure cost-effective usage of both human and financial resources. For example, in Saldanha Bay, the authorities and industries disposing of waste to the bay established the Saldanha Bay Water Quality Forum Trust, to enable each authority/industry to contribute towards an integrated monitoring programme (Taljaard & Monteiro, 2002).

Setting spatial boundaries for a monitoring programme is important because inappropriate boundaries might focus efforts away from driving or consequential factors (ANZECC, 2000b). The anticipated influence of the proposed discharge, therefore, needs to be taken into account when selecting the spatial boundaries. This selection, in turn depends on the transport and fate of the wastewater plume, both in the near and far field, as well as potential synergistic effects associated with other anthropogenic activities occurring in the area.

Numerical modelling has proven to be very useful in enhancing the design of monitoring programmes and improving the interpretation of the results of monitoring. 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: Important insights are provided by the combination of the synthesis of the existing understanding of the 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 (set up as part of the *Scientific and Engineering Assessment* component – Section 6) 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, allowing the investment in the monitoring to be limited to only a number of critical parameters measured on critical time and spatial scales.

i. Measurement Parameters

The selection of measurement parameters is site-specific. A key determining factor in the selection of such parameters is the composition of the proposed wastewater discharges as well as anticipated effects on the physical, biogeochemical and/or biological characteristics of the receiving environment.

Biogeochemical parameters (e.g. pH, dissolved oxygen, turbidity, particulate organic carbon and nitrogen, dissolved nutrients, toxin concentrations and microbiological parameters) can be measured in the water column, and/or sediments, including interstitial waters.

NOTE:

Geochemical ratios of trace metals can be used to determine whether the trace metals are of natural or anthropogenic origin. It is possible for conditions to arise in which the total trace metal concentration in the sediment is high (particularly in depositional areas) but completely linked to the natural structure of clay minerals, in which case the trace metals will not be bio-available. This condition would be characterised by geochemical ratios very similar to those of unpolluted sediments typical of the area. The geochemical ratio of each trace metal relative to aluminium (TM [µg/g]: Al [%]) is used, usually allowing a conservative two-fold natural variation in the geochemical ratios. Natural geochemcial ratios are site-specific for different geographical regions and need to be sourced from the literature (Monteiro & Scott, 2000).

Stable isotope ratios of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) have also been used successfully in tracing the origin of organic matter in marine sediments, e.g. sewage-derived organic matter versus organic matter from natural, marine origin. The use of stable isotope ratios in this manner is discussed in more detail in Sweeney et al., 1980, Vivian, 1986 and Monteiro, 1997.

Toxins (e.g. trace metals and hydrocarbons) can also be detected through the *biotic component* of the receiving environment. For example, filter feeders (such as mussels and oysters) are internationally recognised as suitable bio-indicators for trace metal and hydrocarbon accumulation in the marine environment (Cantillo, 1998). These organisms filter food from the water in which they live and tend to retain contaminants that often accumulate to high concentrations in their tissues, thus reflecting changes in water quality over time. Their sedentary nature also prevents confusion about where a filter feeder might have accumulated a particular chemical compound.

NOTE:

A range of specific organisms can be used as indicators for the likely presence of pathogens and viruses in the receiving marine environment (Taljaard et al., 2000). In South Africa, faecal coliforms (**E. coli*****) are used as indicator organisms. However, new developments in health monitoring propose the expansion of monitoring parameters to include a selection of indicator and/or pathogenic organisms rather than a single indicator organism. The extended surveys need not be conducted frequently, but, for example, could be conducted every three months. In doing so, the assessment of the extended list of parameters assists in detecting anomalies which may otherwise pass undetected when assessing only a single group of organisms. For example, sampling at quarterly intervals for a range of micro-organisms such as*** **E. coli, Salmonellae, Salmonella typhi*****, pathogenic staphylococci, shigellae, helminth parasites and faecal streptococci has proved useful for auditing purposes to detect problems which may have passed unnoticed in routine*** **E. coli** ***assessments. Measuring more than one indicator for microbiological contamination, together with salinity (as a physical parameter for assessing the dilution or impairment of pristine seawater), has proved valuable for interpretation purposes (Rathbone et al., 1998; CSIR 1999).***

Other studies that assessed the suitability of indicators for the likely presence of pathogens and viruses in the receiving marine environment along the South African coast include Grabow **et al*****. (1989), Idema and Kfir (1990), Genthe (1996) and Grabow*** **et al*****. (1999).***

Measurement parameters can also include biota for ecological evaluations. In essence, biological measurements involve field measurements on the relative abundance, species diversity and community structure and composition of the biological communities in the study area to establish any change as a result of the wastewater discharge/s. Changes need to be measured against a pre-impact baseline data set and/or appropriate control sites.

As it is often very expensive to conduct detailed ecological monitoring programmes, that measure entire biotic communities in a particular study area, it is necessary to select indicator species that could be used as proxies for evaluating ecosystem health. In studies throughout the world and also in South Africa, macroinvertebrate communities have been used successfully in assessing ecosystem health as part of monitoring programmes for wastewater disposal to the marine environment (ANZECC, 2000b; CSIR, 2001a; CSIR, 2003 a & b).

Meiofauna distribution patterns, in conjunction with related biogeochemical parameters, have also been used successfully in this regard, for example, in intertidal areas along sandy beaches (Skibbe, 1991; Skibbe, 1992). These are, therefore, useful measurement parameters to include in the monitoring programmes associated with wastewater discharges to the surf zone, in which the wastewater plume is typically trapped in the surf zone with significant risk of negative impact on inter-tidal zones.

In South African estuaries, macrophytes have also been used successfully as long-term indicators of ecosystem health (CSIR, 2003b).

Other biotic parameters that have also been used are fish (ANZECC, 2000b), particularly in areas that support resident populations, such as estuaries, shoals, reefs and settlements on moored substrates.

Where the study boundaries of a monitoring programme include areas that support biotic species of economic importance (e.g. the prawn populations on the Thukela banks off the Kwazulu-Natal coast), these species could also be considered as measurement parameters in ongoing monitoring programmes.

However, it is important that scientifically sound reasons are provided for the selection of specific biotic indicator species in a particular project. Before choosing a particular taxonomic group(s) as a measurement parameter of ecosystem health, it is important to also test it against the following criteria (ANZECC, 2000a &b):

- Sensitive to potential impacts for waste inputs
- Measured response will reflect the ecological condition or integrity of the study area
- Approaches to sampling and data analysis can be highly standardised
- Response can be measured rapidly, cheaply and reliably
- Response has some diagnostic value.

A useful checklist that can be used to assist in the selection of suitable measurement parameters, in general, is provided in Table 7.12 (ANZECC, 2000b).

TABLE 7.12: Checklist for selection of measurement parameters (from ANZECC, 2000b)

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?*

ii. Spatial scales

The selection of sampling locations largely depends on the transport and fate of the wastewater plume, both in the near and far field.

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 numerical modelling assists in defining the most critical space- and time-scales at which monitoring will need to be done in order to obtain the desired output.

Although long-term monitoring programmes may, initially, still require relatively intensive spatial 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. These high sensitivity points, however, need to be justified on the basis of specific criteria, such as high concentrations of mud and silt that indicate a long-term depositional area.

Specific beneficial use sites within the study area can also indicate sampling locations. For example, recreational beaches and mariculture areas will be logical sampling locations in instances in which the transport and fate of a wastewater plume poses a potential risk to human health.

iii. Temporal scales (sampling interval or frequency)

The temporal scale of a monitoring programme (i.e. sampling frequency) largely depends on the:

- variability in the load of contaminants from waste inputs
- variability in processes driving transport and fate in the receiving environment
- temporal sensitivity of the ecosystem to contaminant loading, i.e. exposure time versus negative impact.

The sampling interval or 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, for example, 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.

In the water column, high frequency physical processes, such as tides, currents, wind and waves, mainly control variability. A sampling frequency that is too low relative to the underlying natural variability, therefore, will result in biased data which 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 order to resolve 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 usually not cost-effective.

An instance where water column sampling is considered to be the most appropriate means of addressing the issue of concern is the monitoring of the microbiological status (e.g. *E. coli*) of marine waters, e.g. at recreational or mariculture sites at which a waste input poses a potential risk to human health.

If the cost implications of a monitoring programme based on highly variable parameters, e.g. those in the water column are taken into account, it is usually more appropriate to focus effort on those environmental components that tend to <u>integrate</u> or <u>accumulate</u> impacts or change over time, such as sediments and organisms (e.g. filter feeders).

Sediment sampling frequency is strongly linked to the time-scale which the sampled 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.

NOTE:

Depositional sites can be designated both long- and short-term. For example, an open coast site may be a depositional site for a period of days to weeks whereas an estuary may be such 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. This information provided by both is key to the design of optimal monitoring programmes, particularly in terms of sampling frequency.

Another commonly used technique to partially overcome the problem of high frequency variability is to measure seasonal variability of constituents in filter feeders. Where filter feeders are used to measure variability of constituents, it is important to realise that the body mass of these organisms also has a strong seasonal variability related to spawning cycles. Thus, a variability factor for contaminants inside the organism's tissue is introduced that needs to be separated from potential long-term signals caused by human interference. To achieve distinction, two procedures have to be implemented:

- Samples need to be taken at 6-monthly intervals
- Long-term sampling needs to be undertaken within a narrow time window each year to reduce seasonal uncertainty.

iv. Sampling and Analytical Techniques

The choice of an analytical technique to apply in a monitoring programme is largely dependent on the selection of measurement parameters and the output that is required to evaluate properly whether monitoring objectives are complied with. Key requirements that need to be stipulated in a sampling programme include:

- Sampling technique
- Number of replicates (determined by the statistical technique used in analysis)
- Sample handling and storage.

It is strongly recommended that an appropriately accredited analytical laboratory conduct chemical analyses of marine biogeochemical parameters.

NOTE:

The WHO's suggestion for the design of a monitoring programme for recreational use (e.g. at bathing beaches) is provided below (WHO, 1999). The design is based on an intensive study to test the scientific validity of the long-term sampling approach. It is particularly important to determine the effect and influence of temporal, spatial, and environmental factors, and the intensive study must be adequate to capture all of these factors to ensure that the results of design exercise portray the actual situation at the specific beach.

<u>Measurement parameters</u>. Two microbiological indicators of faecal contamination are recommended by the WHO, namely faecal streptococci/enterococci and Clostridium/Clostridium perfringens. In addition to the microbiological indicators, data on salinity, pH, turbidity, water and air temperature are also collected to assist in the interpretation of results. Other important observations that also need to be recorded include:

- ***Rainfall***
- ***Cloud cover***
- ***Wave height, current direction and speed***
- ***Tidal state and magnitude***
- ***Wind direction and speed relative to beach***
- ***Bather and animal population***
- ***Beach debris and sanitation***
- ***Location and status of stormwater drains, wastewater discharges and beach facilities.***

<u>Spatial scale</u>. To determine the spatial scale on which samples need to be collected to be representative of conditions at a specific beach, a 20-m grid along the width of the bathing area and stretching from the high-water mark to the end of the swimming zone, should be sampled during the intensive study. The sampling grid should cover water depths from ankle deep (0.15 m), through knee deep (0.5 m) to chest deep (1.3 m).

<u>Temporal scales</u>. To determine the sampling frequency, intensive studies should be performed at least over the period of a typical bathing season, e.g. 3 months. A minimum of 50 days, during which sampling is done hourly over a 12-hour period (during the day), is recommended. Because conditions vary in response to the density of users and discharge patterns from WWTW (e.g. peak uses often occur on weekends and holidays), sampling days need to be representative of all situations. Because rainfall events can also affect conditions, typical rain events also need to be included in the sampling period. Samples should be collected from all sites along the grid.

Statistical analysis of the above data set and an evaluation thereof are then used to determine the temporal and spatial scales for a representative and cost effective long-term monitoring programme.

7.4 DATA EVALUATION

Computers and statistical software are valuable tools for the evaluation of environmental data. However, they are only tools: the ultimate assessment depends on scientific expertise, as well as a proper understanding of statistical procedures and their applicability to environmental data. Where statistical expertise is limited, commercially available software packages (or the techniques described in the following section) must be used cautiously. Statistical techniques that are applied inappropriately can result in erroneous results or interpretations.

7.4.1 Data qualification

To ensure compatibility with the wide range of statistical and analytical techniques that are available for the analysis of environmental data, it is crucial that different types of data be logged in pre-defined formats that have been specified internationally (UNESCO/WHO/UNEP, 1992). This will ensure that the transfer of data to targeted users (e.g. researchers, authorities and other interested and affected parties) occurs in the shortest, most effective manner.

Data types can be in any of the following formats:

- Date and time
- Numerical data, including measured, recorded, counted or estimated data
- Alpha-numeric or text format, including observations, description, comments or reference to stored visual material such as digital photos or videos
- Boolean, e.g. yes/no, true/false, present/absent, visible/not visible or occurrence/non-occurrence.

In the case of measured numerical data, they can be:

- Continuous data, for which theoretically an infinite number of values can be assumed between two given values, such as, temperature, salinity or constituent concentrations. For a given sample set, frequency distribution can be either normal or non-normal.

- Discrete data, which are typically counts that results in a discrete, discontinuous data point, e.g. biological data sets. In the case of discrete data, the frequency distributions will generally be non-normal and data manipulation will be required before distribution related statistics can be applied. Without manipulation, non-parametric procedures (e.g. median and percentiles) can be applied.

The required accuracy and precision of data need to be clearly defined before embarking on data acquisition exercises. Rounding-off and the number of significant figures must be defined for each type of data. A high level of confidence with regard to data accuracy is essential for any further analysis.

Where data sets contain values that deviate from the normal cluster of values (referred to as outliers), the validity of these needs to be determined. Where outliers cannot be rejected, approaches need to be applied to analyse such data, including (UNESCO/WHO/UNEP, 1992):

- Application of non-parametric techniques to the entire data set
- Comparison of different statistical analyses on the data set, with and without the outliers, to decide whether the outliers should be part of the data set or not.

Where the measured data are either below or above the detection limit of the analytical technique, they are typically recorded as ‘not detectable’ or ‘below limit of detection’ or ‘maximum detectable level’. Further analysis of such data, as part of a larger data set should be undertaken with caution. More than one approach should be followed to determine the extent of the influence of such data on results. Ways in which to deal with such data are (UNESCO/WHO/UNEP, 1992):

- Use all values
- Ignore all ‘not detectable’ or ‘below limit of detection’ or ‘maximum detectable level’ values
- Use all values, but replace ‘not detectable’ or ‘below limit of detection’ values by 0
- Use all values, but replace ‘not detectable’ or ‘below limit of detection’ values with the detection limit (e.g. 0.5)
- Determine median values (a parameter which is insensitive to extreme data).
- Truncation of data set, by trimming equal amounts of data on both ends of the distribution
- Replace ‘not detectable’ or ‘below limit of detection’ values by the same number of next greater values and replace the same number of greatest values by the same number of next smallest values.

7.4.2 Analysis of data

NOTE:

This section provides a basic overview of statistical techniques that are typically applied in the evaluation of environmental data, where and when appropriate. It highlights important factors that need to be taken into account when applying statistical analyses to data sets and is by no means exhaustive. It is strongly recommended that the reader apply the information provided in this section in conjunction with the detailed statistical sources or with the assistance of a qualified statistician. The information was primarily extracted from UNESCO/WHO/UNEP (1992), Devore and Farnum (1999), Spiegel (1972) and US-EPA (2002c).

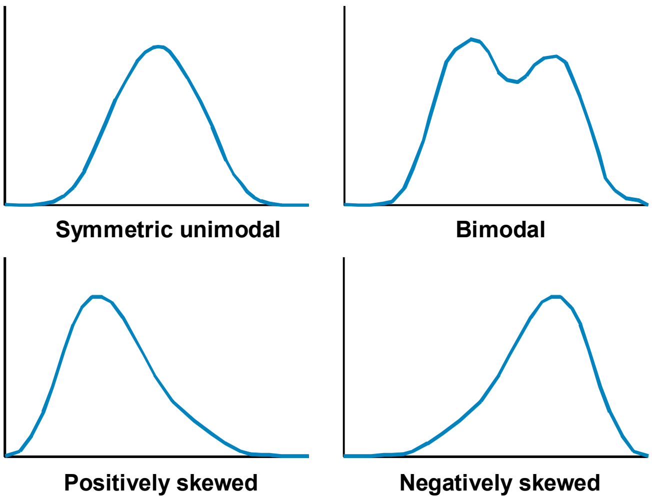
The selection of statistically techniques depends on the type of monitoring programme. Clarke and Green (1988), for example, demonstrate the complexity in the statistical design and analysis for biological studies.

i. Frequency distribution

The bulk of environmental data is in numerical format. These numerical data sets typically have either:

- No specific frequency distribution or
- Normal (or Gaussian) frequency distribution or
- Non-normal (skewed) frequency distribution.

The frequency distribution is determined by counting the number of times each value, or class of values, occurs in a data set. Typical frequency distributions are as follows:



These distribution patterns determine the type of statistical methods that can be applied to a data set with confidence. If the distribution of data does not conform to a specific distribution type, statistical output can be erroneous as a result of the application of invalid techniques.

The frequency distribution of data sets can be determined by:

- Visual methods
- Graphical methods
- Statistical methods.

Visual tests are the simplest procedures for reviewing the distribution of data sets.

This can be done by visual comparison of a histogram of a data set (values divided in a limited number of equal intervals) for the typical bell-shaped characteristics of a normal distribution. As a rule of thumb, the number of intervals can be taken as the square root of the number of values of the data set.

Graphical methods provide a more rigorous determination of the distribution frequency. For a normal distribution, the cumulative frequency distribution will plot as a straight line (at least between 20% and 80%) on a log/normal probability graph.

More rigorous statistical methods can be used, e.g. the Chi-Square Goodness of Fit Test, where the number of samples in a data set is more than 20. Many other statistical tests are available and a qualified statistician should be consulted in the selection of an appropriate method for a specific data set. Examples of such methods are provided in Devore and Farnum (1999).

Other well-known statistical methods that are applied to determine the extent of distortion from a normal distribution frequency are the:

- Skewness check, in which data are not symmetrically distributed about the mean (e.g. the median is not equal to the mean)
- Kurtosis check, in which a data set has a more or less “peaked” distribution curve compared to a normal distribution frequency.

Depending on the frequency distribution, either parametric or non-parametric descriptive statistical techniques can be applied. Non-parametric techniques can typically be applied to any data set. However, parametric techniques should only be applied to data sets showing a normal frequency distribution. Where a data set is non-normal, mathematical functions (e.g. logarithms and square roots) or more advanced transformation (e.g. Poisson) can be applied to transform the raw data into transformed values that may resemble normal frequency distribution. The parametric statistical methods can then be applied to the transformed values.

Where probability statistics are applied, it is important to provide an indication of reliability as well as the degree of confidence in estimating the mean. Standard statistical handbooks can be consulted for methods to determine of the standard error and confidence limits, e.g. Devore and Farnum (1999).

ii. Basic non-parametric descriptive statistical techniques

These techniques are usually suitable for application to any data set because:

- They are non-dependent on the frequency distribution
- Computations are simple and results are more easily understandable
- Missing data or outliers have a lesser effect on computations and results.

Basic non-parametric parameters that can be calculated for a data set include:

- **Sample (or arithmetic) mean** (X), which is a measure of the central tendency:

  $X = \Sigma x_i/n$ (for data set x_i, i = 1 to n)

  (The sample mean should be applied with caution as the effects of outliers or missing data can produce errors in results)

- **Median**, which is a measure of the central tendency that resists the effects of outliers or missing data. The median (M) for n data values is obtained by first ordering the data from the smallest to the largest value, then:

  M = (n=1)/2 th value on the ordered list if n = odd
  M = average of the (n/2) th and the (n/2+1) th value if n = even

- **Range**, which is the difference between the largest and smallest value in a data set.

  $R = x_{max} – x_{min}$ or
  Middle-range (R/2) which is also a crude estimate of the sample mean

- **Percentile,** which is a value on a scale of one hundred that indicates the percent of a distribution that is equal to or below it.

  P = p x 100/(n+1)

  For a given percentile the p value is:
  p = P (n+1)/100

- **Mode,** which is the value occurring most frequently.

iii. Parametric descriptive statistical techniques

Where data sets resemble a normal distribution (or where a transformation of the original data set conforms to a normal distribution), parametric statistical methods can be applied, in addition to non-parametric statistical techniques. A graphic illustration of a normal distribution is as follows:

CLICK TO VIEW GRAPHIC

Typical properties of a data set with a normal frequency distribution are:

- Values are symmetrical about the mean
- Mean (μ) = median = mode
- The curve is bell-shaped
- Extreme values will only constitute a small portion.

Basic parametric statistical parameters include:

- **Sample variance** (s^2), which is a primary measure of variability and which measures deviations from the mean (x_1 - X, x_2 - X, ..):

  $s^2 = \Sigma(x_i - X)^2/(n-1)$ (for data set x_i, i = 1 to n)

  (A simple way to obtain one quantity for the deviations is to sum the averages and divide by the number of samples. Because of the return of a 0 for this summation, the deviations are squared to obtain a measure of variability)

- **Sample standard deviation** (s), which is the square root of the sample variance (s^2):

  $s = \sqrt{s^2}$

- **Variance** (σ^2), which is the discrete distribution with a mean (μ) of a discrete data set (x_i) with probabilities p(x) is:

  $\sigma^2 = \Sigma(x_i-\mu)^2.p(x))$

  And for a continuous data set (x_i) with a distribution density function f(x) the **variance** (σ^2) is:

  $\sigma^2 = \int(x-\mu)^2.f(x)dx$

- **Standard deviation** (σ) is the square root of the σ^2:

  $\sigma = \sqrt{\sigma^2}$

  (The standard deviation is a measure of the spread of the data around the mean and is expressed in the same units as the mean.)

  An empirical rule for a data set with a normal frequency distribution is as follows:

  - Approximately 68 % of the values are within the standard deviation (σ) of the mean
  - Approximately 95 % of the values are within the 2σ of the mean
  - Approximately 99.7 % of the values are within 3σ of the mean

- **Sample co-efficient of variation**, which is the ratio of the standard deviation (σ) to the mean (μ) and is a measure of the extent of variability relative to the mean.

- **Probability density function.** Most environmental data are considered to constitute a stochastic process, which implicates an uncertainty in the results and that the process and the subsequent data from the process are random. Randomness is addressed by normal distributions and predictions can be made and hypotheses can be tested. The probability (between 0 and 1) provides an indication of the likeliness that an event will occur. The probability of an impossible event is 0 and a probability of 1 indicates that it is certain that the event will occur.

  By integration, the probability density function, f(x) for a normal distribution, can be expressed in terms of the mean (μ) and the standard deviation (σ) as:

  $f(x) = (1/\sigma\sqrt{(2\pi)}).\ e^{-0.5(x-\mu)/\sigma)2}$

vi. Time series analysis

Many mathematical techniques are available for the analysis of a time series (a stochastic process with a fixed sampling interval) for preliminary data exploration, detection of trends and forecasting. The most common method is using moving averages over appropriate intervals, which will eliminate irregular patterns and, depending on the width of the 'smoothing window', also cyclical variations. The method of least squares can be used to find the equation for a trend line or curve.

Other methods include the determination of the auto-covariance and the cross covariance functions.

The auto-covariance function provides an indication of any cyclic trends present in a data set, i.e. the dependency of a variable on itself in time. Testing for auto-correlation is important because, if it is present, conventional statistical analyses are not valid. The auto-covariance function is measure of the similarity between a variable and a time-shifted replica (lagged version) of itself and can be determined as follows:

For a time series $x(t)$ $(t = t_1 ....t_n)$

$$\gamma(k) = \frac{1}{n-k} \Sigma \left[(x(t) - \bar{x})(x(t+k) - \bar{x})\right]$$

Where: **k = lag**
m = maximum lag
$\bar{x}$ = average of time series $x(t)$
n = number of data points

Characteristics of $\gamma(k)$ are:

- If $x(t)$ and $x(t+k)$ increase together then $\gamma(k) > 0$
- If $x(t)$ decreases while $x(t+k)$ decreases then $\gamma(k) < 0$
- If $x(t)$ and $x(t+k)$ independent then $\gamma(k)= 0$ for large number of samples
- If $k = 1$ then $\gamma(k)$ = sample variance ($s^2 = \Sigma(x_i - X)^2/(n-1)$)

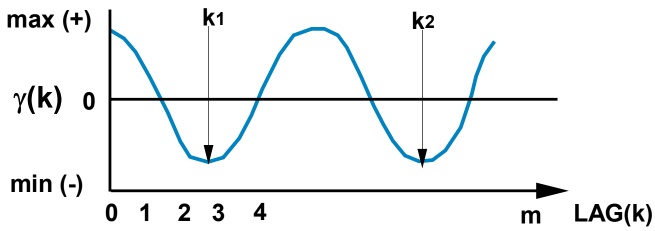
For a sampling interval Δt the periodicity can be determined as follows:

Period (units of Δt) = $\Delta t \times (k_2 - k_1)$

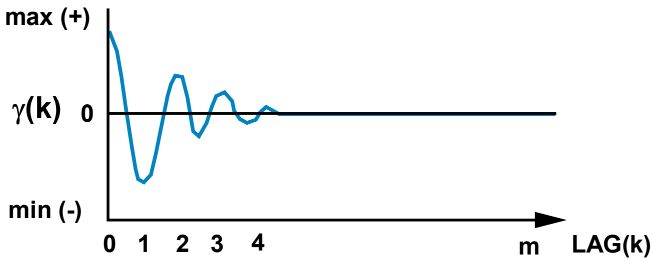
All cyclic events in the time series will be identified, if $(m \times \Delta t)$ > period of the cyclic event.

The transformation of the auto-covariance to a discreet finite co-sinus series will result in the spectral density function (frequency domain).

A high correlation is likely to indicate a periodicity in the signal of the corresponding time duration. A schematic illustration of a time series that contains a periodicity and a random time series, is illustrated below:



Time series with a periodic component



Random time series

The cross-covariance function describes (or indicates) the inter-dependency of two variables in time (two time series with a fixed sampling interval). The cross-covariance function can be expressed as follow:

For two time series $x_1(t)$ and $x_2(t)$ $(t = t_1 \ldots\ldots t_n)$

$$\gamma_{x1x2}(k) = \frac{1}{n-k} \sum_{t=1}^{t=n-k} [(x_1(t) - \bar{x}_1)(x_2(t+k) - \bar{x}_2)]$$

$$\gamma_{x1x2}(-k) = \frac{1}{n+k} \sum_{t=1}^{t=n+k} [(x_1(t-k) - \bar{x}_1)(x_2(t) - \bar{x}_2)]$$

Where: k = lag (k = 0, 1, 2, 3 ...... m)
m = maximum lag
$\bar{x}_1$ = average of time series $x_1(t)$
$\bar{x}_2$ = average of time series $x_2(t)$
n = number of data points

Before a trend calculation is executed, the type of trend should be determined, i.e. if there was only a gradual change or where data before a specific time or event are distinctly different from the data collected after that time or event. It is beyond the scope of this guideline at this stage to discuss details of the numerous methods available, which are described in many statistical handbooks. A practical numerical solution (together with computer routines) for the calculation of the auto-covariance as well as cross covariance functions is described in Botes (1980), Botes (1986) and Liu (1974). Included in the program listings are practical methods to ‘clean’ time series data by applying digital band, low- and high-pass filters.

v. Hypothesis testing

Monitoring objectives can be stated as hypotheses that can be statistically answered, for example:

> There is no difference between sediment trace metal concentrations measured at two locations (e.g. one being a control site)

In proving the hypothesis it can either be the:

- Null hypothesis, showing statistically that the hypothesis is true, i.e. there is no difference, or
- Alternate hypothesis, statistically showing the hypothesis is false, i.e. there is a difference.

Statistical methods such as the *t*-test*, F*-test and the Analysis of Variance (ANOVA) can be used to test a hypothesis (UNESCO/WHO/UNEP, 1992).

A practical procedure of hypothesis testing from means of two data sets, with normal frequency distributions, is by using the *t*-test as provided below (derived from Spiegel, 1972):

For two data sets x_i and y_i (i = 1,2,3,.........,n_1 for x and n_2 for y)

Suppose: The means (μ1 and μ2) are unknown.

To test the null hypothesis: H_0: $\mu 1 - \mu 2 = G$

Where G is a given value.

$$\overline{x} = \frac{1}{n_1}\sum_{i=1}^{n_1} x_i \qquad \overline{y} = \frac{1}{n_2}\sum_{i=1}^{n_2} y_i$$

$$t = \frac{\overline{x} - \overline{y} - G}{\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}\sqrt{\frac{\Sigma x_i^2 - n_1\overline{x}^2 + \Sigma y_i^2 - n_2\overline{y}^2}{n_1 + n_2 - 2}}}$$

Using the *t*-parameter with a degree of freedom of (n1 + n2 -2) the null hypothesis (H0) can be tested (using standard *t*-distribution tables).

vi. Data correlations

An important consideration in the analysis of environmental data is to understand the relationships or interactions between different variables, as well as to determine temporal and spatial trends. The correlation between selected variables, as well as the behaviour over time, is important, for example for determining cause-and-effect relations or effectively predicting future change. The correlation between two parameters can be complex and not easy to establish. For example, temporal variations can bias the correlation of large data sets collected over extended periods.

The relationship (*r*) between two parameters can take many forms, for example:

- Linear positive
- Linear negative
- Logarithmic
- Exponential

- Power
- Trigonometric.

There could also be no relationship at all.

Typical standard methods of fitting a line to a set of data to test the relationship between two variables, which can be mathematically expressed, are:

Linear	$y = a + bx$
Non-linear	$y = a + bx + cx^2 + \ldots$
Exponential	$y = a.e^{(bx)}$
Logarithmic	$y = a + b.\ln(x)$
Power	$y = ax^b$
Trigonometric	$y = a + b.\cos(x)$

A correlation coefficient is a quantitative measure of the strength of a relationship between two variables. The correlation coefficient (r) between two random variables ranges from -1 to 1. A value close to -1 indicates a strong negative correlation, i.e. the value of variable y decreases as variable x increases. When r is close to 1, a strong positive correlation exists between x and y; both variables increase or decrease together. The closer the value of r is to zero the poorer the correlation. For a normal distribution, a frequently used correlation coefficient is the Pearson's Sample Correlation Coefficient (Devore & Farnum, 1999).

Using the method of least squares, practical calculation or computation procedures of these typical relationships (derived from Spiegel, 1972) are as follows:

Straight line (Linear)

For variables x_i and y_i (i = 1,2,3,.........,n)

Equation: $y = a_1.x + a_0$

$$a_1 = \frac{\Sigma xy - \frac{\Sigma x \ \Sigma y}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}} \qquad a_0 = \overline{y} - a_1.\overline{x}$$

Where: $\overline{y} = \Sigma y/n$, $\overline{x} = \Sigma x/n$

$$r^2 = \frac{\left[\Sigma xy - \frac{\Sigma x \ \Sigma y}{n}\right]^2}{\left[\Sigma x^2 - \frac{(\Sigma x)^2}{n}\right]\left[\Sigma y^2 - \frac{(\Sigma y)^2}{n}\right]}$$

Logarithmic fit

For variables x_i and y_i (i = 1,2,3,.........,n)

Equation: $y = a + b \ln x$ ($x_i > 0$)

$$b = \frac{\Sigma y \ln x - \frac{(\Sigma \ln x)(\Sigma y)}{n}}{\Sigma(\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}}$$

$$a = \frac{(\Sigma y - b\Sigma \ln x)}{n}$$

$$r^2 = \frac{\left[\Sigma y \ln x - \frac{\Sigma \ln x \ \Sigma y}{n}\right]^2}{\left[\Sigma (\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}\right]\left[\Sigma y^2 - \frac{(\Sigma y)^2}{n}\right]}$$

continued…

Power curve fit

For variables x_i and y_i (i = 1,2,3,.........,n)

Equation: $y = a.x^b$ (x > 0, y > 0)

or: ln y = b ln x + ln a ... solve linearly

$$b = \frac{\Sigma \ln x \ln y - \frac{(\Sigma \ln x)(\Sigma \ln y)}{n}}{\Sigma (\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}}$$

$$a = \exp\left[\frac{\Sigma(\ln y)}{n} - b\frac{\Sigma \ln x}{n}\right]$$

$$r^2 = \frac{\left[\Sigma(\ln x)(\ln y) - \frac{(\Sigma \ln x)(\Sigma \ln y)}{n}\right]^2}{\left[\Sigma(\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}\right]\left[\Sigma (\ln y)^2 - \frac{(\Sigma \ln y)^2}{n}\right]}$$

Exponential fit

For variables x_i and y_i (i = 1,2,3,.........,n)

Equation: $y = a.e^{bx}$ (a > 0)

or: ln y = ln a + bx

$$b = \frac{\Sigma x \ln y - \frac{(\Sigma x)(\Sigma \ln y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

$$a = \exp\left[\frac{\Sigma(\ln y)}{n} - b\frac{\Sigma x}{n}\right]$$

$$r^2 = \frac{\left[\Sigma x \ln y - \frac{\Sigma x \ \Sigma \ln y}{n}\right]^2}{\left[\Sigma x^2 - \frac{(\Sigma x)^2}{n}\right]\left[\Sigma \ln y - \frac{(\Sigma \ln y)^2}{n}\right]}$$

vii. Multivariate methods

Multivariate statistical methods are designed to evaluate more than one variable at a time. Examples of multivariate methods include (UNESCO/WHO/UNEP, 1922; US-EPA, 2002c):

- **Discriminant function analysis (DFA),** in which multiple variables are used to predict groups of cases
- **Multivariate analysis of variance (Manova**), testing if the groups are significantly different in terms of the independent variables
- **Principal components analysis (PCA)**, which takes multiple variables and defines a smaller number of new variables by constructing linear combinations of the original variables. The new variables separate the cases as much as possible.
- **Canonical correlation**, which uses two sets of variables and, like PCA, creates linear combinations of the initial variables in each set so that the number of variables is reduced. The new linear combinations are selected so that they maximize the correlation between the pairs of variables, one from each set.
- **Cluster analysis**, which defines groups of cases based on the similarity of multiple variables measured for each case

viii. Indices

Another method to assess environmental data is the use of such indices that are obtained by aggregating several variables into one number. This simplified expression of a complex set of variables can be used for a variety of purposes, including (UNESCO/WHO/UNEP, 1992):

- Communicating environmental information in a user-friendly format
- Planning tool for managing water resources
- Assessing changes in the quality of water resources
- Evaluating the performance of wastewater disposal systems.

Different indices are currently in use or under development. These can be grouped as follows:

- General water quality indices, in which physical, chemical and microbiological variables are aggregated to produce an overall index of water quality
- Specific use-quality indices, in which variables are aggregated on the basis of their importance to a specific beneficial use, e.g. a human health index
- Planning indices, which also include social and economic factors
- Chemical indices, which are calculated by grouping water quality variables according to their chemical nature, e.g. toxic metals.
- Biological indices, which are based on selected biological characteristics, including community diversity.

An example of a chemical and health water quality index system, based on a theory by House (1989), has been developed into a statistical computer model for the rivers of the Western Cape (Van Driel & Botes, 2003) to facilitate the transfer of monitoring assessments to Water Quality Forum meetings.

7.4.3 Presentation of data

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.

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.

7.5 REPORTING

7.5.1 Compliance Monitoring

Evaluation of data on the wastewater volume and composition needs to occur in 'real-time' (i.e. as close as possible to the time of sampling). This is to ensure that management actions can be implemented, as soon as possible, to mitigate negative impacts on the receiving environment.

Evaluation of the data comprises a comparison of the measured data against the pre-determined critical limit specified for a particular constituent in the licence agreements issued by the DWAF under section 21 of the National Water Act.

7.5.2 System Performance Monitoring

Monitoring of a wastewater disposal system includes:

- Physical inspections of the outfall system (for offshore marine outfalls)
- Hydraulic performance (for offshore marine outfalls).

A short description of the reporting format is provided below.

Physical inspection. Underwater video recording supplemented by a short written report on the observations needs to be submitted to the DWAF.

Hydraulic performance. A report on the evaluation of the hydraulic performance of the outfall prepared by a qualified environmental consultant, needs to be submitted to the DWAF. In the event of non-compliance with design criteria, management strategies and actions to improve the situation need to be specified as well.

7.5.3 Environmental Monitoring

Depending on the measurement parameters selected, the monitoring data on the receiving marine environment that are typically collected as part of a monitoring programme for wastewater disposal to the marine environment, include:

- Biogeochemical parameters in the water column
- Biogeochemical parameters in sediments (including interstitial waters)
- Biogeochemical parameters (e.g. toxins) in biological tissue
- Data on relative abundance, species diversity and community structure and composition of biological indicators.

A detailed Monitoring Report must be supplied to the DWAF and other relevant authorities (where and if required). The report should contain:

- 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.

A reporting schedule needs to be negotiated with the DWAF, but it is realistic to submit a Monitoring Report after each set of monitoring surveys. Where sampling components of the monitoring programme are conducted at frequent intervals, e.g. microbiological monitoring at recreation areas, the results of these samples need to be submitted in the form of monthly interim reports, clearly highlighting preliminary indications of non-compliance with monitoring objectives. In addition the results of these samples interim reports should contain management strategies and actions that will be taken to address any problem timeously.

Various communication routes can be utilised to communicate findings to wider stakeholder groups, which may not have the relevant scientific or engineering background, including:

- *Pamphlets*. The key findings of the main report can be summarised in layperson's language in the form of colourful pamphlets. These information-sharing documents are then distributed to the wider stakeholder groups either living in a particular study area or who are potentially affected by activities in the area.

- *Stakeholder meetings*. Stakeholders can also be informed through regular meetings at which the results of monitoring programmes are presented in a user-friendly manner.

- *Internet websites*. The Internet is a very powerful tool for disseminating information to a wide spectrum of interested and affected parties. Communication can either be undertaken on a case-by-case basis or it may be more appropriate to link these individual cases to a master website such as that maintained under the auspices of the DWAF.

- *Media reporting.* Media reporting, e.g. in a local newspaper, is another means of communicating information to the wider community that may not have access to the Internet.

7.6 DATA STORAGE FACILITIES AND QUALITY CONTROL

Monitoring data are expensive to collect and require substantial investments of both human and financial resources. As a result, such data must be made as usable, useful and retrievable as possible. The sheer volume of data generated as part of ongoing monitoring programmes dictates that computer-based data management systems must provide the basis for data storage and management (ANZECC, 2000b).

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

- 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.

Although detailed specifications are site-specific, the following are important factors to consider in the selection of the hardware framework and software platform (UNESCO/WHO/UNEP, 1992):

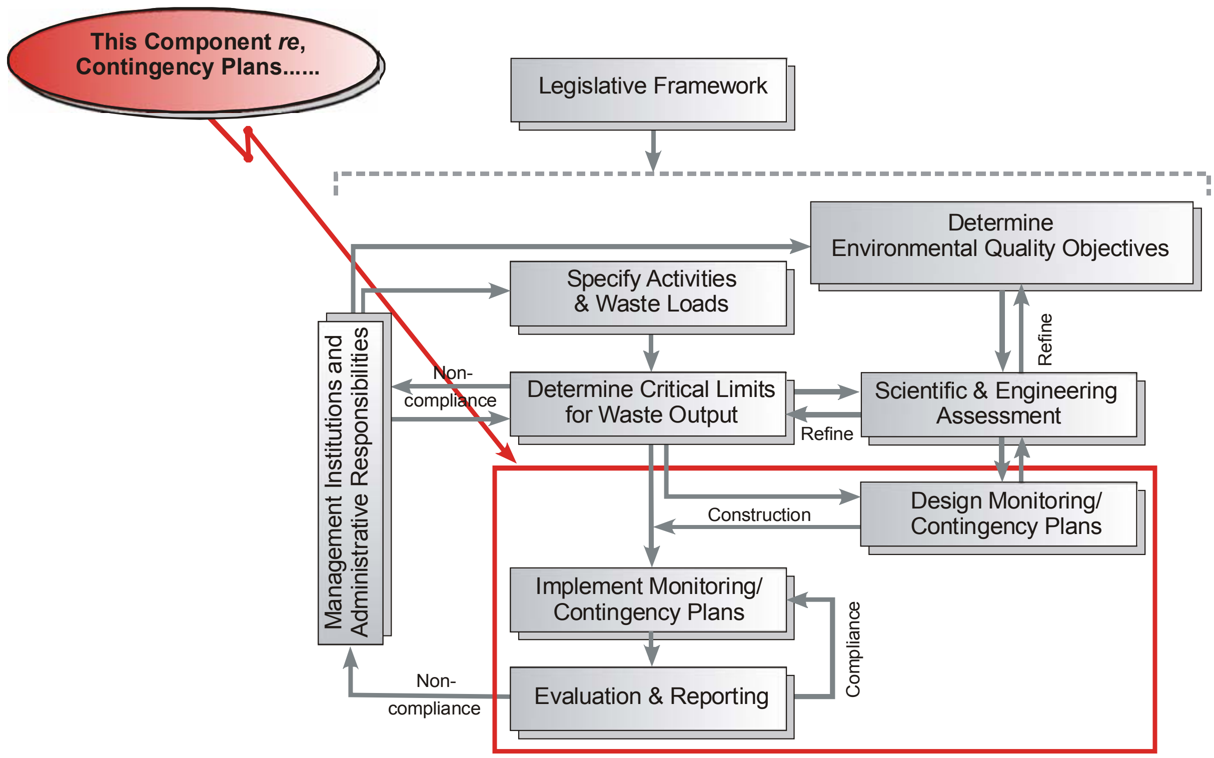
- Physical capability of handling the data load and the implications of expansion
- Ability to transfer data to other data storage systems
- Compatibility of the data storage with facility available data sources
- Choice of software (commercial or developed) with regard to:
  - Expansion and support
  - Delivery of suitable outputs
  - Robustness with regard to changing data formats
  - Data transfer capabilities between different platforms (e.g. Desktop PC, Server, Webserver, Palm devices, mobile phones and sampling/analysis equipment).

The needs of the end-users probably constitute the most critical consideration in the design of a data management system. Although the existing data management system of the DWAF (Water Management System [WMS]) may be suitable in some respects (e.g. storage of source data), the system caters mainly for rivers and groundwater. Consequently, WMS may not necessarily be suitable for capturing the type of data collected in the marine environment (including estuaries).

To ensure conformity across South Africa, it is, therefore, strongly recommended that investigations be undertaken regarding a national framework for setting up management systems to store data collected as part of ongoing monitoring programmes in the marine environment. As there are existing data management systems for the marine environment (e.g. South Africa Data Centre for Oceanography [SADCO] - http://fred.csir.co.za/ematek/sadco/) and the Department of Environmental Affairs and Tourism that are operational in this domain, it is crucial that such a framework be developed in consultation with other relevant departments, taking into account linkages to existing management systems.

SECTION 8:
CONTINGENCY PLANNING

SECTION 8: CONTINGENCY PLANNING



PURPOSE:

The purpose of contingency plans is to identify specific mitigating actions that need to be implemented in the event of malfunctioning, both during construction and operation, to minimise risks to the environment.

The design of a contingency plan is only required as part of a Detailed Investigation stage.

8.1 MOTIVATION FOR CONTINGENCY PLANNING

Contingency planning is required to prevent or minimise potentially negative impacts on the receiving environment both during the construction and the operational phases.

During construction, potentially significant negative impacts (onshore and offshore) typically relate to the activities of the contractors. Contingency plans and mitigation measures are therefore best achieved through the incorporation and enforcement of suitable clauses in the construction contract documents. These clauses must include the best alternatives for ensuring minimum impact, monitoring programmes for the duration of the construction phase and mitigation options, and specifications for reinstatement and rehabilitation.

Contingency plans and mitigation measures for the operation of a marine outfall system relate mainly to accidental damage or failure of the system to perform to expected standards. Negative impacts resulting from the underperformance of the entire system and subsequent failure to perform to expected standards, or negative feedback from the monitoring programme can be the result of:

- Deviations from specifications, such as:
  - Increased loads (flow or quality) resulting from unexpected population increase
  - Extreme or abnormal physical conditions (meteorological or oceanographic) which were not anticipated in the data set used for the design.

- The malfunctioning/underperformance or breakdown of plant/equipment, as a result of:
  - Equipment/plant or outfall breakdown
  - Electrical power failures (local network or national power supply)
  - Overloading (flow conditions or wastewater composition which exceed design standards) that will result in the underperformance of the system due to one or more of the following: 1) ineffective screening; 2) sedimentation in the main pipeline and diffuser section; 3) blocking of ports; 4) insufficient initial dilutions; 5) process failure and malfunctioning due to insufficient maintenance (corrosion, sliming in the pipeline, damaged ports, etc.); 6) operational problems due to deviation from standard operational procedures, insufficient control or incompetent staff; and 7) operational problems related to strikes (staff or suppliers).

- Incidents and disasters, such as:
  - Accidents related to ships (dragging or dropping anchors, direct collision with pipeline)
  - Extreme conditions (wave forces on exposed sections of the pipeline or excessive scour)
  - Vandalism of onshore structures
  - Fires
  - Earthquakes.

8.2 COMPONENTS OF A CONTINGENCY PLAN

A contingency plan needs to address aspects related to the malfunctioning or breakdown of the wastewater disposal system (i.e. the source), as well as preventing of pollution of the receiving environment (the 'resource'). A plan primarily consists of four sub-components:

i. Mechanisms for detection of problems

A well-designed monitoring programme (refer to Section 6) primarily constitutes the mechanism for the detection of problems. Monitoring of the waste disposal system (the source) is particularly important in terms of detecting problems pertaining to the malfunctioning or breakdown of the wastewater disposal system (also providing the 'early warning signal'), while monitoring of the receiving environment is the key mechanism for the prevention of pollution.

ii. Stipulated Procedures and Responsibilities (Provision of schedules)

Provision of schedules is crucial for the rapid and effective implementation of contingency plans.

In the case of *malfunction or breakdown of the plant*, schedules include:

- Standard operating procedures and staff schedules (roles and responsibilities)
- Programmes for the maintenance, replacement, and surveillance of the physical condition of equipment, facilities, and sewer lines
- Standby/alternative personnel/service companies for the continued operation and maintenance of wastewater discharge facilities during employee shortages (strikes, accidents, ill-health, etc.)
- Stock lists and suppliers for chemicals, spare parts, and equipment components that can adequately ensure the continued operation of the wastewater discharge facility during an emergency or breakdown
- Emergency standby power facilities - for high-risk areas, a permanent standby plant may be required. Mobile generators should be considered only for low-risk plants/areas.
- Emergency standby pumps
- Provision for sufficient storage capacity to cope with the normal or typical load for the area (history should be available) during power failures. This capacity should be expressed as the equivalent number of hours of dry weather flow. If practical, provision for the deviation of excess loads should be made, either by tankering or pumping
- Protection of plant/equipment against vandalism/sabotage
- Security protocols and procedures (entrance to premises)
- Repairs, including rapidly implementable action plans to repair failures of, or damage to, equipment and sewer lines (including human resources, contact information, standby and maintenance agreements).

In order to *prevent pollution* of the receiving environment, it is crucial to specify the responsibilities and procedures for staff, as well as for external institutions such as relevant government departments (e.g. DWAF and DEAT), and local authorities. These schedules must include specific contact details.

iii. Action Plans

Associated with the schedule of provision, a clear action plan on mitigating measures needs to be set out. Of particular importance is the action plan to protect other beneficial uses of the affected marine environment. Measures for this plan could include:

- Site notice boards or media releases (newspapers, radio or television) informing users (public) of the potential risks
- Demarcation of polluted areas, if required
- Notification of industrial users of seawater and mariculture farms, as well as procedures to be followed in assisting with protection of such facilities against pollution.

iv. Reporting

Procedures and protocols for reporting events of malfunctioning/breakdown of the wastewater disposal system, as well as pollution events, must be stipulated. These include internal procedures, but also reporting to responsible authorities on local, regional, and national levels.

SECTION 9:
RECOMMENDATIONS FOR FUTURE IMPLEMENTATION

- Operational policies (relating to specific activities) are considered crucial building blocks in achieving an integrated and holistic pollution control and waste management system for South Africa. It is recommended that such policies also be developed for other waste disposal activities to the marine environment. These include activities associated with shipping traffic and dredge spoil dumping, which currently fall within the jurisdiction of the DEAT. To facilitate effective cooperative governance, such policies should eventually be combined in an overarching operational policy for the disposal of waste to the marine environment of South Africa.

- Operational policies need to be developed for the land-based management and control of diffuse wastewater sources (e.g. urban stormwater run-off, agricultural and mining return flows). These need to be dealt with on a catchment level, rather than per individual water resource component. International trends need to be taken into account as well as national initiatives as in the case of urban stormwater:

  - *A framework for implementing non-point source management under the National Water Ac*t (RSA DWAF, 1999a)
  - *Guidelines for human settlement planning and design - The Red Book* (CSIR, 2001c)
  - Set of documents on *Managing the Water Quality Effects of Settlements* (RSA DWAF, 1999b)
  - *Towards a Strategy for a Waste Discharge Charge System* (RSA DWAF 2003c).

- Where multiple developments and activities occur in a study area, it is usually extremely difficult and financially uneconomical to manage marine environmental issues in isolation because of, for example, their potential cumulative or synergistic effect on the receiving environment. Collaboration is often best achieved through a joint local management institution. It is, therefore, recommended that the DWAF and DEAT, jointly investigate an official route whereby local management institutions can be formally constituted to assist in the management and control of the quality of marine water resources in South Africa. Towards enforcing the involvement of local role players, the DWAF already requires the establishment of a local monitoring committee, as a licence condition for the disposal of land-derived wastewater to the marine environment.

- To incorporate new learning, both national and international, it is recommended that a review be undertaken of the *South African Water Quality Guidelines for Coastal Marine Waters* for the protection of the marine environment and other beneficial uses. These guidelines also need to include List I and List II substances (List I substances are regarded as particularly hazardous and need to be *eliminated* from wastewater discharges, while List II substances are regarded as less hazardous but nevertheless need to be *controlled*). List II substances are typically those for which specific target values need to be determined. It is also recommended that future updates of the *South African Water Quality Guidelines for Coastal Marine Waters* include sediment quality guidelines.

- It is recommended that South Africa regularly update the inventory of waste discharges to the marine environment, both in terms of volumes and loads. This information should be accessible to the public through the Internet. This publication has become general practice in many countries and provides a sound base from which to holistically assess effectiveness of an operational policy.

- It is recommended that a *Code of Practice* be developed for specific industries in South Africa, specifically addressing ways in which to eliminate or minimise the production of waste, based on best available techniques. This Code of practice should provide clear guidance to industries with regard to their environmental obligation by specifying environmentally sound technologies. This source directed approach to waste elimination and minimisation is considered to be of great value. Documentation available for use in other countries, such as Canada and New Zealand, could to a large extent be adopted for South Africa.

- In countries in which industries (and their waste loads) are not well-defined, prohibited or controlled, substance lists consist of individual substances, e.g. benzene. However, in countries, like Canada and New Zealand, in which industry types and their waste are well-defined, the prohibited or controlled lists also include certain waste stream types. To accommodate, for example synergistic effects from complex effluent, this is an approach that should be investigated for South Africa, once industry types and their waste are more clearly defined.

SECTION 10:
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