Environmental Impact Assessment (EIA) for the
Proposed Construction, Operation and
Decommissioning of a Sea Water Reverse Osmosis
Plant and Associated Infrastructure Proposed at
Lovu on the KwaZulu-Natal South Coast

FINAL EIA REPORT

CHAPTER 6:
MARINE ECOLOGY

ABBREVIATIONS, UNITS & GLOSSARY

Abbreviations

ANZECC	Australian and New Zealand Environment and Conservation Council
BCF	Bioconcentration Factor
CCC	Criteria Continuous Concentration
CCME	Canadian Council of Ministers of the Environment
CD	Chart Datum
CEB	Chemically Enhanced Backwash
CIP	Clean in Place
CITES	Convention on International Trade in Endangered Species
CMC	Criteria Maximum Concentration
CMS	Convention on Migratory Species
CSIR	Council for Scientific and Industrial Research
DAF	Dissolved Air Flotation
DBNPA	2,2-dibromo-3-nitrilopropionamide
DEAT	Department of Environment Affairs and Tourism
DFS	Detailed Feasibility Study
DSP	diarrehetic shellfish poisoning
DWAF	Department of Water Affairs and Forestry
E	East
EC50	median effective concentration
EDTA	Ethylenediaminetetraacetic acid
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
ENE	East-Northeast
ESE	East-Southeast
GMF	Granular Media Filtration
GRP	Glass-fibre Reinforced Polyester
GRT	Gross Registered Tonnage
HAB	Harmful Algal Blooms
HDPE	High-density polyethylene
HSDB	Hazardous Substances Data Bank
IUCN	International Union for Conservation of Nature
KZN	KwaZulu-Natal
LC50	median lethal concentration
M&CM	Marine and Coastal Management
MF	microfiltration
MPA	Marine Protected Area
N	North
NaOCl	Sodium Hypochlorite
NNE	North-Northeast
NNW	North-Northwest
NOEC	no observed effect concentration
NPA	National Ports Authority
NSF	National Sanitation Foundation

NW	Northwest
NWA	National Water Act
PAM	Passive Acoustic Monitoring
PIM	Particulate Inorganic Matter
PNEC	predicted no effect concentrations
POM	Particulate Organic Matter
ppm	parts per million
psu	parts per thousand
PSP	paralytic shellfish poisoning
RO	Reverse Osmosis
DWAF	Department of Water Affairs and Forestry
RSA	Republic of South Africa
S	South
SACW	South Atlantic Central Water
SCUBA	Self-Contained Underwater Breathing Apparatus
SE	Southeast
SLS	Sodium lauryl sulphate
SSE	South-Southeast
SSW	South-Southwest
STPP	Sodium tripolyphosphate
SW	Southwest
SWRO	Seawater Reverse Osmosis
TAE	a Total Applied Effort
TOC	Total Organic Carbon
TRC	Total Residual Chlorine
TSP	Trisodium phosphate
TSPM	Total Suspended Particulate Matter
UF	Ultrafiltration
US-EPA	United States Environmental Protection Agency
W	West
WET	Whole Effluent Toxicity
WSW	West-Southwest

Units used in the report

µg/ ℓ	micrograms per litre
µM	microMol
cm	centimetres
cm/ s	centimetres per second
g/ kg	grams per kilogram
g C/ m^2/ day	grams Carbon per square metre per day
gfd	gallons per square foot per day
h	hours
ha	hectares
kg	kilogram
km	kilometres
km^2	square kilometres
m	metres
m/ s	metres per second
mm	millimetres
m^2	square metres
m^3/ day	cubic metres per day

m^3/ hr	cubic metres per hour
m^3/ s	cubic metres per second
m^3/ yr	cubic metres per year
m/ s	metres per second
mg/ ℓ	milligrams per litre
ng/ ℓ	nanograms per litre
mg Chl a/ m^3	milligrams Chlorophyll a per cubic metre
PAM	Passive Acoustic Monitoring
psu	practical salinity units, which in normal oceanic salinity ranges are the same as $^{o}/_{oo}$
s	seconds
tons/ hr	tons per hour
tons/ km^2	tons per square kilometre
%	percentage
~	approximately
<	less than
>	greater than
°C	degrees centigrade

Glossary

Acute toxicity	Rapid adverse effect (*e.g.* death) caused by a substance in a living organism. Can be used to define either the exposure or the response to an exposure (effect).
Benthic	Referring to organisms living in or on the sediments of aquatic habitats (lakes, rivers, ponds, etc.).
Benthos	The sum total of organisms living in, or on, the sediments of aquatic habitats.
Benthic organisms	Organisms living in or on sediments of aquatic habitats.
Biodiversity	The variety of life forms, including the plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are a part.
Biomass	The living weight of a plant or animal population, usually expressed on a unit area basis.
Biota	The sum total of the living organisms of any designated area.
Bivalve	A mollusc with a hinged double shell.
Community structure	All the types of taxa present in a community and their relative abundance.
Community	An assemblage of organisms characterized by a distinctive combination of species occupying a common environment and interacting with one another.
DBNPA	A non-oxidising biocide (2,2-dibromo-3-nitrilopropionamide).
Effluent	A complex waste material (*e.g.* liquid industrial discharge or sewage) that may be discharged into the environment.
Epifauna	Organisms, which live at or on the sediment surface being either attached (sessile) or capable of movement.
Ecosystem	A community of plants, animals and organisms interacting with each other and with the non-living (physical and chemical) components of their environment.
Guideline trigger values	These are the concentrations (or loads) of the key performance indicators measured for the ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystem specific investigations or implementation of management/remedial actions.
Habitat	The place where a population (*e.g.* animal, plant, micro-organism) lives and its surroundings, both living and non-living.
Infauna	Animals of any size living within the sediment. They move freely through interstitial spaces between sedimentary particles or they build burrows or tubes.

Macrofauna	Animals >1 mm.
Macrophyte	A member of the macroscopic plant life of an area, especially of a body of water; large aquatic plant.
Meiofauna	Animals <1 mm.
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 nearshore zones, and open-ocean-deep-sea regions.
Pollution	The introduction of unwanted components into waters, air or soil, usually as result of human activity; *e.g.* hot water in rivers, sewage in the sea, oil on land.
Population	The total number of individuals of the species or taxon.
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 millilitres/litre.
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).
Recruitment	The replenishment or addition of individuals of an animal or plant population through reproduction, dispersion and migration.
Sediment	Unconsolidated mineral and organic particulate material that settles to the bottom of aquatic environment.
Species	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce viable offspring if bred with members of another group.
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.
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.
Suspended material	Total mass of material suspended in a given volume of water, measured in mg/ℓ.
Suspended matter	Suspended material.
Suspended sediment	Unconsolidated mineral and organic particulate material that is suspended in a given volume of water, measured in mg/ℓ.
Tainting	This refers to the tainting of seafood products as a result of the presence of objectionable chemical constituents which may greatly influence the quality and market price of cultured products.
Taxon (Taxa)	Any group of organisms considered to be sufficiently distinct from other such groups to be treated as a separate unit (*e.g.* species, genera, families).
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.
Turbidity	Measure of the light-scattering properties of a volume of water, usually measured in nephelometric turbidity units.
Turgor	The normal rigid state of fullness of a cell or blood vessel or capillary resulting from pressure of the contents against the wall or membrane.
Vulnerable	A taxon is vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future.

EXECUTIVE SUMMARY

General Introduction

Umgeni Water Amanzi (Umgeni Water), as the bulk water provider to six water services authorities in KwaZulu-Natal (KZN), has investigated the feasibility of seawater desalination through reverse osmosis as an alternative to the proposed Mkomazi Water Project. Two potential sites located along the KZN coastline to the north and south of the Mngeni Supply Area have been identified on which sea water reverse osmosis (SWRO) desalination plants could be constructed to sufficiently augment the Mngeni System in the medium term. The southern site is located on the banks of the Lovu River and the northern site on the coast near Tongaat, to the north of the Mdloti River mouth.

As part of the proposed project, Aurecon are undertaking a Detailed Feasibility Study (DFS) of the two potential sites to investigate and identify the least cost option for both the inlet and outlet works. In accordance with National Environmental Management Act (NEMA), Act No. 108 of 1997 and the associated Regulations of June 2010, a full "Scoping and Environmental Impact Assessment (EIA) process" is required. Umgeni Water has appointed the CSIR to conduct the relevant EIAs and compile Environmental Management Plans (EMPs) for two proposed 150 Ml/day SWRO Plants and associated infrastructure. The CSIR has subcontracted Pisces Environmental Services (Pty) Ltd to provide marine specialist inputs into the EIA processes for each of the Lovu and Tongaat sites.

This Marine Biology Specialist Study was undertaken by Dr Andrea Pulfrich and forms part of the Environmental Impact Assessment for the Lovu site.

The Scope of Work for this Marine EIA, as provided by the CSIR is:

- Describe the affected environment and determine the status quo at each site.
- Indicate how a resource or community will be affected.
- Map sensitive areas.
- Discuss gaps in baseline data.
- Assess potential impacts, including cumulative impacts and address public concerns.
- Propose and explain mitigation measures and summarise residual impacts after mitigation.

Approach to the study

The ecological assessment is limited to a desktop approach and relies on existing information only. It should be noted that some important conclusions and associated impact assessments and recommendations made in this study are based on results from the initial dilution modelling and far-field brine dispersion modelling studies undertaken by WSP Africa Coastal Engineers (Pty) Ltd. The predictions of these models, whilst considered to be robust in terms of the major discharge constituent, need to be validated by field observations and subsequent monitoring.

The proposed SWRO project at Lovu will comprise the following main infrastructural components:

- Sea water intake structures;
- Sea water intake pipelines;
- Sea water pump station;
- Sea Water Reverse Osmosis desalination plant;
- Brine discharge pipeline;

- Brine diffuser system;
- Potable water pipelines to connect into existing bulk water infrastructure; and
- Power supply infrastructure.

This Marine Environmental Impact Assessment Study deals only with infrastructure that may have an effect on the marine environment, *i.e.* the seawater abstraction and brine discharge components.

Assessment of Impacts

The main marine impacts associated with the proposed desalination plant at Lovu are related to the construction of the intake and outfall structures during the construction phase, the intake of feed water from, and consequent discharge of a high-salinity brine back into the ocean during the operational phase.

Five negative impacts of ***medium*** significance (before mitigation) associated with the construction phase were identified:

- Disturbance and destruction of intertidal beach macrofauna during pipeline construction as a result of vehicular traffic, jetty construction, and excavation.
- Accidental spillage or leakage of fuel, chemicals, or lubricants that may cause water or sediment contamination and/or disturbance to beach and subtidal biota.
- Disturbance and destruction of subtidal sandy and rocky reef biota duringthe laying of the intake and brine pipelines, including jetty construction, surf-zone excavation and rock blasting.
- Effects of blasting on macrophytes, invertebrates and fish communities.
- Effects of blasting on marine communities, particularly turtles and marine mammals.

One negative impacts of ***high*** significance (before mitigation) associated with the operational phase was identified:

- Permanent loss of habitat under submerged intake and discharge pipelines.

Three negative impacts of ***medium*** significance (before mitigation) associated with the operational phase were identified:

- Effects of discharged antiscalants.
- Heavy metals (if present in the brine from corrosion processes) may affect dissolved metal concentrations in the receiving water.

One ***positive*** impact of medium significance associated with the operational phase was identified:

- The intake structure and submerged pipelines act as artificial reefs.

With few exceptions, recommended management actions and mitigation measures will reduce the negative impacts of medium and high significance to ***low*** significance.

Ideally, a small-scale pilot plant should be developed to facilitate detailed assessments of expected impacts and validate the predictions of the brine dispersion studies. An entrainment study should form part of this approach.

Cumulative Impacts

Anthropogenic activities in the coastal zone can result in complex immediate and indirect effects on the natural environment. Effects from disparate activities can combine and interact with each other in time and space to cause incremental or cumulative effects. Cumulative effects can also be defined as the total impact that a series of developments, either present, past or future, will have on the environment within a specific region over a particular period of time (DEAT IEM Guideline 7, Cumulative effects assessment, 2004).

From a coastal and marine environmental perspective, the proposed intake/discharge sites cannot be considered particularly "pristine". The coastline is relatively uniform over the 1-1.5 km stretch under consideration at each location, has undergone substantial developments over the past decades and is already impacted by seasonally high visitor numbers who utilize the area primarily for coastal recreation, rock- and surf-angling and kite-surfing. Water and sediment quality have no doubt already been compromised by the various marine outfalls along the coast. Likewise, the river water shows measurable anthropogenic contamination due to discharges from wastewater treatment plants within the river's catchment areas. Therefore, given the current past and future proposed development along the coastline of the project area, cumulative impacts as well as further disturbances to marine or coastal systems or features can be expected. The magnitude and significance of these to the nearshore benthic ecosystem and potential cascade effects on higher order consumers are, however, difficult to predict and impossible to quantify. Of importance is the recognition that cumulative effects may occur and this should be kept in mind during any monitoring studies undertaken as part of this (or any other similar) project.

Conclusions

The recommended mitigation measures for the construction phase of the SWRO Plant are:

- Keep heavy vehicle traffic associated with pipeline or breakwater construction on the beach to a minimum.
- Restrict vehicles to clearly demarcated access routes and construction areas only.
- All construction activities in the coastal zone must be managed according to a strictly enforced Environmental Management Plan.
- Good house-keeping must form an integral part of any construction operations on the beach from start-up.
- Maintain vehicles and equipment to ensure that no oils, diesel, fuel or hydraulic fluids are spilled.
- For equipment maintained in the field, oils & lubricants to be contained & correctly disposed of off-site.
- Construction vehicles to have a spill kit (peatsorb/ drip trays) onboard in the event of a spill.
- Restrict disturbance of the sea bottom to the smallest area possible.
- Lay pipeline in such a way that required rock blasting is kept to a minimum.
- Restrict vibration-generating activities to the absolute minimum required.
- All blasting activities should be conducted in accordance with recognised standards and safety requirements.
- Search the area around the blasting area and postpone blasting if turtles, marine mammals or flocks of diving or swimming birds are spotted within a 2 km radius of the blasting point.
- Restrict the number of blasts to the absolute minimum required, and to smaller, quick succession blasts directed into the rock using a time-delay detonation.
- Undertake only one blast per day.
- Avoid onshore blasting during the breeding season of shore-birds.

The recommended mitigation measures for the operational phase of the SWRO Plant are:

- Design plant properly, e.g. by eliminating dead spots and threaded connections, to reduce corrosion to a minimum (corrosion resistance is considered good when the corrosion rate is <0.1 mm/a (UNEP 2008).
- Keep intake velocities below ~0.15 m/s to ensure that fish and other organisms can escape the intake current.
- Ensure that residual chlorine is suitably neutralised with sodium bisulfite (SBS); residual chlorine in the brine discharge must be below No Observed Effect Concentration (NOEC) and/or the relevant water quality target values.
- Monitor the brine for decreased dissolved oxygen levels potentially caused by overdosing of sodium bisulfite, and aerate if necessary.
- Avoid the use of nutrient-enriching antiscalants, and use antiscalants with low toxicity to aquatic invertebrate and fish species.
- Collect residual cleaning solutions and membrane filter washes and neutralize and remove solids before discharge into the brine stream. If practicable dispose of removed solids at an accredited landfill site.

Monitoring recommendations include:

- Conduct a study on the chemical and physical properties of the raw water at the proposed intake site prior to the design and construction of the desalination plant.
- Conduct an entrainment study prior to commissioning.
- Once in operation, conduct a study to ensure that the diffuser is performing to the expected specifications and that required dilution levels are achieved.
- Confirm brine and thermal footprints by sampling with a conductivity-temperature-depth (CTD) probe to confirm the performance of the discharge system and the numerical model predictions.
- Undertake WET testing of the discharged effluent for a full range of operational scenarios (i.e. shock dosing, etc.) to ensure complete confidence in the potential effects of co-discharged constituents and the antiscalant to be used.
- Continuously monitor the effluent for residual chlorine and dissolved oxygen levels.
- Periodically assess bacterial regrowth.
- Regularly monitor the effluent for heavy metals until a profile of the discharge in terms of heavy metal concentrations is determined.
- Check corrosion levels of plant constituent parts and the physical integrity of the intake and outlet pipes and diffuser and replace or modify components if excessive corrosion is identified or specific maintenance is required.
- Implement a monitoring program to study the effects of the discharged brine on the receiving water body, which is associated with the validation of the model results, and use the information to develop a contingency plan that examines the risk of contamination, and considers procedures that must be implemented to mitigate any unanticipated impacts.

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6. MARINE ECOLOGY SPECIALIST STUDY

This chapter presents the marine ecology specialist study undertaken by Dr Andrea Pulfrich from Pisces as part of the Environmental Impact Assessment for the proposed 150 Ml Seawater Reverse Osmosis Plant and associated infrastructure in Lovu, KwaZulu Natal.

6.1 INTRODUCTION

6.1.1 Background

Umgeni Water Amanzi (Umgeni Water), as the bulk water provider to six water services authorities in KwaZulu-Natal (KZN), has investigated the feasibility of seawater desalination through reverse osmosis as an alternative to the proposed Mkomazi Water Project. Two potential sites located along the KZN coastline in the north and south of the Mngeni Supply Area have been identified at which sea water reverse osmosis (SWRO) desalination plants could be constructed to sufficiently augment the Mngeni System in the medium term. The southern site is located on the banks of the Lovu River and the northern site on the coast near Tongaat, to the north of the Mdloti River mouth.

As part of the proposed project, Aurecon were appointed in December 2011 to undertake a Detailed Feasibility Study (DFS) of desalination plants at the two potential sites, which included investigations of least cost options for the inlet and outlet works. With respect to the proposed project, and in accordance with National Environmental Management Act (NEMA), Act No. 108 of 1997 and the associated Regulations of June 2010, a full "Scoping and Environmental Impact Assessment (EIA) process" is required. Umgeni Water has appointed the CSIR to conduct the relevant Environmental Impact Assessments (EIAs) and compile Environmental Management Plans (EMPs) for two proposed 150 Ml/day SWRO Plants and associated infrastructure. The two projects will be run independently of one another, under two separate EIA processes. The CSIR in turn have subcontracted Pisces Environmental Services (Pty) Ltd to provide marine specialist inputs into the EIA processes for each of the Lovu and Tongaat sites.

6.1.2 Scope of Work

This Marine Biology Specialist Study forms part of the Environmental Impact Assessment processes for the two potential sites as outlined in Section 1.1 above. More specifically, it comprises the marine ecology assessment for the southern Lovu site. The Scope of Work for this Marine EIA, as provided by the CSIR is outlined below.

- **Describe the affected environment and determine the status quo at each site.** The existing environment must be described from a marine biology perspective. Impacts to the Marine Environment which are most likely to occur at each site or sensitive receptors which are most likely to be impacted upon as a result of the proposed developments must be identified and described.
- **Indicate how a resource or community will be affected.** Typical impacts that could be expected from the proposed development must be listed, as well as the resultant expected impact on sensitive receptors. Impacts which are identified must then be quantified (if

possible) and a full description of predicted impacts (direct, indirect and cumulative) must be provided.

- **Gaps in baseline data.** Gaps in baseline data must be highlighted and discussed. An indication of the confidence levels must be given. The best available data sources must be used to predict the impacts, and extensive use must be made of local knowledge. Information derived from similar specialist studies conducted previously within the area should also be made use of.
- **Assessment of impacts.** The potential impact on sensitive receptors must be assessed and evaluated according to the magnitude, spatial scale, timing, duration, reversibility, probability and significance (or any other criteria required by the CSIR). The cumulative impact must also be considered and assessed. The impacts of any inappropriately sited project components on sensitive receptors would need to be assessed.
- **Assessment of cumulative impacts.** The cumulative impact on sensitive receptors likely to be generated as a result of the proposed project and any other similar (marine) projects proposed for implementation in the surrounding area must be identified and assessed.
- **Address public concerns:** Any concerns raised by Interested and Affected Parties (I&APs) during the respective public participation processes which may be relevant to the specialist's area of expertise must also be addressed.
- **Propose and explain mitigation measures.** Practical mitigation measures with which to minimize any negative impacts associated with the proposed developments must be recommended and discussed. Mitigation measures must be proposed for the construction, operation and decommissioning phases of development.
- **Summarise residual impacts after mitigation.** An impact summary table must be provided for each application, discussing expected impacts on sensitive receptors before and after mitigation. The expected significance of impacts after having undergone mitigation must be mentioned and compared to the significance of the same impacts prior to mitigation.
- **Mapping of sensitive areas.** Sensitive areas must be mapped in a sensitivity map for easy reference

6.1.3 Approach and Methodology

6.1.3.1 Marine Environmental Baseline

The ecological assessment is limited to a "desktop" approach and thus relies on existing information only. The description of the baseline marine environment was compiled following a literature search and review of all relevant, available local and international publications and information sources on southern African East Coast communities.

6.1.3.2 Environmental Impact Assessment

The identification and description of all factors resulting from the construction and operation of the desalination plant and associated infrastructure that may influence the marine and coastal environments in the region was based on a review and expert interpretation of all relevant, available local and international publications and information sources on the disturbances and risks associated with coastal construction and the discharge of hypersaline effluents.

The assessment methodology applied in the Marine Biology specialist study for the proposed desalination project was specified by the CSIR and is set out in Chapter 4.

6.1.4 Limitations and Assumptions

The following are the assumptions and limitations of the study:

- The study is based on the project description provided to the specialist;
- The marine ecological impact assessment is limited to a "desktop" approach and thus relies on existing information only;
- Some important conclusions and associated impact assessments and recommendations made in this EIA are based on results from the initial dilution modelling and far-field brine dispersion modelling studies undertaken by WSP Africa Coastal Engineers (Pty) Ltd. The predictions of these models, whilst considered to be robust in terms of the major discharge constituent, need to be validated by field observations and subsequent monitoring. If field observations and monitoring fail to mirror predicted results, the forecasted impacts will need to be re-assessed; and
- Potential changes in the marine environment such as sea level rise and/or increases in the severity and frequency of storms related to climate change are not explicitly considered here. Such scenarios are difficult to assess due to the uncertainties surrounding climate change. Should evidence or more certain predictions of such changes become available, Umgeni Water should re-assess their development and management plans to include the impacts of these anticipated macro-scale changes. However, it is not expected that these climate changes will affect the effluent plume behaviour to the extent that the conclusions of this study will be drastically altered.

6.1.5 Structure of the Report

This Marine Biology Specialist Assessment is structured as follows:

Section 1: General Introduction - provides a general overview to the proposed project, and outlines the Scope of Work and objectives of the study and the report structure. The assessment methodology is outlined and the assumptions and limitations to the study are given;

Section 2: Project Description Relative to the Marine Environment - gives a brief overview of the marine components of the proposed SWRO Plant, giving some technical detail on the volume, nature and water quality of the proposed discharges from the SWRO Plant;

Section 3: Legislative and Permitting Requirements - details the regulatory requirements, as well as other guidelines that are applicable to the marine aspects of the project;

Section 4: Description of the Marine Environment - describes the receiving biophysical environment that could be impacted by the proposed SWRO Plant. Existing impacts on the environment are discussed and sensitive and/or potentially threatened habitats or species are identified;

Section 5: Identification of Key Issues - here key issues for the proposed SWRO Plant are identified and summarised in terms of the preferred options for both the inlet and outlet works, the construction phase, operational phase and decommissioning phase. This includes inputs from the Scoping Phase and Public Consultation process;

Section 6: Assessment of impacts and identification of management actions - identifies and assesses the significance of potential direct, indirect and cumulative environmental impacts on the marine environment associated with the construction and operation of the desalination plant and associated infrastructure, based on information provided by the client and the results of the modelling studies;

Section 7: Conclusions and Recommendations – summarises the environmental acceptability of the proposed project and provides mitigation measures and management recommendations; and

Section 8: References - provides a full listing of all information sources and literature cited in this chapter.

6.2 DESCRIPTION OF THE PROJECT DETAILS RELATIVE TO THE MARINE ENVIRONMENT

6.2.1 Preferred Options for the Umgeni Water Project

The proposed SWRO project at Lovu will comprise the following main infrastructural components:

- Sea water intake structures;
- Sea water intake pipelines;
- Sea water pump station;
- Sea Water Reverse Osmosis desalination plant;
- Brine discharge pipeline;
- Brine diffuser system;
- Potable water pipelines to connect into existing bulk water infrastructure; and
- Power supply infrastructure.

This Marine Environmental Impact Assessment Study will deal only with infrastructure that may have an effect on the marine environment, *i.e.* the seawater abstraction and brine discharge components.

6.2.2 Sea Water Intake Pipelines

The sea water intakes will be located ~1,000 m offshore to ensure that the intake structures are situated at a depth of approximately 20 m. The structures will be about 6 m high with the intakes at 8 - 12 m depth. The intakes would consist of coarse screens and would have an inflow velocity of between 0.075 - 0.15 m/s. The main objective of locating the intake structure at mid-depth (4 - 6 m above the seabed) is to avoid the intake of marine sediment as well as any floating matter. The low intake velocities will reduce the intake of small fish and other marine organisms. It is assumed that a potable water recovery of 45% will be achieved by the proposed desalination plant, while the remaining 55% will constitute the brine that will be discharged back into the marine environment. To function at 150 Ml/day, the sea water intake would need to abstract a seawater flow of between 389 to 428 Ml/day.

The seawater intake conduits would comprise two 1.6-m diameter pipelines. The installation of two pipelines will enable maintenance to be conducted on one pipe, while the other continues to abstract water. The pipelines would be buried from the pump station situated 100 m inland across the beach (Figure 6.1) and through the surf zone. This would require the construction of a temporary sheet pile jetty to excavate the ~14 m-wide trench to lay the pipeline well below the depth of scour. Beyond the surf zone, the pipelines would be laid on the seabed.

The offshore pipelines would be constructed from High-Density Polyethylene (HDPE). The burial depth for a pipeline across the beach area would be ~11 m. The sea water intake pipelines would be sited at 90° to the coast so as to be optimally located for construction and lifetime wave conditions.

The pump station would be sited in a disturbed forest on a levelled dune area about 100 m inland from the beach and would pump the seawater ~3 km inland to the desalination plant.

Figure 6.1: The wide beach at Lovu.

6.2.3 Brine Diffuser System

As brine is negatively buoyant and tends to sink towards the seabed, it would be discharged from the effluent pipeline through a diffuser system, to ensure optimum dilution. The region where the brine settles to the sea floor is termed the “near field” or “sacrificial mixing zone” as it represents an area in which large changes in water quality, sediments or biota can be expected. In other words, contaminant concentrations will be such that they will result in changes beyond natural variation in the natural diversity of species and biological communities, rates of ecosystem processes and abundance/biomass of marine life.

To ensure maximum dilution of the brine, the brine would be discharged via a number of ports along the final 60 m of the discharge pipeline (WSP Africa Coastal Engineers 2013a). The diffusers would comprise 15 ports of 200 mm diameter spaced at 4 m intervals. To provide good mixing with the seawater, the ports would discharge at an angle of 60° from horizontal, to alternate sides of the main diffuser pipe. The diffuser design will ensure that the brine is diluted down to 10 % of ambient salinity or less within 300 m from the point of discharge.

Other potential waste-water streams would be generated during the RO process, but the specifications for these will only be known once the SWRO plant operator has been appointed and the membrane type decided on. As different chemicals are suited for different types of membranes, the membrane manufacturers would provide relevant information in product manuals and are likely to offer consultation with regard to pre-treatment and process chemicals. Other discharges to the marine environment are likely to include:

- Backwash waters from pre-treatment filters, comprising mainly sediments and organic matter. It is assumed that these will be generated on a daily basis. The backwash will be disposed of through the brine disposal line.
- Depending on the quality of the feed-water, the RO membranes would need to be cleaned at intervals of three to six months. The Clean-In-Place (CIP) process chemicals used are typically weak acids and detergents (citric acid, sodium polyphosphate and Ethylenediaminetetraacetic Acid (EDTA), which is used to remove carbonate deposits). Any effluent from the cleaning process will be returned to the sea by gradually bleeding it from the mixing tank into the RO concentrate effluent.
- Residual chlorine or other biocides will be used to prevent fouling of the intake (see below). Typically, a chlorine residual of 0.1 mg/l NaOCl is expected in the intake however this would neutralised ahead of the membranes at the plant and there would be no chlorine residual in the brine.
- An organic scale inhibitor, which will be an approved chemical for potable water systems and will be bio-degradable.

Table 6.1 lists the expected composition of the brine effluent and the typical cleaning reagents and pre-treatment chemicals to be used. The brine effluent at build-out capacity is anticipated to have a 1 - 1.5 °C temperature elevation above the ambient average seawater temperature (which ranges from 18 - 22°C), a salinity of between 57 600 – 67 400 mg/ℓ (based on the maximum feed-water salinity) and a density of 1 046 kg/m^3 with an effluent flow of a maximum of 92 Mm^3/year.

6.2.4 Brine Discharge Pipeline

The brine discharge pipeline would extend 630 m offshore to reach a water depth of 10 m, thereby ensuring that adequate dilutions are obtained and to avoid short-circuiting of higher salinity concentrations at the intake system. The outfall system would comprise a 1.6 m diameter HDPE outfall pipeline fitted at its terminal end with a 60-m long 1.5 m diameter tapered diffuser with multiple outlet ports that eject the brine upwards into the water column.

The discharge conduits to the diffusers would be designed for normal operational brine flows of ~55% of the seawater, whilst being able to handle maximum flows.

The brine pipeline would be laid across the beach and through the surf zone in the same trench as the intake pipeline. The brine discharge conduits would be located 530 m inshore of the intake structure.

Table 6.1: Proposed plant capacity for the Umgeni Water SWRO Plant Project and expected composition and flow of the discharged brine.

Description	Units	Quantity
Feed-water Intake for 150 000 m^3/day production	m^3/day	248 000 – 428 000
Average brine discharge for 150 000 m^3/day production	m^3/day	149 000 – 263 000
Co-discharges (Pre-treatment Membrane Filtration Backwash and CIP rinse water)	m^3/h	310 - 535
Supernatant from DAF sludge treatment	m^3/h	723 – 1,248
Intake Velocity	m/s	1 - 2
Discharge velocity	m/s	2 - 4
Salinity	mg/ℓ psu	57 600 – 67 400 57.6 – 67.4
ΔT	°C	1 - 1.5
pH		7.3 – 8.2
Antiscalant (manufacturer TBD)	mg/ℓ	4.0
Chlorine	µg/ℓ	neutralised (<3)
Ethylenediaminetetraacetic Acid (EDTA) Intermittent	mg/ℓ	0.013
Coagulant: Ferric Chloride (FeCl$_3$) will precipitate into Ferric Hydroxide, which will be removed as a solid in the sludge handling facility.	mg/ℓ	0.5 - 10

6.2.5 Sea Water Reverse Osmosis (SWRO) Desalination Plant

The proposed Lovu desalination plant will be situated several kilometres inland of the Lovu River estuary, and on the left bank of Lovu River.

Although the locations or operation of the plant would not directly affect the marine environment, for the sake of completeness the basic process for the treatment of water in a SWRO plant are summarised here. Reverse Osmosis (RO) is a membrane filtration process utilised to reduce the salinity of seawater (feedwater). The feedwater is supplied through a seawater intake and appropriately treated before being pumped to a seawater buffer storage tank. To overcome the natural osmotic pressure of seawater, it is then pumped at high pressure through to the RO membranes. This process retains the brine (high salinity) on one side of the membranes and allows the water of very low salinity to pass to the other side. The desalinated water is piped to the potable water reservoir and the brine is released back in to the ocean through discharge pipes.

The SWRO plant will be designed, and the process equipment selected, for continuous operation 24 hours per day, for 350 days per year, with approximately 15 days per year allowed for maintenance. The actual operational time may vary, depending on the maintenance requirements. The anticipated life-span of the desalination plants would be a minimum of 25 years, with provision to expand and renew equipment as and where it is needed (Voutchkov 2013).

The engineering technologies likely to be applied at the desalination plant would be flocculation, Dissolved Air Flotation (DAF) or low-rate granular media filtration (GMF), pre-treatment membrane filtration (*i.e.* ultra- and microfiltration membranes (UF/MF) or finer size GMF), cartridge filtration, reverse osmosis and post-treatment. The ultrafiltration (UF) membrane system removes fine suspended sediments, pathogens, and bacteria, thus reducing the use of pre-treatment process chemicals (coagulants and flocculants) and reducing the cleaning requirements on the RO membranes. A maximum of 60% of the sea water abstracted would be returned to the sea as brine.

Chemical pre-treatment of the intake water is essential in the effective operation of desalination plants. The type of pre-treatment system used depends primarily on the feedwater quality. The various pre-treatment processes may include:

- Prevention of bio-fouling of the intake pipes by a pigging system. This involves the use of a ‘pig’ (bullet-shaped device with bristles), which is introduced into the intake pipeline(s) to mechanically clean out the structure;
- Use of a biocide (sodium hypochlorite) to inhibit biological growth in the pipelines and on the screens. For example, mussels and barnacles can grow in the intake pipe impeding the intake flow of the feed-water, and biofouling of the membranes by algae, fungi and bacteria can lead to the formation and accumulation of slimes and biofilms, which can increase pumping costs and reduce the lifespan of the membranes. Intermittent shock dosing of biocide will be implemented. However, to avoid damage to the RO membranes, the chlorinated water must be neutralised with sodium bisulphite before it can pass through the membranes;
- Sulphuric acid may be added every other week for 4 to 6 hours per day (following chlorination) to periodically remove shellfish growth from the intake piping;
- If DAF or granular media filtration is implemented for source water pretreatment, a coagulant (ferric sulfate or ferric chloride) would be added upstream of the DAF and filtration units to improve the performance of these pretreatment facilities;
- Continuous addition of a polymer upstream of the DAF system and downstream of the point of coagulant addition to enlarge the size of the coagulated particles for more efficient removal;
- Continuous addition of sulphuric acid upstream of the pre-filtration system to adjust pH and thereby enhance coagulation;
- Prevention of scaling and inorganic precipitation by acid addition (lowering the pH of the incoming seawater) and/or dosing of special ‘antiscalant’ chemicals;
- Addition of sodium hydroxide upstream of the RO system to increase the pH of the feed water to enhance removal of boron from the seawater; and
- Removal of other elements such as silica, and organic matter accumulated on the coarse screens.

Once every 2 - 4 months the RO membrane trains need to be cleaned using a CIP procedure. Membrane cleaning would involve low pH cleaning with citric acid; high pH cleaning with sodium hydroxide and commercial soap cleaning as per the recommendations of the SWRO membrane supplier.

6.3 LEGISLATIVE AND PERMITTING REQUIREMENTS

The legislative requirements associated with the proposed development are detailed in the Scoping Report for the project and is covered in Chapter 2. These will not be repeated in detail here, but for the sake of completeness are summarised below.

6.3.1 South African Legislation

Listed below are the regulatory requirements specific to the coastal zone and marine environment:

- National Environmental Management Act 107 of 1998, as amended (NEMA);
- National Water Act 36 of 1998 (NWA);
- National Environmental Management: Biodiversity Act 10 of 2004 (NEM:BA);
- National Environmental Management: Integrated Coastal Management Act 24 of 2008 (NEM:ICMA);
- Marine Living Resources Act: Act 18 of 1998 (MLRA); and
- National Environmental Management Act 107 of 1998: Regulations: Control of Vehicles in the Coastal Zone (Government Notice No:1399).

6.3.2 International Standards and Guidelines

In addition to national legislation, there are international standards, protocols and guidelines that are applicable for a desalination plant project:

- In August 2007, the Department of Water Affairs & Forestry (DWAF 2007) of South Africa published the "*Guidelines for the evaluation of possible environmental impacts during the development of seawater desalination processes*". This document gives general guidance on the assessment procedure, lists possible environmental impacts which can be expected during implementation of seawater desalination, and provides recommendations for specialist and monitoring studies.
- The International Finance Corporation (IFC), a member of the World Bank Group, has developed operational policies (IFC 1998) that, inter alia, require that an impact assessment is undertaken within the country's overall policy framework and national legislation, as well as international treaties, and that natural and social aspects are to be considered in an integrated way. IFC has published Environmental, Health, and Safety Guidelines (known as the 'EHS Guidelines') containing guidelines and standards applicable to projects discharging industrial wastewater (IFC 2007). The EHS Guidelines contain the performance levels and measures that are normally acceptable to IFC and are generally considered to be achievable in new facilities at reasonable costs by existing technology. The EHS Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice, as defined in IFC's Performance Standard 3 on Pollution Prevention and Abatement (IFC 2006). This Performance Standard has the objective to avoid and minimize adverse impacts on human health and the environment by avoiding or minimizing pollution from project activities. It outlines a project approach to pollution prevention and abatement in line with internationally disseminated pollution prevention and control technologies and practices. In addition, Performance Standard 3 promotes the private sector's ability to integrate such technologies and practices as far as their use is technically and financially feasible and cost-effective in the context of a project that relies on commercially available skills and resources.
- Other guidance documents are those by the California Coastal Commission (Seawater Desalination and the California Coastal Act, 2004), the United Nations Environmental Programme (UNEP 2008) and the World Health Organisation (WHO 2008) that include international best practices and principles such as the precautionary approach and describe how design and construction approaches can mitigate likely impacts.

- The Rio Declaration on Environment and Development (1992), which calls for use of EIA as an instrument of national decision making (Principle 17). Moreover, it establishes important principles for sustainable development that should be reflected in EIAs, such as the application of the precautionary principle (Principle 15, whereby, where there is uncertainty in the nature and severity of a potential impact, conservative assumptions are made with respect to the significance and potential severity of the impact being assessed).

As signatory to the Convention of Biological Diversity, South Africa is committed to the preservation of rare and endemic species, and to provide protection for ecosystems and natural life-support processes within the country's boundaries. As a signatory of the United Nations Law of the Sea Convention of 1982, South Africa is required to adopt legislation to reduce marine pollution from seabed activities in the Exclusive Economic Zone (EEZ) and on the continental shelf, and from land-based sources.

6.3.3 Water Quality Guidelines

Environmental quality objectives need to be set for the marine environment, based on the requirements of the site-specific marine ecosystems, as well as other designated beneficial uses (both existing and future) of the receiving environment. The identification and mapping of marine ecosystems and the beneficial uses of the receiving marine environment provide a sound basis from which to derive site-specific environmental quality objectives (Taljaard *et al.* 2006). To ensure that these are practical and effective management tools, they need to be set in terms of measurable target values, or ranges for specific water column and sediment parameters, or in terms of the abundance and diversity of biotic components.

The *South African Water Quality Guidelines for Coastal Marine Waters* (DWAF 2005) provide recommended target values (as opposed to standards) for a range of substances, but these are not exhaustive. Therefore, in setting site-specific environmental quality objectives, the information contained in the DWAF guideline document should be supplemented by additional information obtained from published literature, best available international guidelines (*e.g.* ANZECC 2000; World Bank 1998), and site-specific data and information (*e.g.* obtained through numerical modelling outputs). Recommended target values are also reviewed and summarized in the Benguela Current Large Marine Ecosystem (BCLME) document on water quality guidelines for the BCLME region (CSIR 2006). Recommended target values extracted from these guidelines are provided in Table 6.2.

Table 6.2: Water quality guidelines for the discharge of a high-salinity brine into the marine environment.

VARIABLE	SOUTH AFRICA (DWAF 1995)	AUSTRALIA/NEW ZEALAND (ANZECC 2000)	WORLD BANK [a] (World Bank 1998)	US ENVIRONMENTAL PROTECTION AGENCY (EPA 2006)
Zone of impact / mixing zone	To be kept to a minimum, the acceptable dimensions of this zone informed by the EIA and requirements of licensing authorities, based on scientific evidence.	No guideline found	100 m radius from point of discharge for temperature	No guideline found
Temperature	The maximum acceptable variation in ambient temperature is ± 1°C	Where an appropriate reference system is available, and there are sufficient resources to collect the necessary information for the reference system, the median (or mean) temperature should lie within the range defined by the 20%ile and 80%ile of the seasonal distribution of the ambient temperature for the reference system.	< 3°C above ambient at the edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 meters from the point of discharge when there are no sensitive aquatic ecosystems within this distance.	No guideline found
Salinity[b]	33 – 36 psu	Low-risk trigger concentrations for salinity are that the median (or mean) salinity should lie within the 20%ile and 80%ile of the ambient salinity distribution in the reference system(s). The old salinity guideline (ANZECC 1992) was that the salinity change should be <5% of the ambient salinity.	No guideline found	No guideline found
Total residual Chlorine	No guideline, however, deleterious effects recorded for concentrations as low as 2 – 20 µg/ ℓ. A conservative trigger value is <2 µg/ℓ.	3 µg Cl/ℓ measured as total residual chlorine (low reliability trigger value at 95% protection level, to be used only as an indicative interim working level) (ANZECC 2000)[c]	0.2 mg/ℓ at the point of discharge prior to dilution	Long-term and short-term water quality criteria for chlorine in seawater are 7.5 µg/l and 13 µg/l, respectively

VARIABLE	SOUTH AFRICA (DWAF 1995)	AUSTRALIA/NEW ZEALAND (ANZECC 2000)	WORLD BANK [a] (World Bank 1998)	US ENVIRONMENTAL PROTECTION AGENCY (EPA 2006)
Total residual dibromonitrilopropionamide (DBNPA)	No guideline exists, suggest values ranging between 0.035 mg/ ℓ and 0.070mg/ ℓ	No guideline found	No guideline found	No guideline found
Dissolved oxygen (DO)	For the West Coast, the dissolved oxygen should not fall below 10 % of the established natural variation. For the South and East Coasts the dissolved oxygen should not fall below 5 mg/ℓ (99 % of the time) and below 6 mg/ℓ (95 % of the time)	Where an appropriate reference system is available, and there are sufficient resources to collect the necessary information for the reference system, the median lowest diurnal DO concentration for the period for DO should be >20%ile of the ambient dissolved oxygen concentration in the reference system(s) distribution. The trigger value should be obtained during low flow and high temperature periods when DO concentrations are likely to be at their lowest.	No guideline found	No guideline found
Nutrients	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for dissolved oxygen (see above)	Default trigger values of PO_4-P: 100 µg/ℓ NO_x-N: 50 µg/ℓ NH_4^+-N: 50 µg/ℓ for the low rainfall southern Australian region (Table 3.3.8 in ANZECC 2000)	No guideline found	No guideline found
Chromium	8 µg/ℓ (as total Cr)	Marine moderate reliability trigger value for chromium (III) of 10 µg./ℓ with 95% protection Marine high reliability trigger value	0.5 mg/ℓ (total Cr) for effluents from thermal power plants	1 100 µg/ℓ for highest concentration at brief exposure without unacceptable effect 50 µg/ℓ highest concentration at

VARIABLE	SOUTH AFRICA (DWAF 1995)	AUSTRALIA/NEW ZEALAND (ANZECC 2000)	WORLD BANK [a] (World Bank 1998)	US ENVIRONMENTAL PROTECTION AGENCY (EPA 2006)
		for chromium (VI) of 4.4 µg/ℓ at 95% protection		continuous exposure without unacceptable effect
Iron	No guideline found	Insufficient data to derive a reliable trigger value. The current Canadian guideline level is 300 µg/ℓ	1.0 mg/ℓ for effluents from thermal power plants	No guideline found
Molybdenum	No guideline found	Insufficient data to derive a marine trigger value for molybdenum. A low reliability trigger value of 23 µg/ℓ was adopted to be used as indicative interim working levels.	No guideline found	No guideline found
Nickel	25 µg/ℓ (as total Ni)	7 µg/ℓ at a 99% protection level is recommended for slightly-moderately disturbed marine systems.	No guideline found	74 µg/ℓ for highest concentration at brief exposure without unacceptable effect 8.2 µg/ℓ highest concentration at continous exposure without unacceptable effect

[a] The World Bank guidelines are based on maximum permissible concentrations at the point of discharge and do not explicitly take into account the receiving environment, *i.e.* no cognisance is taken of the fact of the differences in transport and fate of pollutants between, for example, a surf-zone, estuary or coastal embayment with poor flushing characteristics and an open and exposed coastline. It is for this reason that we include in this study other generally accepted Water Quality guidelines that take the nature of the receiving environment into account.

[b] The ANZECC (2000) Water Quality guideline for salinity is less stringent than, but roughly approximates, the South African Water Quality guideline that requires that salinity should remain within the range of 33 psu to 36 psu (=ΔS of approximately 1 psu). Scientific studies have shown that effects on marine biota are primarily observed for increases of >4 psu above ambient level. ΔS 1 psu and 4 psu have been chosen for assessment purposes.

[c] In case of chlorine “shocking”, which involves using high chlorine levels for a short period of time rather than a continuous low-level release, the target value is a maximum value of 2 mg/ℓ for up to 2 hours, not to be repeated more frequently than once in 24 hours, with a 24-hour average of 0.2 mg/ℓ (The same limits would apply to bromine and fluorine).

6.3.4 Mixing Zones

A mixing zone is the area around an effluent discharge point where the effluent is actively diluted with the water of the receiving environment. This zone usually encompasses the near-field and mid-field regions of dilution to allow for the plume to mix throughout the water column. Within the mixing zone, no water quality criteria for physical and chemical stressors are defined (with the exception of a select few contaminants that may potentially bioaccumulate). Instead, these water quality criteria ('trigger values') are defined at the boundary of the mixing zone to ensure the quality of nearby waters does not deteriorate as a result of the effluent discharge. The boundaries of a proposed mixing zone are typically defined according to an estimated distance from the discharge point at which point defined water quality guidelines will be met, as predicted by numerical modelling of the discharge.

Internationally, requirements for the maximum size of a mixing zone vary from as little as 30 m in the USA to 1 000 m in the Netherlands (Anchor Environmental Consultants 2015). The recent assessment framework for the management of effluent discharged from land-based sources to the marine environment (Anchor Environmental Consultants 2015), recommended that in a nearshore open coast environment, the combined size of the mixing zone around a multiple-port diffuser should not exceed the total area permitted by the applicable single mixing zone of 282 743 m^2. For a diffuser with 9 discharge ports this amounts to a radius not exceeding 100 m (31 400 m^2) around each diffuser port.

6.4 THE MARINE RECEIVING ENVIRONMENT

The summary presented below is based on information provided in the Generic EMPRs for Oil and Gas Prospecting off the Coast of South Africa (CCA & CMS 2001). It is supplemented by more recent information from other EIAs, EMPs and specialist reports compiled for the area.

6.4.1 The Physical Environment

The orientation of the coastline along the East Coast is relatively uniform, and north-northeast. The only significant topographical feature is the Natal Bight, a coastal indentation between Cape Vidal and Durban. The majority of the East Coast region has a narrow continental shelf and a steep continental slope. A prominent feature on the continental shelf is the Tugela Bank located along the KZN coast between 28° 30' S and 30° 20' S. Here the continental shelf widens to 50 km offshore, the maximum width reached along the East Coast (Lutjeharms *et al.* 1989), and the continental slope is more gentle (Martin & Flemming 1988). To the south, the continental margin descends into the Natal Valley, while northeastwards it develops into the Central Terrace. The Tugela Bank is interrupted by two canyons; the large and prominent Tugela Canyon and the smaller Goodlad Canyon. Further canyons and feeder valleys typify the edge of the continental shelf in the area off Sodwana Bay (Sink & Atwood 2008; Green *et al*. 2009).

The KZN continental shelf is characterised by Cretaceous and Cenozoic marine sediments, with the uppermost Cretacean sediments being predominantly a soft and muddy layer, rich in marine fossils. Stratified Quaternary marine deposits have also resulted in a series of prominent north-south oriented sandy dune ridges (Sink & Atwood 2008).

The Tugela Bank is the major sedimentary deposition centre of the KZN continental shelf. North of Durban, the shelf region is dominated by terrigenous sand (0.063 – 2 mm), with patches of gravel (>2 mm) occurring throughout the area. In contrast, areas on the mid-shelf contain sediments comprising up to 60% terrigenous mud. Two large mud depo-centres are found off the Tugela River mouth, while a smaller one is located off St Lucia. These muds and their associated elevated organic contents provide habitat for important benthic communities. South of Durban, sand dominates both the inshore and offshore surficial sediments, although a substantial gravel component is present on the middle and outer shelf to as far as Port St Johns, occurring as coarse lag deposits in areas of erosion or non-deposition. Traces of mud are present on most areas of the shelf, although significant mud depo-centres are absent. The outer shelf is dominated by gravels of shell-fragment and algal-nodule origin (Heydorn *et al.* 1978).

The Agulhas Current and/or waves affect the sediment bedform patterns on the KZN continental shelf. North and south of the Tugela Cone, the Agulhas Current generates active dune fields at the shelf edge (Flemming & Hay 1988). In contrast, sediments on the shelf area of the Tugela Bank to a depth of 100 m are affected mostly by wave action (CSIR 1998). South of the Ilovo River the inner shelf comprises sand sheets, while sand ribbons and streamers occur on the mid-shelf, with gravel pavements dominating the outer shelf.

The oceanography of this coast is almost totally dominated by the warm Agulhas Current that flows southwards along the shelf edge and seawards of the 200 m depth contour (Schumann 1998). The current forms between 25° and 30° S, flowing southwards along the East Coast of southern Africa as part of the anticyclonic Indian Ocean gyre (Shannon 1985), before retroflecting between 16° and 20° E. It is a well-defined and intense jet some 100 km wide and 1,000 m deep (Schumann 1998), flowing in a south-west direction at a rapid rate, with current speeds of 2.5 m/s or more having been recorded (Pearce *et al.* 1978).

Nearshore counter currents periodically occur, possibly generated by strong local winds, and during cold fronts that travel up the coast from the Cape. Where it meets the northern part of the Tugela Bank/Natal Bight near Cape St Lucia, the inertia of the Agulhas Current carries it poleward into deep water. This generates instability in the current (Gill & Schumann 1979) resulting in meanders and eddies (Pearce *et al.* 1978). Three eddy types have been identified in the Agulhas Current (Gründlingh 1992):

- Type I meanders that comprise smaller shear/frontal features to a depth of at least 50 m, which dissipate over a period of days;
- Type II meanders comprising the large clockwise loops generated within the Natal Bight. Of these, the extremely transient Natal Pulse occurs when meanders move the southward flow offshore, enabling sluggish and sometimes even northward flow to develop close inshore (Schumann 1988). The larger Natal Gyre is a roughly clockwise circulation cell that extends from south of Durban to south of Richard's Bay, resulting in northward flow inshore (Pearce 1977a, 1977b). The Natal Gyre, however, is temporally and spatially variable (CSIR 1998), being affected by a number of Type I disturbances (Gründlingh 1992). The entrainment of cold water in the south may result in local shelf upwelling; and
- Type III meanders, which are the larger meanders that originate north of St Lucia.

South of Durban, the continental shelf again narrows and the Agulhas Current re-attaches itself to the coast, until off Port Edward it is so close inshore that the inshore edge (signified by a temperature front) is rarely discernible (Pearce 1977a).

As the Agulhas Current originates in the equatorial region of the western Indian Ocean, its waters are typically blue and clear with low nutrient levels. On the Tugela Bank, however, nutrient concentrations are characterised by short-term temporal variations, but are higher than in areas where the continental shelf is narrower (Carter & d'Aubrey 1988). This is attributed in part, to the topographically induced upwelling that occurs in the area as a result of the bathymetric arrangement of the Natal Bight (Gill & Schumann 1979; Schumann 1986; Lutjeharms *et al.* 1989). The cold nutrient-rich upwelled waters are a source of bottom water for the entire Natal Bight (Lutjeharms *et al.* 2000a, b). However, from all other perspectives, the Bight may be considered a semi-enclosed system (Lutjeharms & Roberts 1988) as the strong Agulhas Current at the shelf edge forms a barrier to exchanges of water and biota with the open ocean.

The surface waters are a mix of Tropical Surface Water (originating in the South Equatorial Current) and Subtropical Surface Water (originating from the mid-latitude Indian Ocean). Surface water temperatures in summer may exceed 28°C but fall to about 21°C in winter (Pearce 1978). Thermal stratification of the water column in the nearshore is usually weak as the water column is typically well mixed (Pearce 1978; Schumann 1998). Salinities are lower than those of the Equatorial Indian Ocean, South Indian Ocean and Central water masses found below. Surface water characteristics, however, vary due to insolation and mixing (Schumann 1998). Salinity measurements taken by WSP Coastal Engineers as part of the DFS indicated typical salinities of 35.3- 35.5 psu, with local reductions in salinity occurring in the vicinity of river mouths in response to increased river flow.

Meteorologically, the KZN coastline is affected by the position and seasonal movements of both the South Atlantic and Indian Ocean anti-cyclone cells, and mid-latitude cyclones that originate from the westerly wind belt (Schumann 1998). South-westerly winds result from the eastward moving mid-latitude cyclones (and their associated coastal low pressure systems) and prevail during both summer and winter, although the occurrence of north-east winds increases during summer (Schumann 1998). The basic weather cycle is related to the eastward movement of the coastal low-pressure systems generated along the southern African West Coast during pre-frontal conditions (Hunter 1988). These coastal lows are ~100 km wide, moving anti-clockwise along the coast and traversing the East Coast in under three days (CSIR 1998; Schumann 1998; Jury *et al*. 1990). As the coastal low approaches the KZN coastline, north-east winds freshen, occasionally reaching gale force. Once the coastal low has passed, winds swing to the south-west, persisting for more than a day before returning to through the south-east back to a north-easterly direction. The main wind axis off the KZN coast is thus parallel to the coastline, with north-easterly and south-westerly winds predominating for most of the year (Schumann & Martin 1991). In the region of Durban, stronger winds generally approach from the North-northeast (NNE) and Northeast (NE) sectors, with those from the Southeast (SE) sectors being less powerful. The average wind speed is 7.2 m/s.

In the sea areas off Durban, the majority of swells are from the south and south-southwest, with the largest attaining >7 m. During summer and autumn, some swells also arrive from the east. The less regular weather patterns affecting the East Coast (*e.g.* low pressure cells present Northeast of Durban, cut-off low pressure cells and tropical cyclones) strongly influence the wave climate, resulting in swells in excess of 10 m (Hunter 1988; Schumann 1998). The giant waves (>20 m high) that are at times encountered within the Agulhas Current (Heydorn & Tinley 1980), arise from the meeting of the south-westerly swells and the southerly flowing Agulhas Current, and may be a navigation hazard at times.

The current regime off the KZN coast is thought to follow the Agulhas Current 50% of the time. The circulation of shelf waters is thus predominantly wind-driven, while in the nearshore zone both wind and wave driven currents are important (Schumann & Martin 1991; Mardon & Stretch, 2002). Currents strengths average < 10 cm/s (Pearce 1977a, b; CSIR 2009). Calm periods (current velocities < 2 cm/s) occur up to 40% of the time. The dominant current directions are typically East-Northeast (ENE) and West (W), with the ENE flowing currents being stronger. Westward flowing currents, however, occur more frequently. In the surf zone, the net direction of current flow is NNE, resulting in a net North-eastward longshore transport of sediment. This bedload transport necessitates the continuous dredging of sediment (to form a sand trap) from the south of the southern breakwater guarding the entrance to the Port of Richards Bay. This material is transferred to beaches to the north of the northern breakwater, as part of a beach nourishment programme (CSIR 2009).

Current measurements taken by WSP Coastal Engineers as part of the DFS indicated that the current regime at the Lovu site is primarily along a NNE – South-Southwest (SSW) axis. Stronger currents tend toward NNE. At Lovu offshore flows are limited, possibly due to the narrower shelf there. The average current speed at Lovu is 0.13 m/s.

The tide is semi-diurnal with a typical range of 0.3 m during Neap tide and 1.8 m during Spring tide. The highest astronomical tide is 2.30 m MSL (Mather & Stretch 2012).

6.4.2 The Biological Environment

Biogeographically the coastline of the study area falls into the subtropical Natal bioregion, which extends from the Mbashi Mouth to Cape Vidal (Lombard *et al*. 2004). The coastline comprises primarily sandy beaches, punctuated by numerous rocky shores. Consequently, marine ecosystems along the coast comprise a limited range of habitats that include:

- Sandy intertidal and subtidal substrates;
- Intertidal rocky shores and subtidal reefs; and
- The water body.

The benthic communities within these habitats are generally ubiquitous throughout the southern African East Coast region, being particular only to substratum type, wave exposure and/or depth zone. They consist of many hundreds of species, often displaying considerable temporal and spatial variability. The biological communities ‘typical’ of each of these habitats are described briefly below, focusing both on dominant, commercially important and conspicuous species, as well as potentially threatened or sensitive species, which may be affected by the proposed project.

6.4.2.1 Plankton

The nutrient-poor characteristics of the Agulhas Current water are reflected in comparatively low primary productivity in KZN inshore areas, with *chlorophyll a* concentrations ranging between 0.03 and 3.88 µg/l (Carter & Schleyer 1988). Short-term increases in productivity are associated with localised upwelling on the Tugela Bank (Oliff 1973). Consequently, continental shelf waters support greater and more variable concentrations of zooplankton biomass than offshore waters (Beckley & Van Ballegooyen 1992), with species composition varying seasonally (Carter & Schleyer 1988). Ichthyoplankton, likewise, is confined primarily to inshore waters, with concentrations decreasing rapidly with distance offshore (Beckley & Van Ballegooyen 1992). The project area thus overlaps with major fish spawning and migration routes, and ichthyoplankton abundance is likely to be seasonally high (Figure 6.2).

6.4.2.2 Soft-sediment Benthic Macro and Meiofauna

The benthic biota of soft bottom substrates constitutes invertebrates that live on (epifauna), or burrow within (infauna) the sediments, and are generally divided into megafauna (animals >10 mm), macrofauna (>1 mm) and meiofauna (<1 mm). The community structure of benthic biota is shaped by the prevailing physical (abiotic) conditions such as sediment grain size, temperature, salinity, turbidity and currents. Further shaping is derived from biotic factors such as predation, food availability, larval recruitment and reproductive success. The naturally high spatial and temporal variability for these factors results in seabed communities being both patchy and variable. In particular, the seabed off the KZN coastline tends to be patchy in terms of sediment composition, with significant sediment movement being frequently induced by the typically dynamic wave and current regimes (Fleming & Hay 1988). Consequently, the benthic macrofauna will be adapted to typically harsh conditions and frequent disturbance. Further offshore where near-bottom conditions are more stable, the macrofaunal communities will primarily be determined by sediment characteristics and depth.

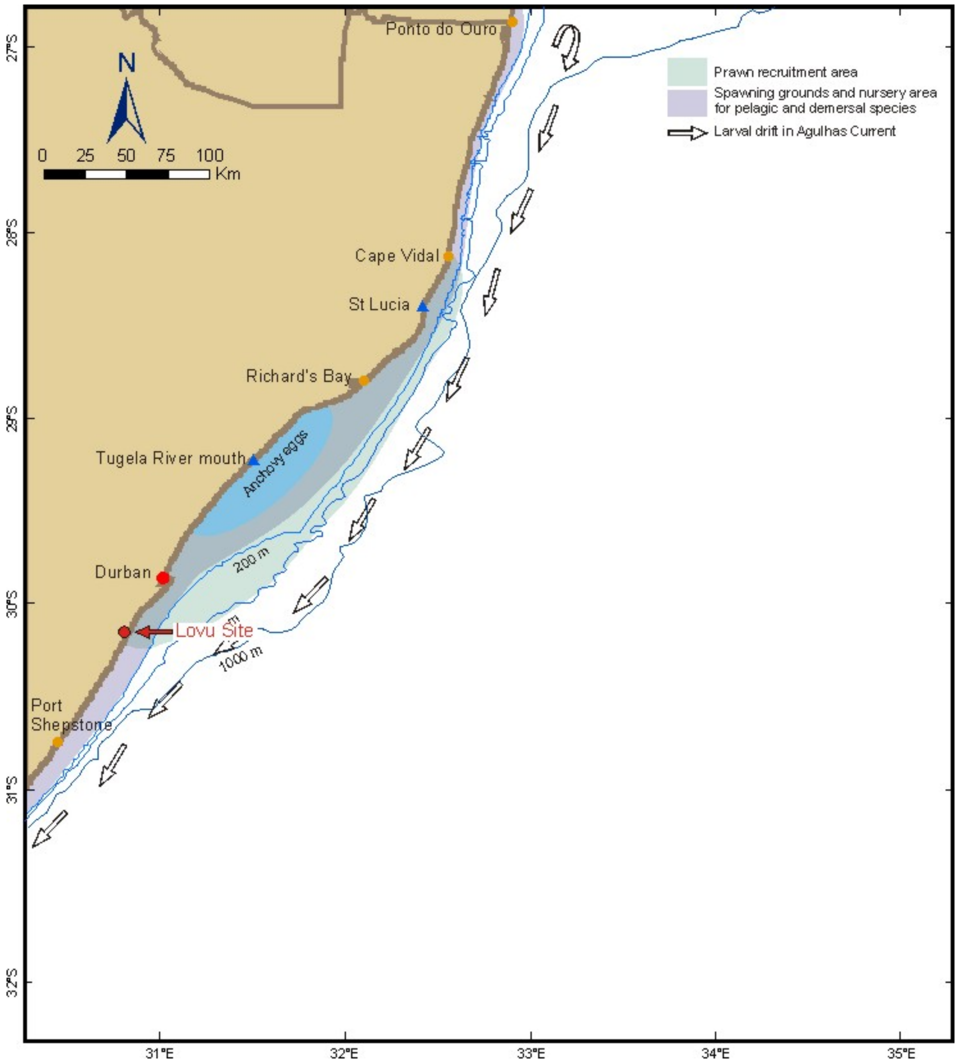

Figure 6.2: Major fish spawning, nursery and recruitment areas along the KZN coast in relation to the proposed Lovu desalination plant site at Lovu.

Intertidal Beaches

The beaches in central and northern KZN comprise coarse grained sediments (Jackson & Lipschitz 1984) and are typically exposed to high wave energy. The beaches tend to be reflective and unstable, resulting in depauperate macrofaunal assemblages (CSIR 1998). The macrofaunal assemblages are characterised by tropical crustaceans (*e.g.* ghost crabs *Ocypode* spp, and mole crabs *Emerita austroafricana* and *Hippa adactyla*) (Dye *et al*. 1981), with gastropods and isopods being comparatively poorly represented (Wooldridge *et al*. 1981).

Subtidal Macrobenthos

There is insufficient information available on benthic invertebrates in the project area to allow for a description of the zoogeographic distribution of benthic macrofaunal communities (McClurg 1988). Typical components of the subtidal macrobenthos are polychaete worms, molluscs, echinoderms and a variety of crustaceans. While some species live at the water/sediment interface, others burrow into the sediment, usually to depths not exceeding 30 cm. Typical species reported by CSIR (2009) from nearshore sediments off Richard's Bay include the amphipods *Urothoe* (various species), *Mandibulophoxus stimpsoni* and *Cunicus profundus*, anthurid and arcturid isopods, the bivalves *Macra* spp., *Modiolus* spp. and *Tellina* spp., the gastropods *Bullia similis* and *Oliva caroliniana*, and a wide variety of polychaete species including *Glycera* sp., *Lumbrineris* sp., *Nephtys* spp., *Orbinia* spp. and *Prionospio* sp. (Figure 6.3). The meiobenthos includes the smaller species such as nematode worms, flat worms, harpacticoid copepods, ostracods and gastrotriches. Some of the meiofauna are adept at burrowing while others live in the interstitial spaces between the sand grains.

Figure 6.3: Benthic macrofaunal genera commonly found in nearshore sediments include: (top: left to right) *Ampelisca*, *Prionospio*, *Bullia similis*; (middle: left to right) *Modiolus sirahensis*, *Orbinia*, *Tellina*; (bottom: left to right) *Nephtys*, hermit crab, *Urothoe*. (Not to scale).

Long-term studies in the Richard's Bay area (Connell *et al.* 1985, 1989; McClurg *et al.* 1999, 2000, 2001, 2002, 2003, 2004; McClurg & Blair 2005, 2006, 2007, 2008; CSIR 2007, 2009) have identified that the benthic macrofaunal communities have a low diversity and abundance, particularly on sandy inshore substrates. Further offshore where sediments tend to be muddier, diversity and abundance increases (CSIR 2009). Similar surveys undertaken off Durban, and on the KZNcontinental shelf in general, have yielded much richer communities (McClurg 1998).

A number of larger crustacean species form the basis for a small multispecies trawl fishery on the Tugela Bank and the shallow-water mud banks along the north East Coast of KZN. The species in question include various penaeid prawns, particularly *Fenneropenaeus indicus* (white prawn), *Metapenaeus monoceros* (brown prawn) and *Penaeus monodon* (tiger prawn) (Figure 6.4, left), as well as pink and red prawns (*Haliporoides triarthrus* and *Aristaeomorpha foliacea*), langoustines (*Metanephrops mozambicus* and *Nephropsis stewarti*) and red crab (*Chaceon macphersoni*). Most of the prawn species are fast-growing and short-lived (~1 year), and dependent on estuarine environments (*e.g.* Amatigkula and Tugela River mouths, St Lucia) during the early phase of their life cycle. Juveniles move out of estuaries in January and start recruiting onto the mud banks (and into the fishery) from February onwards, where they subsequently mature and reproduce (Wilkinson & Japp 2010). Abundance of these crustaceans varies seasonally and for shallow water species is strongly dependent on recruitment from estuarine nursery areas and river discharges (M&CM 2007). Prolonged closure of estuary mouths due to reduced river flow thus has important implications for the recruitment success of these crustaceans. The shallow-water penaeids typically occur on unconsolidated sandy to muddy sediments in <50 m depth on the Tugela and St Lucia Banks, whereas the deep-water species occur at depths between 360-460 m.

Other deep-water crustaceans that may occur in the proposed survey area are the shovel-nosed crayfish (*Scyllarides elisabethae*) and the Natal deep-sea rock lobster (*Palinurus delagoae*) (Figure 6.4, right). The shovel-nosed crayfish occurs primarily on gravelly seabed at depths of around 150 m, although it is sometimes found in shallower water. Its distribution range extends from Cape Point to Maputo. The Natal rock lobster similarly occurs on open areas of mud and rubble at depths of 100-600 m (Groeneveld & Melville-Smith 1995). Larvae settle offshore with juveniles and adults migrating inshore as they age. This species primarily occurs north of Durban. Other rock lobster species occurring on the East Coast include the East Coast rock lobster (*Palinurus homarus*) and the painted spiny lobster (*Palinurus versicolor*), all of which, however, are typically associated with shallow-water reefs (Branch *et al.* 2010).

Figure 6.4: The tiger prawn *Panaeus monodon* (left) occur on shallow-water mud banks along the KZNcoast, whereas the Natal deep-sea rock lobster *Palinurus delagoae* (right) occurs on mud and rubble at depths of 100-600 m (Photos: platinum-premium.com; visualsunlimited.photoshelter.com).

6.4.2.3 Reef Communities

Intertidal Rocky Shores

Rocky intertidal habitats comprise less than one third of the KZNcoastline (Jackson & Lipschitz, 1984), most of which are regularly inundated by sand. Rocky intertidal shores on the southern African East Coast can be divided into five zones on the basis of their characteristic biological communities. Tolerance to the physical stresses associated with life in the intertidal, as well as biological interactions such as herbivory, competition and predation interact to produce these five zones. The biological zones, however, also correspond roughly to zones based on tidal heights. East Coast rocky intertidal fauna is comparatively diverse, with assemblages characterised by more tropical species. These are described briefly below (Branch & Branch 1981, Branch *et al*. 2010):

Supralittoral fringe – Littorina zone - The supralittoral fringe, is the uppermost part of the shore most exposed to air, thus perhaps having more in common with the terrestrial environment. The supralittoral is characterised by low species diversity, with the tiny gastropods *Afrolittorina africana*, *Littoraria glabra* and *Echinolittorina natalensis*, and the tufted algae *Bostrychia tenella* (Rhodophyta) constituting the most common macroscopic life.

Upper midlittoral – Upper Balanoid zone - The upper midlittoral is characterised by a dense band of the Natal rock oyster *Saccostrea cuccullata*, which gives way to a mixed community of brown mussel *Perna perna*, various barnacles (*e.g.* volcano barnacle *Tetraclita serrata*, eight-shell barnacle *Octomeris angulosa*) and limpets such as *Helcion concolor*, *Cellana capensis*, and various species of false limpet *Siphonaria* spp.

Lower midlittoral – Lower Balanoid zone - On the lower shore, biological communities are characterised by several species of zoanthids, urchins, sponges and upright coralline algae.

Sublittoral fringe - The well-marked sublittoral fringe is characterised by dense algal beds, which include species such as *Hypnea specifera*, *Spyridia hypnoides* and *Callithamnion stuposum*. In the extreme low-shore, where wave action is strongest the algal communities include various species of coralline algae, *Gelidium amansii* and *Plocamium corallorhiza*. Fauna in the low shore are relatively sparse being represented primarily by urchins and octopus.

Subtidal Reefs

The subtidal shallow reefs of the East Coast range from rich, coral-encrusted sandstone reefs in the north to the more temperate rocky reefs further south. In the north, the Maputaland Coral Reef system, which extends from Kosi Bay to Leven Point, constitute the southernmost coral-dominated reefs of Africa (UNEP-WCMC 2011). South of the iSimangaliso Wetland Park (St Lucia) reef habitat is provided by rock outcrops, although both hard and soft corals still occur. Both reef types are characterised by diverse invertebrate and ichthyofaunal biota of Indo-Pacific origin (Figure 6.5, left). The invertebrate benthic communities associated with hard substrata boast a high diversity of hard and soft corals, sponges, tunicates and bivalve molluscs. Mobile benthic organisms associated with the reefs include a wide variety of echinoderms (urchins, starfish and sea cucumbers), gastropod molluscs and crustaceans. The coral reef habitat also provides shelter and a food source for the highly diverse Indo-Pacific reef fish community.

Both the coral-dominated reefs off Sodwana Bay and the sandstone reefs off Durban and the KZN South Coast are popular amongst divers for its wealth of invertebrate and fish diversity.

6.4.2.4 Pelagic and Demersal Fish

Pilchards (*Sardinops sagax*) are a small pelagic shoaling species typically found in water between 14°C and 20°C. Spawning occurs on the Agulhas Bank during spring and summer. During the winter months of June to August, the penetration of northerly-flowing cooler water along the Eastern Cape coast and up to southern KZNeffectively expands the suitable habitat available for this species, resulting in a 'leakage' of large shoals northwards along the coast in what has traditionally been known as the 'sardine run'. The cool band of inshore water is critical to the 'run' as the sardines will either remain further south or move northwards further offshore if the inshore waters are above 20 °C. The shoals can attain lengths of 20-30 km and are typically pursued by Great White Sharks, Copper Sharks, Common Dolphins, Cape Gannets (Figure 6.5, right) and various other large pelagic predators (www.sardinerun.co.za). Catch rates of several important species in the recreational shoreline fishery of KZN have been shown to be associated with the timing of the sardine run (Fennessey *et al.* 2010). Other pelagic species that migrate along the KZN South Coast include elf/shad (*Pomatomus saltatrix*), geelbek (*Atractoscion aequidens*), yellowtail (*Seriola lalandi*), kob (*Argyrosomus* sp.), seventy-four (*Cymatoceps nasutus*), strepie/karanteen (*Sarpa salpa*), Cape stumpnose (*Rhabdosargus holubi*), red steenbras (*Petrus rupestrus*), poenskop (*Cymatoceps nasutus)* and mackerel (*Scomber japonicus*), which are all regular spawners within KZN waters (Van der Elst 1988; Hutchings *et al.* 2003). Both the Tugela Bank as well as the many estuaries along the KZN coastline serve as important nursery areas for many of these species.

Figure 6.5: The reefs in KZN are characterized by highly diverse invertebrate benthic communities and their associated fish fauna (Left, photo: www.sa-venues.com). The annual 'sardine run' attracts a large number of pelagic predators, which follow the shoals along the coast (Right, photo: www.sea-air-land.com).

A wide variety of demersal fishes and megabenthic invertebrates have been recorded in experimental trawls off Richards Bay (Figure 6.6) since sampling was initiated in 1982. This unique long-term dataset shows wide spatio-temporal variability in the diversity and abundance of trawl catches over the years (CSIR 2009). Similar variability has been reported from other regions of the world, and it appears to be an inherent feature of demersal fish and megabenthic invertebrate communities from nearshore soft-sediment habitats (Otway *et al.* 1996).

Figure 6.6: A trawl sample taken 7 km off Richards Bay showing the wide variety of demersal fish and megabenthic invertebrates occurring in nearshore areas (CSIR 2009).

A high diversity of pelagic Teleosts (bony fish) (Figure 6.7) and Chondrichthyans (cartilaginous fish) is associated with the inshore and shelf waters of the study area. Many fish are endemic to the Southern African coastline and form an important component of the commercial and recreational linefisheries of KZN (Figure 6.1).

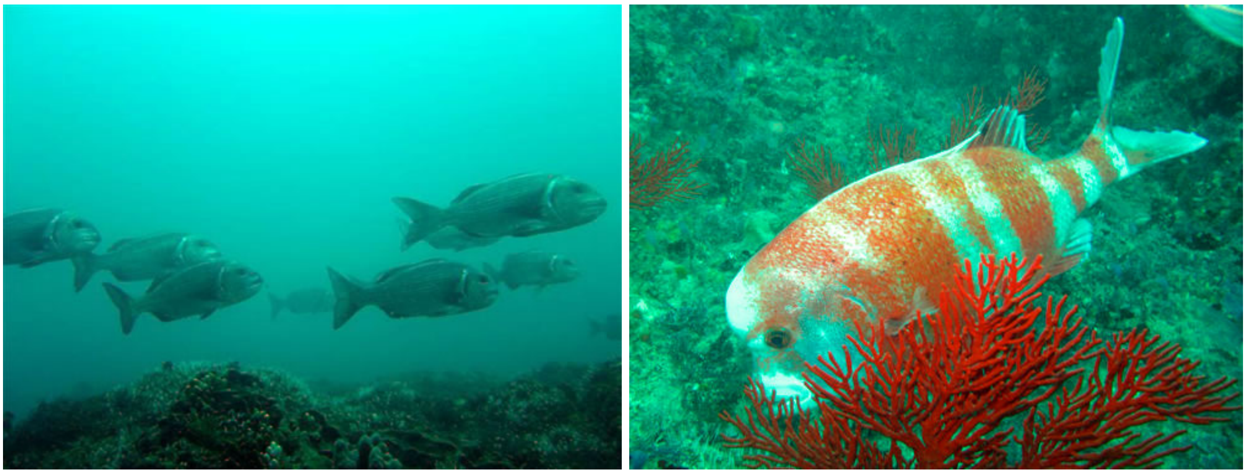

Figure 6.7: The East Coast reefs support a wide diversity of teleost species including musselcracker (left; www.spearfishingsa.co.za) and red stumpnose (right; www.easterncapescubadiving. co.za).

Table 6.2: Some of the more important linefish species landed by commercial and recreational boat fishers along the East Coast (adapted from CCA & CMS 2001).

Common Name	Species Name
Demersal teleosts	
Blue hottentot	*Pachymetopon aeneum*
Cape stumpnose	*Rhabdosargus holubi*
Dageraad	*Chrysoblephus christiceps*
Englishman	*Chrysoblephus anglicus*
Mini kob	*Johnius dussumieri*
Natal stumpnose	*Rhabdosargus sarba*
Poenskop/Musselcracker	*Cymatoceps nasutus*
Pompano	*Trachinotus africanus*
Red steenbras	*Petrus rupestris*
Red stumpnose	*Chrysoblephus gibbiceps*
River bream	*Acanthopagrus berda*
Rockcod	*Epinephalus* spp.
Santer	*Cheimerius nufar*
Scotsman	*Polysteganus praeorbitalis*
Slinger	*Chrysoblephus puniceus*
Snapper salmon	*Otolithes ruber*
Spotted grunter	*Pomadasys commersonnii*
Squaretail kob	*Argyrosomus thorpei*
White steenbras	*Lithognathus lithognathus*
Pelagic species	
Elf	*Pomatomus saltatrix*
Garrick/leerfish	*Lichia amia*
Geelbek	*Atractoscion aequidens*
Green jobfish	*Aprion virescens*
King mackerel	*Scomberomorus commerson*
Kob	*Argyrosomus spp*
Kingfish species	*Caranx* spp.
Queenfish	*Scomberoides commersonianus*
Queen mackerel	*Scomberomorus plurilineatus*
Tenpounder	*Elops machnata*
Wahoo	*Acanthocybium solandri*
Yellowtail	*Seriola lalandi*
Chondrichthyans	
Bronze whaler shark	*Carcharhinus brachyurus*
Dusky shark	*Carcharhinus obscurus*
Hammerhead shark	*Sphyrna* spp.
Sandshark	Rhinobatidae
Milkshark	*Rhizoprionodon acutus*
Skates	Rajiformes
Stingray	Dasyatidae

Large migratory fish species occur in offshore waters and beyond the shelf break. These include dorado (*Coryphaena hippurus*), sailfish (*Istiophorus platypterus*) and black, blue and striped marlin (*Makaira indica, M. nigricans, Tetrapturus audax*) (Figure 6.8, left), frigate tuna (*Auxis thazard*), eastern little tuna (*Euthynnus affinis*), skipjack (*Katsuwonus pelamis*), longfin tuna (*Thunnus alalunga*) (Figure 6.8, right) and yellowfin tuna (*Thunnus albacores*) (Van der Elst 1988). Many of these are targeted by the pelagic longline fishery, which operates extensively from the continental shelf break into deeper waters, all year-round.

Figure 6.8: Large migratory pelagic fish such as blue marlin (left) and longfin tuna (right) occur in offshore waters (photos: www.samathatours.com; www.osfimages.com).

6.4.3 Turtles

Five species of sea turtles occur along the East coast of South Africa; the green turtle (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*), leatherback (*Dermochelys coriacea*) (Figure 6.9, left), hawksbill (*Eretmochelys imbricata*) and loggerhead (*Caretta caretta*) (Figure 6.9, right). Green turtles are non-breeding residents often found feeding on inshore reefs. They nest mainly along the coast of Mozambique and on both Europa and Tromelin Islands (Lauret-Stepler *et al*. 2007). Hawksbills also occur on inshore reefs but nest along the coastlines of Madagascar and the Seychelles (Mortimer 1984). Olive ridleys are infrequent visitors to South African waters and nest throughout the central and northern regions of Mozambique (Pereira *et al.* 2008). Leatherback turtles inhabit the deeper waters of the Atlantic Ocean and are considered a pelagic species. They travel the ocean currents in search of their prey (primarily jellyfish) and may dive to over 600 m and remain submerged for up to 54 minutes (Hays *et al*. 2004; Lambardi *et al.* 2008). They come into coastal bays and estuaries to mate, and lay their eggs on the adjacent beaches. Loggerheads tend to keep more inshore, hunting around reefs, bays and rocky estuaries along the African East Coast, where they feed on a variety of benthic fauna including crabs, shrimp, sponges, and fish. In the open sea, their diet includes jellyfish, flying fish, and squid (www.oceansafrica.com/turtles.htm).

Figure 6.9: Leatherback (left) and loggerhead turtles (right) occur along the East Coast of South Africa (Photos: Ketos Ecology 2009; www.aquaworld-crete.com).

Loggerheads and leatherbacks nest along the sandy beaches of the northeast Coast of KZN, South Africa, as well as southern Mozambique during summer months. These loggerhead and leatherback nesting populations are the southern-most in the world (Nel *et al.* 2013). Even though these populations are smaller (in nesting numbers) than most other populations, they are genetically unique (Dutton *et al.* 1999; Shamblin *et al.* Submitted) and thus globally important populations in terms of conservation of these species.

Loggerhead and leatherback females come ashore to nest from mid-October to mid-January each year. They crawl up the beach and deposit an average of ~100 (loggerheads) or ~80 (leatherback) eggs in a nest excavated with their hind flippers. The eggs incubate for two months and hatchlings emerge from their nests from mid-January to mid-March. The mean hatching success for loggerheads (73 %) and leatherbacks (76 %) on the South African nesting beaches (de Wet 2013) is higher than reported at other nesting sites globally. Nevertheless, eggs and emerging hatchlings are nutritious prey items for numerous shoreline predators, resulting in the mean emergence success and hatchling success being slightly lower than the hatching success. However, emergence and hatchling success for both species is similarly higher in South Africa than reported at other nesting beaches as mortality is largely limited to natural sources due to strong conservation presence on the nesting beach, which has reduced incidents of egg poaching and female harvesting to a minimum (Nel 2010). The production of both loggerhead and leatherback hatchlings is thus remarkably high in South Africa, making the nesting beaches in northern KZN some of the most productive (relative to nesting numbers) in the world.

Those hatchlings that successfully escape predation on their route to the sea, enter the surf and are carried ~10 km offshore by coastal rip currents to the Agulhas Current (Hughes 1974a). As hatchlings are not powerful swimmers they drift southwards in the current. During their first year at sea, the post-hatchlings feed on planktonic prey items (Hughes 1974b), with their activities largely remaining unknown (Hughes 1974b). After ~10 years, juvenile loggerheads return to coastal areas to feed on crustaceans, fish and molluscs and subsequently remain in these neritic habitats (Hughes 1974a). In contrast, leatherbacks remain in pelagic waters until they become sexually mature and return to coastal regions to breed. Loggerheads reach sexual maturity at about 36 years of age whereas leatherbacks reach maturity sooner, at approximately 15 years (Tucek *et al.* Submitted). It has been estimated that only 1 to 5 hatchlings survive to adulthood (Hughes 1974a; de Wet 2013).

Sea turtles are highly migratory and travel extensively throughout their entire life cycle. Adult turtles migrate thousands of kilometres between foraging and breeding grounds, returning to their natal beaches (Hughes 1996; Papi *et al.* 2000; Schroeder *et al.* 2003) by using geomagnetic (Lohmann *et al.* 2007) and olfactory cues (Grassman *et al.* 1984), hearing (Wyneken & Witherington 2001) as well as vision (Witherington 1992) to find their way back to the beach. The Maputaland loggerheads appear to use the higher sulphide concentrations along that particular stretch of coast as a chemical cue for nesting (Brazier 2012). Post-nesting females and hatchlings use natural ambient light to orientate towards the ocean (Bartol & Musick 2002). Artificial light, however, acts as deterrents for nesting females (Witherington 1992; Salmon 2003; Brazier 2012) and brightly lit beaches thus have reduced female emergences. In contrast, hatchlings are attracted to light even if the source is inland and may consequently suffer higher mortality rates due to desiccation and increased predation (Witherington & Bjorndal 1991; Salmon 2003).

Satellite tracking of female loggerhead and leatherback turtles during inter-nesting periods revealed that loggerheads remained close to the shore (within the boundaries of the iSimangaliso Wetland Park) between nesting events (Figure 6.10), whereas leatherbacks travelled greater distances (more than 300 km) and beyond the borders of the MPA. Consequently, a southward extension of the MPA has been proposed in order to include a greater portion of the core range of inter-nesting leatherbacks and provide better protection. These inter-nesting migrations, however, do not coincide with the proposed desalination plant marine infrastructure.

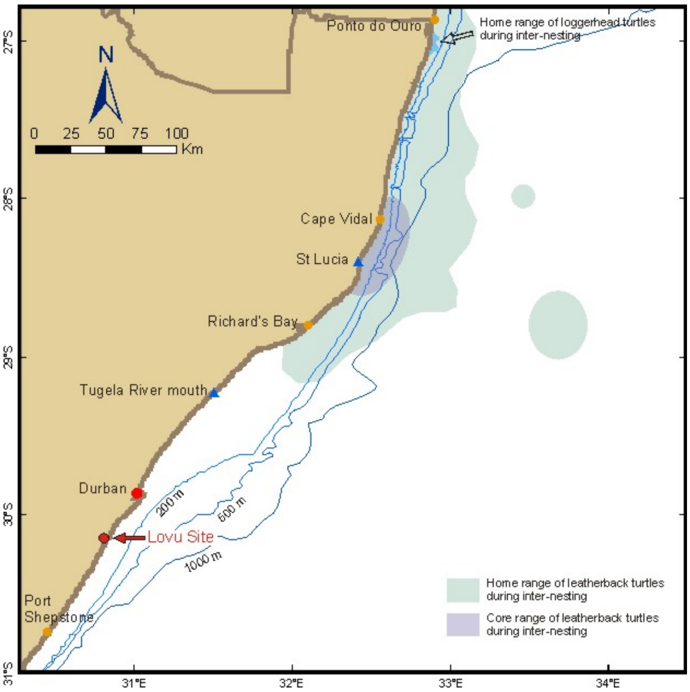

Figure 6.10: The home and core ranges of loggerheads and leatherbacks during inter-nesting relative to the proposed Lovu desalination plant site (DEAT, unpublished data).

Female turtles do not nest every year due to the high energetic costs of reproduction (Wallace & Jones 2008). During this remigration interval they travel thousands of kilometres (particularly leatherbacks) with ocean currents in search of foraging grounds (Luschi *et al.* 2003a; Luschi *et al.* 2003b). Turtles marked with titanium flipper tags have revealed that South African loggerheads and leatherbacks have a remigration interval of 2 – 3 years, migrating to foraging grounds throughout the

South Western Indian Ocean (SWIO) as well as in the eastern Atlantic Ocean. They follow different post-nesting migration routes (Hughes *et al.* 1998; Luschi *et al.* 2006), with loggerheads preferring to stay inshore whilst travelling northwards to foraging grounds along the southern Mozambican coastline or crossing the Mozambique Channel to forage in the waters off Madagascar. In contrast, leatherbacks move south with the Agulhas Current to deeper water in high-sea regions to forage (Hughes *et al.* 1998; Luschi *et al.* 2003b; Luschi *et al.* 2006), with some individuals following the Benguela Current along the West Coast of South Africa, as far north as central Angola (de Wet 2013).

The South African nesting populations of loggerhead and leatherback sea turtles have been actively protected since 1963 when an annual monitoring and conservation programme was established (Hughes 1996). During the more than 50 years of sea turtle conservation the loggerhead nesting population has increased exponentially from ~ 80 to approximately 700 individuals. The leatherback nesting population showed an initial increase from ~20 to approximately 80 individuals and has remained relatively stable over the last few decades.

This conservation programme is considered a global success story and has inspired the inception and persistence of numerous other programmes (Hughes 2012). Nonetheless, the extensive migrations undertaken by these species not only exposes them to threats such as becoming incidental bycatch in commercial and artisanal fisheries but makes protecting them from such potential threats very difficult.

In the IUCN Red listing, the leatherback and hawksbill turtles are described as “Critically Endangered”, the loggerhead and green turtles are “Endangered” and Olive Ridley is “Vulnerable” on a global scale. Leatherback Turtles are thus in the highest categories in terms of need for conservation in the Convention on International Trade in Endangered Species (CITES), and the Convention on Migratory Species (CMS). As a signatory of CMS, South Africa has endorsed and signed two sister agreements specific to the conservation and management of sea turtles (these are the Africa-Atlantic and Indian Ocean South East Asia Memoranda of Understanding). South Africa, as a nation, is therefore committed to the protection of all species of sea turtles occupying its national waters, whether they are non-resident nesters (loggerhead and leatherback turtles) or resident foragers (hawksbill and green turtles) (Oceans and Coast, unpublished data). In addition to sea turtle habitat and physical protection in the St. Lucia and Maputaland Marine Reserves, turtles in South Africa are protected under the Marine Living Resources Act (Act 18 of 1998).

6.4.3.1 Seabirds

Forty-six seabird species occur commonly along the KZN coast (Table 6.3). As the East Coast provides few suitable breeding sites for coastal and seabirds, only three species (Grey-headed gull, Caspian tern and Swift tern) breed regularly along the coast (CSIR 1998). Many of the river mouths and estuaries along the East Coast, however, serve as important roosting and foraging sites for coastal and seabirds birds, especially those at St Lucia and Richards Bay (Underhill & Cooper 1982; Turpie 1995).

6.4.3.2 Marine Mammals

The marine mammal fauna of the East Coast comprises between 28 and 38 species of cetaceans (whales and dolphins) known (historic sightings or strandings) or likely (habitat projections based on known species parameters) to occur here (Table 6.4) (Findlay 1989; Findlay *et al.* 1992; Ross 1984; Peddemors 1999), with seals occurring only occasionally in the form of vagrant Cape fur seals (*Arctocephalus pusillus pusillus*) (CSIR 1998). The offshore areas have been particularly poorly studied with almost all available information from deeper waters (>200 m) arising from historic whaling records. Information on smaller cetaceans in deeper waters is particularly poor.

Table 6.3: Resident and fairly-common to common visiting seabirds present along the KZN coast (from CSIR 1998).

Species name	Common name	Status
Diomedea exulans	Wandering albatross	Non-breeding winter visitor. Most abundant off continental shelf
Diomedea cauta	Shy albatross	Non-breeding winter visitor
Diomedea melanophris	Blackbrowed albatros	Non-breeding winter visitor
Diomedea chlororhynchos	Yellownosed albatross	Non-breeding winter visitor
Macronectes giganteus	Southern giant petrel	Non-breeding winter visitor
Macronectes halli	Northern giant petrel	Non-breeding winter visitor
Daption capense	Pintado petrel	Non-breeding visitor, mainly in winter
Pterodroma macroptera	Greatwinged petrel	Non-breeding winter visitor
Pterodroma mollis	Softplumaged petrel	Non-breeding visitor, mainly in winter
Pachyptila vittata	Broadbilled prion	Non-breeding visitor, mainly in winter
Procellaria aequinoctialis	Whitechinned petrel	Non-breeding visitor, mainly in winter
Calonectris diomedea	Cory's shearwater	Summer visitor
Puffinus gravis	Great shearwater	Summer vagrant
Puffinus griseus	Sooty shearwater	Non-breeding visitor, mainly in winter
Hydrobates pelagicus	European storm petrel	Non-breeding visitor, mainly in summer
Oceanodroma leucorhoa	Leach's storm petrel	Summer vagrant
Oceanites oceanicus	Wilson's storm petrel	Non-breeding visitor, common year round
Morus capensis	Cape gannet	Common, follows 'sardine run'
Stercorarius parasiticus	Arctic skua	Summer visitor from Palaearctic
Catharacta skua	Antarctic skua	Present all year, more abundant in winter
Larus dominicanus	Kelp gull	Year-round visitor from South & West Coast
Larus cirrocephalus	Greyheaded gull	Coastal breeding resident
Hydroprogne caspia	Caspian tern	Coastal breeding resident
Sterna bergii	Swift tern	Coastal breeding resident
Sterna paradisaea	Arctic tern	Summer visitor from Palaearctic
Sterna sandvicensis	Sandwich tern	Summer visitor from Palaearctic
Sterna bengalensis	Lesser crested tern	Visitor to the coast, mainly in summer
Sterna albifrons	Little tern	Palaearctic migrant, common in summer
Sterna hirundo	Common tern	Summer visitor from Palaearctic

The distribution of whales and dolphins on the East Coast can largely be split into those associated with the continental shelf and those that occur in deep, oceanic waters. Species from both environments may, however, be found associated with the shelf (200 – 1,000 m), making this the most species-rich area for cetaceans. Cetacean density on the continental shelf is usually higher than in pelagic waters as species associated with the pelagic environment tend to be wide-ranging across thousands of kilometres. The most common species within the study area (in terms of likely encounter rate not total population sizes) are likely to be the common bottlenose dolphin (Figure 6.11, left), common short-beaked dolphin (Figure 6.11, right), long-finned and short-finned pilot whale, southern right whale and humpback whale (Figure 6.12).

Figure 6.11: Toothed whales that occur on the East Coast include the Bottlenose dolphin (left) and the common short-beaked dolphin (right) (Photos: www.fish-wallpapers.com; www.pixshark.com).

Figure 6.12: The humpback whale (left) and the southern right whale (right) migrate along the East Coast during winter (Photos: www.divephotoguide.com; www.aad.gov.au).

Cetaceans comprised two basic taxonomic groups: the mysticetes (filter-feeding baleen whales) and the odontocetes (toothed predatory whales and dolphins). Due to large differences in their size, sociality, communication abilities, ranging behaviour and acoustic behaviour, these two groups are considered separately.

The majority of baleen whales fall into the family Balaenidae. Those occurring in the proposed project area include the Blue, Fin, Sei, Minke, Dwarf Minke, Bryde's, Pygmy Right, Humpback and Southern Right. Most of these species occur in pelagic waters, with only occasional visits into shelf waters. Humpbacks and Southern Rights, however, are likely to be encountered frequently inshore during winter months. All of these species show some degree of migration either to, or through, the proposed project area when *en route* between higher-latitude feeding grounds (Antarctic or Sub-Antarctic) and lower-latitude breeding grounds. Depending on the ultimate location of these feeding and breeding grounds, seasonality off South Africa can be either unimodal (usually in June-August, *e.g.* Minke and Blue whales) or bimodal (usually May-July and October-November, *e.g.* Fin whales), reflecting a northward and southward migration through the area.

Table 6.4: Cetaceans occurrence off the East Coast of South Africa, their seasonality and likely encounter frequency.

Common Name	Species	Shelf	Offshore	Seasonality	Likely encounter freq.	IUCN Conservation Status
Delphinids						
Common bottlenose dolphin	*Tursiops truncatus*	Yes	Yes	Year round	Monthly	Least Concern
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	Yes		Year round	Monthly	Data Deficient
Common (short beaked) dolphin	*Delphinus delphis*	Yes	Yes	Year round	Monthly	Least Concern
Common (long beaked) dolphin	*Delphinus capensis*	Yes		Year round	Monthly	Data Deficient
Fraser's dolphin	*Lagenodelphis hosei*		Yes	Year round	Occasional	Least Concern
Pan tropical Spotted dolphin	*Stenella attenuata*	Yes	Yes	Year round	Occasional	Least Concern
Striped dolphin	*Stenella coeruleoalba*		Yes	Year round	Occasional	Least Concern
Spinner dolphin	*Stenella longirostris*	Yes		Year round	Occasional	Data Deficient
Indo-Pacific humpback dolphin	*Sousa chinensis*	Yes		Year round	Monthly	Near Threatened
Short-finned pilot whale	*Globicephala macrorhynchus*		Yes	Year round	<Weekly	Data Deficient
Killer whale	*Orcinus orca*	Occasional	Yes	Year round	Occasional	Data Deficient
False killer whale	*Pseudorca crassidens*	Occasional	Yes	Year round	Monthly	Data Deficient
Risso's dolphin	*Grampus griseus*	Yes (edge)	Yes	Year round	Occasional	Data Deficient
Pygmy killer whale	*Feresa attenuata*		Yes	Year round	Occasional	Least Concern
Sperm whales						
Pygmy sperm whale	*Kogia breviceps*		Yes	Year round	Occasional	Data Deficient
Dwarf sperm whale	*Kogia sima*		Yes	Year round	Occasional	Data Deficient
Sperm whale	*Physeter macrocephalus*		Yes	Year round	Occasional	Vulnerable

Common Name	Species	Shelf	Offshore	Seasonality	Likely encounter freq.	IUCN Conservation Status
Beaked whales						
Cuvier’s	*Ziphius cavirostris*		Yes	Year round	Occasional	Least Concern
Arnoux’s	*Beradius arnouxii*		Yes	Year round	Occasional	Data Deficient
Southern bottlenose	*Hyperoodon planifrons*		Yes	Year round	Occasional	Not assessed
Hector’s	*Mesoplodon hectori*		Yes	Year round	Occasional	Data Deficient
Layard’s	*Mesoplodon layardii*		Yes	Year round	Occasional	Data Deficient
Longman’s	*Mesoplodon pacificus*		Yes	Year round	Occasional	Data Deficient
True’s	*Mesoplodon mirus*		Yes	Year round	Occasional	Data Deficient
Gray’s	*Mesoplodon grayi*		Yes	Year round	Occasional	Data Deficient
Blainville’s	*Mesoplodon densirostris*		Yes	Year round	Occasional	Data Deficient
Baleen whales						
Antarctic minke	*Balaenoptera bonaerensis*	Yes	Yes	>Winter	Monthly	Data Deficient
Dwarf minke	*B. acutorostrata*	Yes		Year round	Occasional	Least Concern
Fin whale	*B. physalus*		Yes	MJJ & ON, rarely in summer	Occasional	Endangered
Blue whale	*B. musculus*		Yes	MJJ	Occasional	Endangered
Sei whale	*B. borealis*		Yes	MJ & ASO	Occasional	Endangered
Bryde’s (inshore)	*B brydei (subspp)*		Yes	Year round	Occasional	Data Deficient
Pygmy right	*Caperea marginata*	Yes		Year round	Occasional	Least Concern
Humpback	*Megaptera novaeangliae*	Yes	Yes	AMJJASOND	Daily	Least Concern
Southern right	*Eubalaena australis*	Yes		JJASON	Daily	Least Concern

The most abundant baleen whales off the coast of South Africa are Southern Right and Humpback whales (Figure 6.12). Southern Rights migrate to the southern Africa subcontinent to breed and calve, where they tend to have an extremely coastal distribution mainly in sheltered bays (90% <2 km from shore; Best 1990, Elwen & Best 2004). Winter concentrations have been recorded all along the southern and eastern coasts of South Africa as far north as Maputo Bay, with the most significant concentration currently on the South Coast between Cape Town and Port Elizabeth. They typically arrive in coastal waters off the South Coast between June and November each year, although animals may be sighted as early as April and as late as January. While in local waters, Southern Rights are found in groups of 1-10 individuals, with cow-calf pairs predominating in inshore nursery areas. From July to October, animals aggregate and become involved in surface-active groups, which can persist for several hours.

Best (2000) estimated that Southern Right population was increasing at approximately 7% per annum. The most recent abundance estimate for the South African Southern right whale population (2008) puts the population at approximately 4,600 individuals of all age and sex classes, which is thought to be at least 23% of the original population size (Brandão *et al*. 2011).

The majority of humpback whales on the south and East Coasts of South Africa are migrating past the southern African continent. The main winter concentration areas for Humpback whales on the African East Coast include Mozambique, Madagascar, Kenya and Tanzania on the East Coast. Three principal migration routes for Humpbacks in the south-west Indian Ocean have been proposed. On the first route up the East Coast, the northern migration reaches the coast in the vicinity of Knysna continuing as far north as central Mozambique. The second route approaches the coast of Madagascar directly from the south, possibly *via* the Mozambique Ridge. The third, less well established route, is thought to travel up the centre of the Mozambique Channel to Aldabra and the Comore Islands (Findlay *et al*. 1994; Best *et al*. 1998). Humpbacks have a bimodal distribution off the East coast, most reaching southern African waters around April, continuing through to September/October when the southern migration begins and continues through to December. The calving season for Humpbacks extends from July to October, peaking in early August (Best 2007). Cow-calf pairs are typically the last to leave southern African waters on the return southward migration, although considerable variation in the departure time from breeding areas has been recorded (Barendse *et al*. 2010). Off Cape Vidal, whale abundances peak around June/July on their northward migration, although some have been observed still moving north as late as October. Southward moving animals on their return migration were first seen in July, peaking in August and continuing to late October (Findlay & Best 1996a, b).

Minke whales are present year-round with a large portion of this population consisting of small, sexually immature animals that primarily occur beyond 30 nautical miles from the coast during summer and autumn. Off Durban, Minke whales are reported to increase in numbers in April and May, remaining at high levels through June to August and peaking in September (Best 2007).

Two types of Bryde's whales are recorded from South African waters - a larger pelagic form described as *Balaenoptera brydei, and* a smaller neritic form (of which the taxonomic status is uncertain, but is included by Best (2007) with the *B. brydei* of the subregion). The migration patterns of Bryde's whales differ from those of all other baleen whales in the region as they are not linked to seasonal feeding patterns. The inshore population is unique in that it is resident year round on the Agulhas Bank only undertaking occasional small seasonal excursions up the East Coast during winter. Sightings over the last two decades suggest that its distribution may be shifting eastwards (Best 2007, 2001; Best *et al*. 1984). This is a small population, which may be decreasing in size (Penry 2010), suggesting that it is unlikely to be encountered in the proposed project area. The offshore form does not occur off the southern African East Coast.

Sei whales migrate through South African waters, where they were historically hunted in relatively high numbers, to unknown breeding grounds further north. Their migration pattern thus shows a bimodal peak with numbers on the East Coast highest in June (on the northward migration), and with a second larger peak in September. All whales were caught in waters deeper than 200 m with most deeper than 1,000 m (Best & Lockyer 2002). Almost all information is based on whaling records 1958-1963 and there is no current information on abundance or distribution patterns in the region.

Fin whales were historically caught off the East Coast of South Africa, with a unimodal winter (June-July) peak in catches off Durban. However, as northward moving whales were still observed as late as August/September, it is thought that the return migration may occur further offshore. The location of their winter breeding grounds remains a mystery (Best 2007). Some juvenile animals may feed year round in deeper waters off the shelf (Best 2007). There are no recent data on abundance or distribution of Fin whales off Southern Africa.

Blue whales were historically caught in high numbers off Durban, showing a single peak in catches in June/July. Sightings of the species in the area between 1968-1975 were rare and concentrated in March to May (Branch *et al.* 2007) and only from far offshore (40-60 nautical miles). However, scientific search effort (and thus information) in pelagic waters is very low. The chance of encountering blue whales in the project area is considered low.

All information about sperm whales in the southern African subregion results from data collected during commercial whaling activities prior to 1985 (Best 2007). Sperm whales are the largest of the toothed whales and have a complex, well-structured social system with adult males behaving differently from younger males and female groups. They live in deep ocean waters, occasionally coming into depths of 500-200 m on the shelf (Best 2007). Seasonality of catches off the East Coast suggest that medium- and large-sized males are more abundant during winter (June to August), while female groups are more abundant in summer (December - February), although animals occur year round (Best 2007). Although considered relatively abundant worldwide (Whitehead 2002), no current data are available on density or abundance of sperm whales in African waters. Sperm whales feed at great depth, during dives in excess of 30 minutes, making them difficult to detect visually.

There are almost no data available on the abundance, distribution or seasonality of the smaller odontocetes (including the beaked whales and dolphins) known to occur in oceanic waters off the shelf of eastern South Africa. Beaked whales are all considered to be true deep water species usually being seen in waters in excess of 1 000-2 000 m depth (see various species accounts in Best 2007). Their presence in the area may fluctuate seasonally, but insufficient data exist to define this clearly.

Two species of bottlenose dolphins occur around southern Africa, the smaller Indo-Pacific bottlenose dolphin (*aduncus* form), which occurs exclusively to the east of Cape Point in water usually less than 30 m deep and generally within 1 km of the shore (Ross 1984), and the larger common bottlenose dolphin (*truncatus* form), which on the East Coast occurs further offshore. Although their distribution is essentially continuous from Cape Agulhas eastwards to southern Mozambique, the Indo-Pacific bottlenose dolphins seem to have ‘preferred areas’ along the KZN coast (Ross *et al.* 1987; Ross *et al.* 1989; Cockcroft *et al.* 1990, 1991). The areas in which they are more frequently encountered are about 30 km apart, and are thought to correspond to discrete home ranges within a resident population occurring along the KZN coast. There are also seasonal movements of a genetically distinct ‘migratory stock’ of Indo-Pacific bottlenose dolphins into KZN waters in association with the ‘sardine run’ (Natoli *et al.* 2008). On average, 37 animals die annually as bycatch in the shark nets set along the KZN coast to protect bathers. Although listed as ‘Data deficient’ in the IUCN Red Data book, the *aduncus* form in general is listed as ‘Vulnerable’ in the South African Red Data Book, while the migratory subpopulation is considered ‘Endangered’ (Peddemors & Oosthuizen 2004).

Two species of common dolphin are currently recognised, the short-beaked common dolphin (*Delphinus delphis*) and the long-beaked common dolphin (*Delphinus capensis*). Although common dolphins occur world-wide in warm-temperate and tropical waters, off South Africa the short-beaked appear to prefer offshore habitats, whereas the long-beaked seems to be distributed as a series of disjunct populations in nearshore waters <500 m deep. During winter they migrate from the Eastern Cape into KZN waters following the 'sardine run' (Cockcroft & Peddemors 1990; O'Donoghue *et al.* 2010a, 2010b, 2010c), although sightings off KZN have also been made during summer. In 1988/89 the population of long-beaked common dolphins between Port Elizabeth and Richard's Bay was estimated at 15,000 – 20,000 animals, although this is thought to be an underestimate. As with the common bottlenose dolphins, an average of 39 animals die annually through entanglement in the shark nets (Best 2007). The species most likely to be encountered in the project area is the short-beaked common dolphin, but estimates of the population size and seasonality for the subregion is lacking.

The Indo-Pacific humpback dolphin has a more or less continuous distribution from Danger Point in the Western Cape to Mozambique, Tanzania, Kenya, the Comoros Islands and the western coast of Madagascar. It is primarily a shallow-water species restricted to <50 m depth. Localised populations in the Plettenberg Bay - Algoa Bay region are concentrated around shallow reefs, whereas those off Richard's Bay in KZN appear to prefer large estuarine systems. Seasonal movements and migrations are not characteristic of the species, but sightings rate and group size appears to increase between January and April, and again in September. The population off KZN is estimated at 160 individuals, with that for South Africa numbering no more than 1,000. The species is similarly caught accidentally in the shark nets, with on average 6.8 animals being killed annually, of which more than half were taken off Richard's Bay (Best 2007). There is considerable concern over the future of this species in the subregion resulting in it being listed as 'Vulnerable' in the South African Red Data Book (Peddemors *et al.* 2004), but 'Data deficient' by the IUCN. Encounters with this species in the project area is likely to be very low.In summary, the majority of data available on the seasonality and distribution of large whales in the proposed project area is largely the result of commercial whaling activities mostly dating from the 1960s. Changes in the timing and distribution of migration may have occurred since these data were collected due to extirpation of populations or behaviours (*e.g.* migration routes may be learnt behaviours). The large whale species for which there are current data available are the humpback and southern right whale, although with almost all data being limited to the continental shelf. Whaling data indicates that several other large whale species are also abundant on the South and East Coasts for much of the year: fin whales peak in May-July and October-November and sei whale numbers peak in May-June and again in August-October.

Of the migratory cetaceans, the Blue, Sei and Humpback whales are listed as "Endangered" and the Southern Right and Fin whale as "Vulnerable" in the IUCN Red Data book. All whales and dolphins are given protection under the South African Law. The Marine Living Resources Act, 1998 (No. 18 of 1998) states that no whales or dolphins may be harassed[1], killed or fished. No vessel or aircraft may approach closer than 300 m to any whale and a vessel should move to a minimum distance of 300 m from any whales if a whale surfaces closer than 300 m from a vessel or aircraft.

6.4.3.3 Marine Protected Areas

KZN boasts three Marine Protected Areas (MPAs). The Maputaland and St Lucia Marine Reserves form a continuous protected area stretching 150 km from the Mozambique border southwards to

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[1] In the Regulations for the management of boat-based whale watching and protection of turtles as part of the Marine Living Resources Act of 1998 the definition of "harassment" is given as "behaviour or conduct that threatens, disturbs or torments cetaceans".

Cape Vidal, and three nautical miles out to sea. They are components of the iSimangaliso Wetland Park. The MPA protects a large number of turtle nesting sites; the migration of whales, dolphins and whale-sharks offshore; and a considerable number of waterfowl associated with the iSimangaliso Wetland Park, including large breeding colonies of pelicans, storks, herons and terns. .

The Aliwal Shoal MPA is situated on the South Coast between Umkomaas and Ocean View. The northern boundary of the reserve is located ~ 10 km southwest of the Lovu site. The Aliwal Shoal MPA is 125 km^2 in size, approximately 18 km long and stretches ~4 nautical miles offshore. The Aliwal Shoal is especially known for its abundance of Grey nurse sharks that congregate there to mate between August and November. Further south lies the small Trafalgar Marine Reserve, which stretches for only 6 km along the KZN South Coast adjacent to the Mpenjati Nature Reserve, and extends 500 m offshore. This reserve, which primarily protects a petrified forest that is exposed in the intertidal zone at low tide, may be incorporated into the proposed Pondoland Marine Protected Area which (although still in the concept phase) would extend from southern KZN into the northern part of the Eastern Cape.

World Heritage Site

The iSimangaliso Wetland Park is recognised as a wetland of international importance under the Ramsar Convention and has been designated a World Heritage Site in terms of the World Heritage Convention Act (No. 49 of 1999). The iSimangaliso Wetland Park covers an area on 324 441 ha, including 230 km of coastline from Kosi Bay (bordering Mozambique) to south of Maphelane and three nautical miles out to sea. The Park is governed by the National Environmental Management Protected Areas Act (No. 57 of 2003). In terms of Section 50(5), no development is permitted in a World Heritage Site without prior written approval from the management authority, namely iSimangaliso Wetland Park Authority.

Proposed Marine Biodiversity Protection Areas

Through systematic biodiversity planning to identify a potential offshore MPAs network, a number of priority areas have identified off KZN for the protection of benthic and pelagic habitats and their associated biodiversity, protected species, and bycatch management in the prawn-trawl fishery (Harris *et al.* 2011; Sink *et al.* 2011; Ezemvelo KZN Wildlife 2012). Twenty-three focus areas have been identified (Table 6.5, Figure 6.13 and Figure 6.14), with the species targeted for protection in each area being detailed in Ezemvelo KZN Wildlife (2012). Most of these focus on estuaries and shoreline areas, but some offshore areas have been identified. As one of its strategic objectives, Ezemvelo aim to identify and submit priority focus areas to the Department of Environmental Affairs to achieve the 8% inshore and 3% offshore targets required within an MPA by 2013. The proposed MPA (Figure 6.14) covers an area of ~6,421 km^2 and will include a sanctuary zone in which no extraction or resource use will be permitted, surrounded by a controlled-use zone in which limited fishing and usage will be permitted. Although not yet formally declared, applicants for any future activities along the KZN coast should keep these areas in mind as extractive use within these areas is likely to be limited.

Table 6.5: Proposed focus areas for additional marine biodiversity protection along the KZN coast (Ezemvelo KZN Wildlife 2012).

Focus Area Number	Area	Description
1	iSimangaliso Wetland Park extension	Offshore extension of iSimangaliso
2	Cape St Lucia Area	Southern extension of iSimangaliso
3	Tugela Banks Area	Soft Sediment habitat
4	Zinkwazi Estuary and shoreline area	Zinkwazi Estuary and shoreline areas
5	Mhlali estuary and shoreline	Mhlali Estuary and southern shoreline area
6	KZN Bight	Offshore area near continental shelf edge of the KZN Bight
7	Beachwood Mangroves	Shoreline area near Beachwood Mangroves, and incorporating Umgeni River mouth shoreline
8	Durban	Subtidal area off of the Durban
9	Bluff Area	Subtidal area off of the Bluff
10	KZN Bight	Offshore area in southern section of KZN Bight
11	iSipingo	iSipingo estuary and northern shoreline
12	Karridene	Shoreline area south of Karridene between the Msimbazi and Mgababa Rivers
13	Aliwal Shoal	Shoreline and subtidal areas within Aliwal Shoal
14	Umdoni	Shoreline area between Umdoni Park and Bazley beach
15-19	Hibiscus Coast	Shoreline areas along the Hibiscus coast
20-23	Offshore areas	Offshore areas in the south and north of the planning area

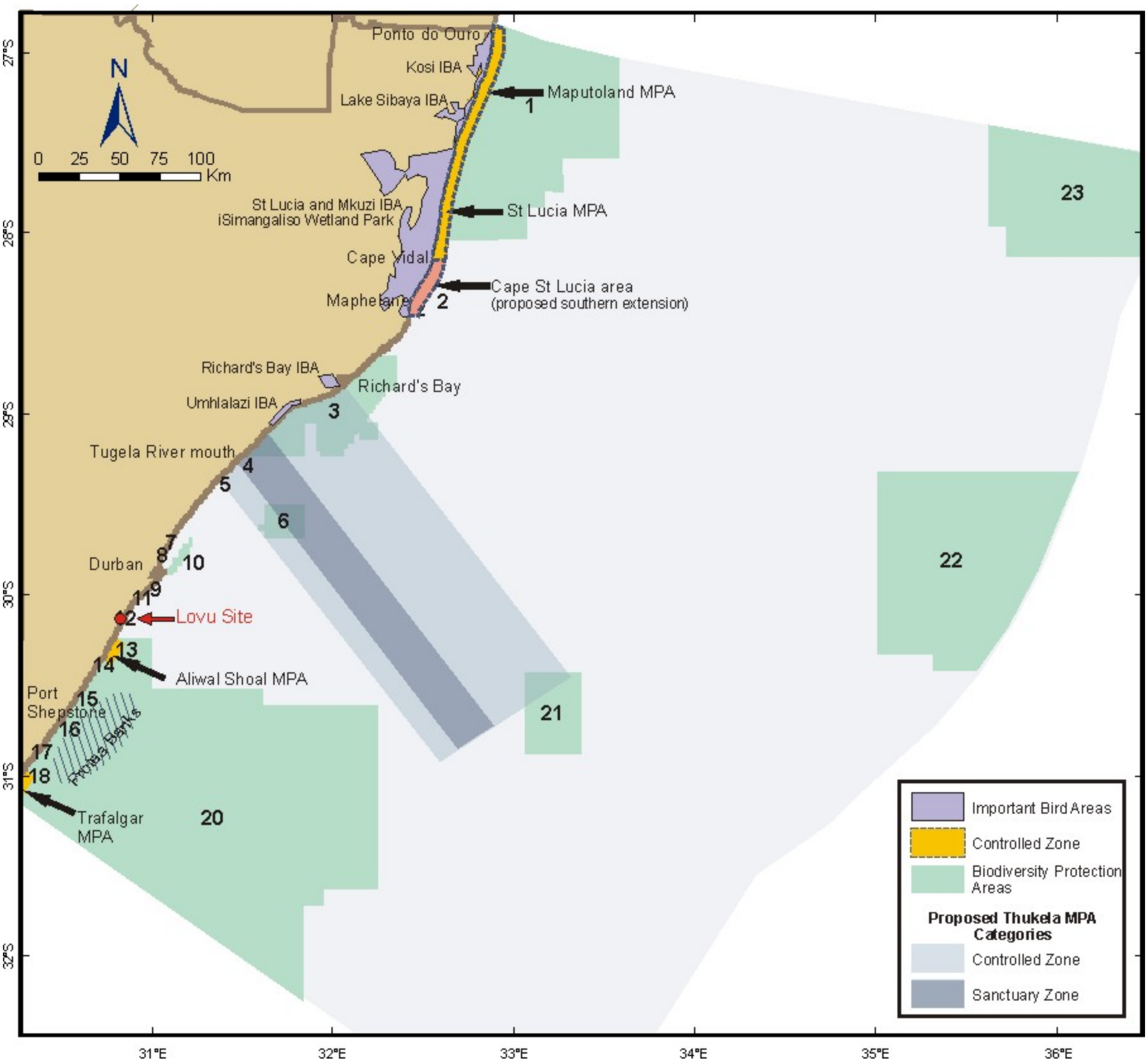

Figure 6.13: Marine Protected Areas, Important Bird Areas (IBAs), proposed biodiversity protection areas and the proposed Thukela Marine Protected Area (MPA) within the Exclusive Economic Zone off the KZN coast in relation to the proposed Lovu SWRO Plant site. The numbers represent the various biodiversity focus areas provided in Table 6.5.

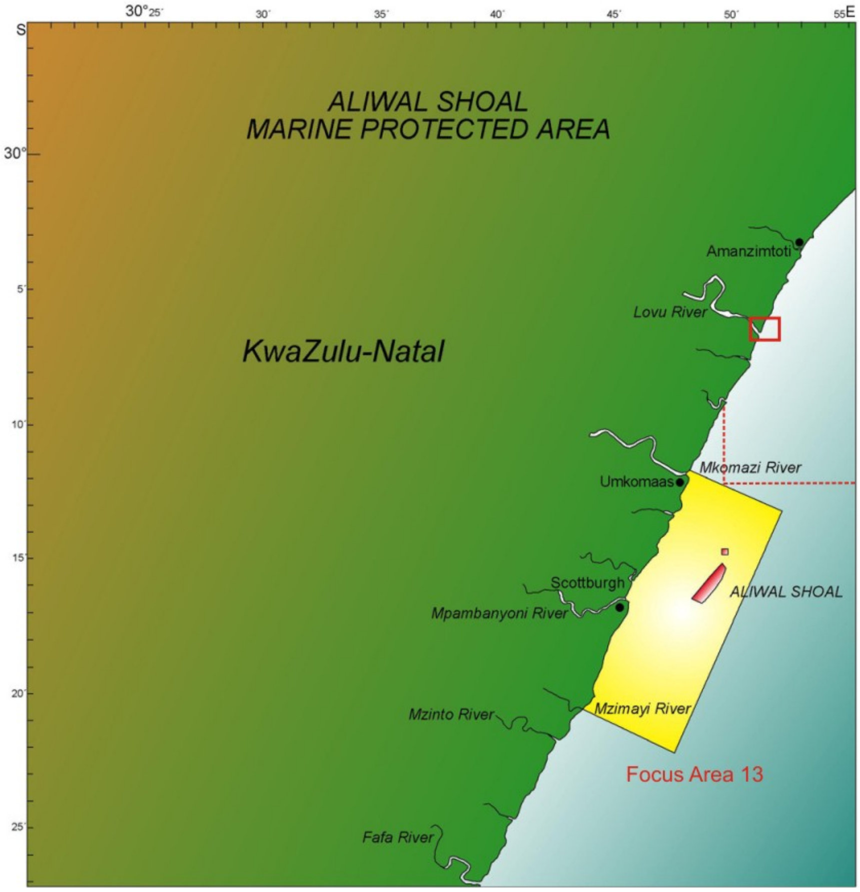

Figure 6.14: Marine Protected Areas and biodiversity protection focus areas in the vicinity of the proposed Lovu site (red rectangle).

6.4.4 Fisheries

KZN Prawn Trawl Fishery

A number of larger crustacean species form the basis for a small multispecies trawl fishery on the shallow water mud banks along the north East Coast of KZN. The fishery targets various commercial penaeid prawn species, particularly white prawn (80% of prawn catch), brown prawn and tiger prawn. The shallow water component targets the muddy/sandy inshore regions (5-40 m depth and within 10 nautical miles of the shore) of the Tugela Bank and at St Lucia in an area of roughly 500 km^2 (Figure 6.15). The catch composition typically comprises 20% prawn species, while approximately 10% of the remainder of the catch is also retained for its commercial value and includes crab, octopus, squid, cuttlefish and linefish. The remainder of the catch is discarded because of perceived low commercial value (Fennessy & Groeneveld 2003; M&CM 2007). To minimize high bycatch levels, a seasonal closure of the Tugela Bank grounds is enforced. Trawlers thus only operate within the inshore grounds during March to August. Activity shifts northwards towards St Lucia during summer months, where the fishery targets bamboo prawns (*Penaeus japonicus*) in addition to the previously mentioned species.

The prawn species on which the inshore fishery is based are fast-growing and short-lived (~1 year), and dependent on estuarine environments during the early phase of their life cycle. Juveniles move out of estuaries in January and start recruiting onto the mud banks (and into the fishery) from February onwards, where they subsequently mature and reproduce (Wilkinson & Japp 2010). Abundance of these crustaceans varies seasonally and is strongly dependent on recruitment from estuaries and river discharges (M&CM 2007).

Further offshore, at 100 - 600 m depth between Amanzimtoti and Cape Vidal, the deep water fishery targets pink and red prawns, langoustines, Natal rock lobster and red crab. Offshore trawling takes place year-round. Catches are packed and frozen at sea and landed at the ports of Richards Bay or Durban. The KZN prawn trawl fishery is comparatively small, with landed catches worth approximately R21 million per annum (M&CM 2005).

The KZN prawn trawler fleet comprises steel-hulled vessels ranging in length from 25 – 40 m and up to a Gross Registered Tonnage (GRT) of 280 tons. Most vessels are single otter trawlers, deploying nets from the stern or side at a speed of two to three knots. Tickler chains may be used. Trip lengths range from three to four weeks. Trawl net sizes range from 25 m to 72 m footrope length, with a minimum mesh size of 60 mm. The duration of a typical trawl is four hours (Wilkinson & Japp 2010).

The fishery is managed using a Total Applied Effort (TAE) strategy, which limits the number of vessels permitted to fish on the inshore and offshore grounds. A TAE of seven fishing permits was issued for 2007. In the 2008 season there were five vessels operating within the inshore grounds with another two vessels restricted to working in the offshore grounds only (Wilkinson & Japp 2010).

Commercial and Recreational Linefishery

The highly diverse ichtyofauna along the KZN coastline form the basis of the commercial and recreational linefishery, which operates within two major fishing areas; a narrow zone of scattered reefs along the 50 m isobath and along deeper reefs south of Durban and north of the Tugela River (100 – 200 m) (Penney *et al.* 1999 in Atkinson & Sink 2008) (Figure 6.16). Fishing techniques consist of hook and line deployments, with up to 10 hooks per line. Fishing vessels range up to a maximum of 20 nautical miles offshore. The line-fishery also includes subsistence and recreational sectors.

Pelagic Longline

The large pelagic longline fishery operates extensively within the South African Exclusive Economic Zone (EEZ) targeting primarily tuna and other migratory tuna-like species and billfishes. Being migratory stocks they are managed as a “shared resource” amongst various countries. There are currently 50 commercial large pelagic fishing rights issued and 31 longline vessels active in the fishery. The fishery operates extensively from the continental shelf break (500 m contour) into deeper waters, all year-round. Activity is especially concentrated where the continental slope is steepest. The vessels are typically 30 – 54 m in length, using monofilament mainlines of up to 40 nautical miles in length. These are suspended 20 m below from the water surface from buoys and marked at each end. Baited hooks are attached to the mainline via 20 m long trace lines, thereby targeting fish at a depth of 40 m below the surface. Up to 1 500 hooks may be set per line. Lines are usually set at night and hauled in the next morning. However, lines may be left drifting for a considerable length of time. They are retrieved by means of a powered hauler at a speed of approximately one knot, during which time the vessel’s manoeuvrability is severely restricted (Wilkinson & Japp 2010).

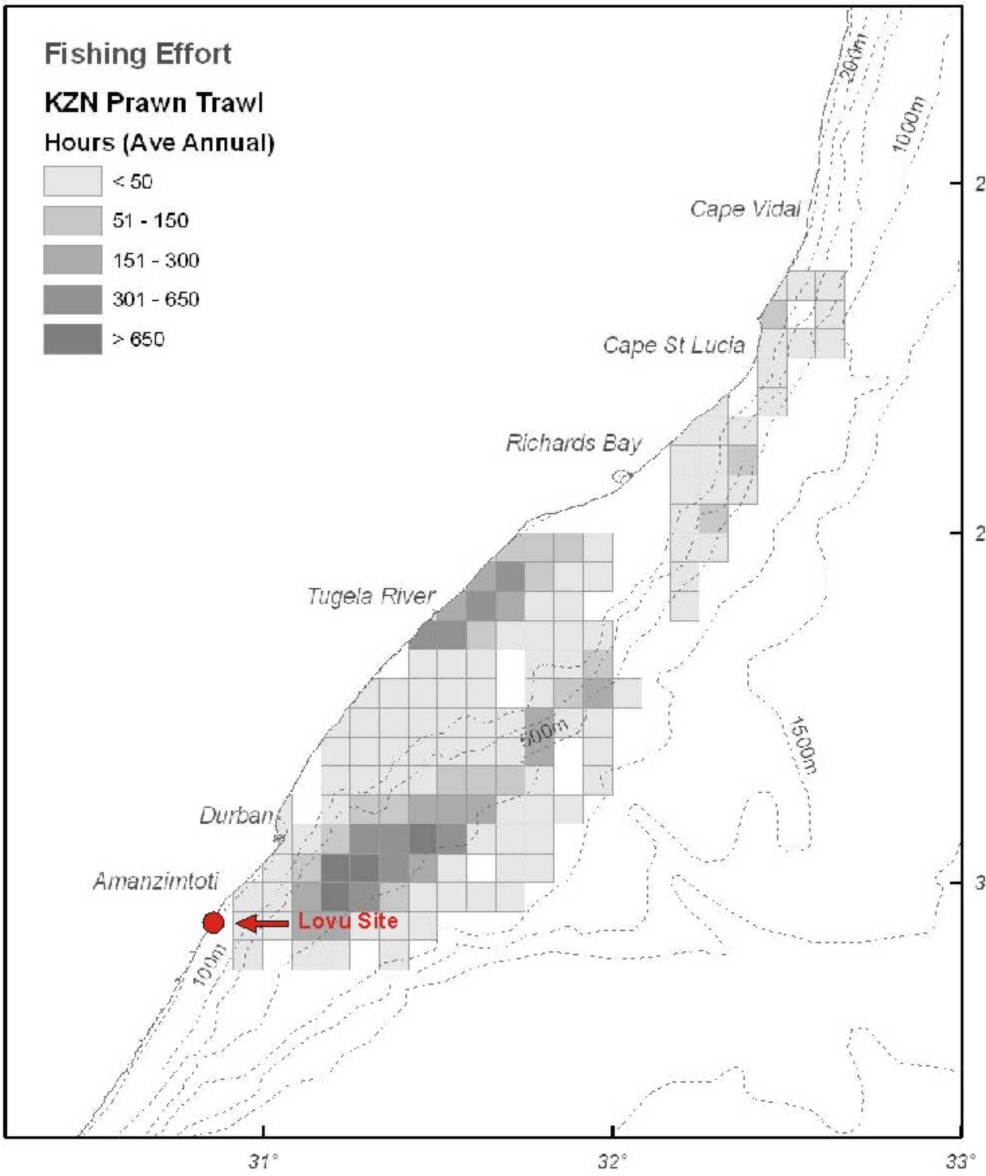

Figure 6.15: Distribution of KZN prawn trawl fishing effort in relation to the proposed project area (adapted from Wilkinson & Japp 2010).

Shore-based Linefishery

Shore angling is the most common form of linefishing in KZN (Fennessey *et al.* 2010). While most angling activity is recreational, it is probable that subsistence fishing has become increasingly important, or at least more recognised over recent years. A wide range of fish species is targeted and harvested with at least some degree of overlap occurring with species targeted in the boat fisheries (Figure 6.1).

Other fisheries

Although attracting far fewer participants than linefishing, two other fishery based activities on the KZN coast are worth noting, as these rely upon water quality safe to swim in, as well as supportive of the targeted fisheries species. They are a recreational spear-fishery and crayfish fishery. Both are however more prevalently practised north of Durban where the coast is rockier and more reef habitat exists.

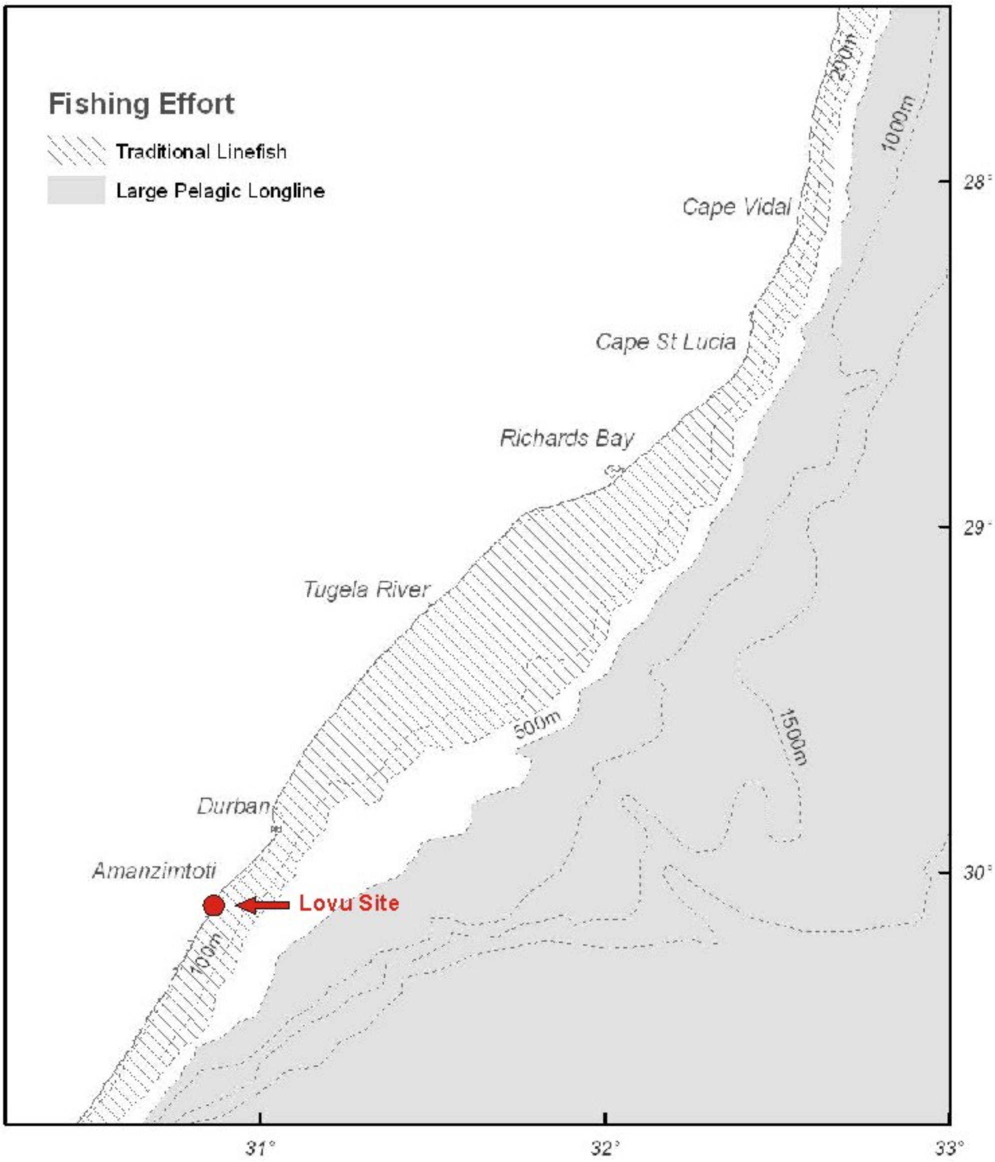

Figure 6.16: Distribution of traditional linefish and pelagic longline fishing effort in relation to the proposed project area (adapted from Wilkinson & Japp 2010).

6.4.5 Recreation

Marine waters in KZN are used for a variety of full contact recreational activities which underpin a significant social benefits and tourism value. These include swimming, snorkelling and SCUBA diving, board sports (*e.g.* surfing, kite boarding), paddling and sailing. These activities all inherently rely on good marine water quality. In this respect the Lovu site is on a densely populated part of the KZN coast and lies in reasonably close proximity to beaches that attract significant usage for full contact recreational activities. Probably of most relevance near Lovu are the Winkelspruit, Warner and Amanzimtoti beaches, which are well-used family beaches where swimming and board sports are favoured.

6.4.6 Marine Outfalls

The exposed nature of the KZN coast, dynamic current regime and high assimilative capacity render it attractive for use as a wastewater disposal resource. There are several outfalls along the section of coast from Richards Bay in the north to Umkomaas in the south (Figure 6.17). Most pertinent here are those operated by Sappi Saiccor, Huntsman Tioxide and Heartland Leasing, and eThekwini Municipality. The Sappi Saiccor outfall discharges effluent from a cellulose mill into marine waters about 40 m deep, approximately 6.5 km off the Mkommas River just over 10 km south of the Lovu site. Industrial effluent from the Umbogintwini Industrial Complex, a similar distance north of the Lovu site, is discharged via outfalls operated by Huntsman Tioxide and Heartland Leasing. These outfalls, adjacent to one another, are in shallower waters (26 to 32 m, 1.5 km and 1.8 km offshore respectively). The shorter outfall carries waste (largely organic) that arises from a variety of processes within the Umbogintwini Industrial Complex. The longer outfall is dedicated to wastewater generated by Huntsman Tioxide in the manufacture of pigments. It is an ‘acid-iron’ effluent characterised by a low pH and the presence of a suite of metals. Further north still, and in significantly deeper waters are two outfalls owned and operated by eThekwini Municipality. These discharge domestic and industrial wastewaters to the marine environment. The Southern Works outfall is roughly 20 km north of the Lovu mouth and discharges in depths between 55 and 60 m, while the Central Works is roughly 20 km north of the Lovu mouth (~25 km south of the Mdloti) and discharges in depths between 45 and 50 m.

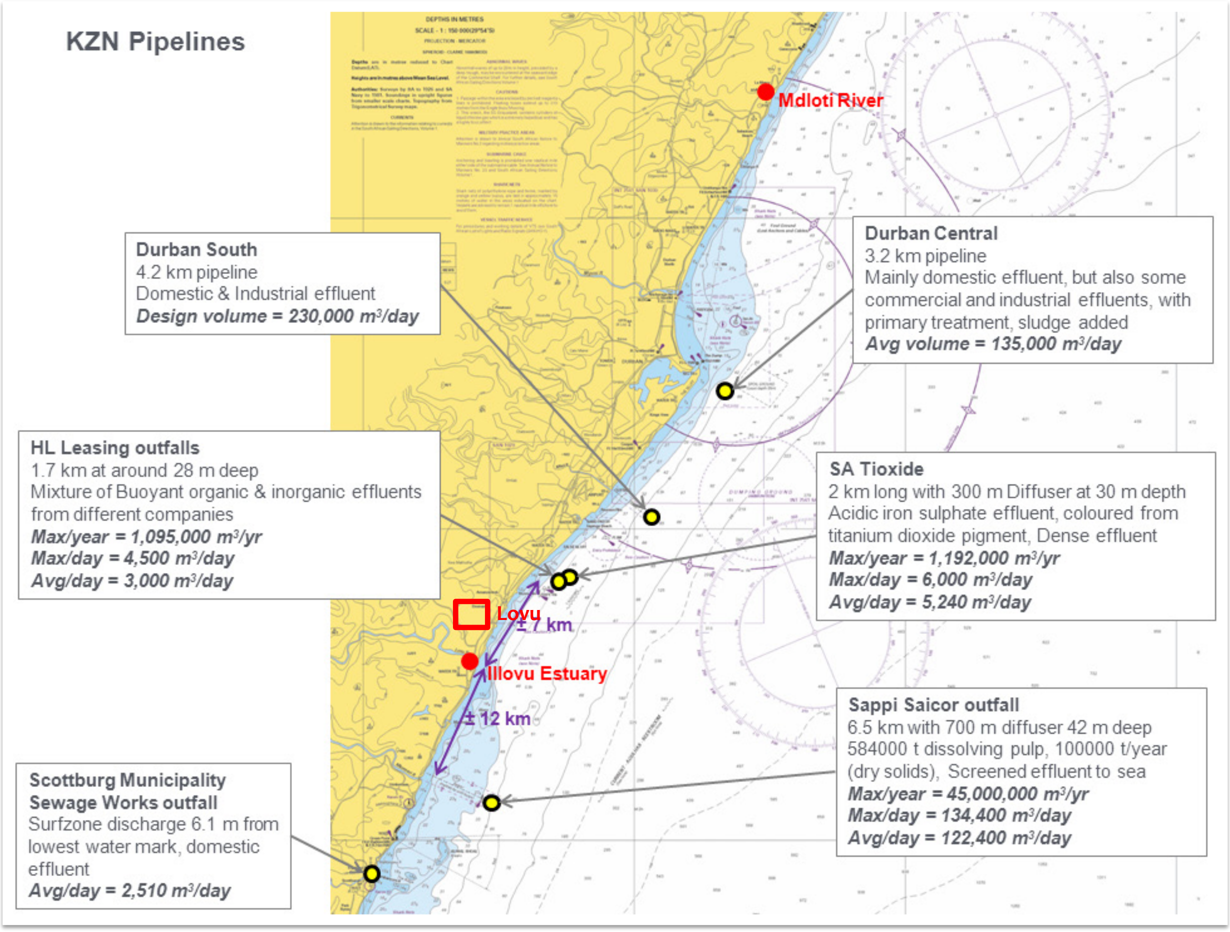

Figure 6.17: Location of marine outfalls in the project area and description of the discharges (Source: Aurecon 2012). The red square indicates the location of the proposed Lovu RO Plant.

6.5 IDENTIFICATION OF KEY ISSUES AND SOURCES OF POTENTIAL ENVIRONMENTAL IMPACT

In the course of the environmental screening process for the proposed SWRO Plant, key issues were identified relating to potential impacts on the marine environment. These are briefly summarised below in terms of the construction, commissioning, operation and decommissioning phase, and then discussed in more detail later in this report.

6.5.1 Construction Phase

The potential impacts associated with the construction of feed-water intake and brine discharge structures in the marine environment are related to:

- Onshore construction (human activity, air, noise and vibration pollution, dust, blasting and piling driving, disturbance of coastal flora and fauna and other users of the coastal environment); and
- Construction and installation of offshore pipeline intakes and discharge (construction site, pipe lay-down areas, and trenching in the marine environment, vehicular traffic on the beach and consequent disturbance of intertidal and subtidal biota).

The proposed SWRO plant at Lovu, including the pump stations, will be constructed at appropriate set-back distances from the existing shorelines. Consequently, issues associated with the location of the plant and pump station and the associated pipelines leading to and from these constructions are not deemed to be of relevance to the marine environment, and will not be discussed further here. However, infrastructure extending into the sea will potentially impact on intertidal and shallow subtidal biota during the construction phase in the following ways:

- Temporary loss of benthic habitat and associated communities due to preparation of seabed for buried pipeline laying and associated activities (*e.g.* temporary jetty, ;
- Possible temporary short-term impacts on habitat health due to turbidity generated during construction;
- Temporary disturbance of marine biota, particularly marine mammals, due to construction activities (blasting and piling driving);
- Interruption of longshore sediment movement by sheet piling and jetty structure resulting in increased erosion and/or accretion around the construction site;
- Possible impacts to marine water quality and sediments through hydrocarbon pollution by marine construction infrastructure and plant; and
- Potential contamination of marine waters and sediments by inappropriate disposal of spoil and/or surplus rock from construction activities or backfilling, used lubricating oils from marine machinery maintenance and human wastes, which could in turn lead to impacts upon marine flora, fauna and habitat.

6.5.2 Commissioning Phase

Once construction has been completed, it will take 6-12 months to commission the new desalination plant. During the commissioning phase, seawater will be pumped into the plant at up to peak production rates. However, any fresh water produced will be combined with the brine and discharged. As the discharge will have a salinity equivalent to that of normal seawater, it will not have an environmental impact during the commissioning phase.

It may be necessary to discard the membrane storage solution and rinse the membranes before plant start-up. If the storage solution contains a biocide or other chemicals potentially harmful to marine life and this solution is discharged to the sea, local biota and water quality may be affected.

6.5.3 Operational Phase

The key issues and major potential impacts are mostly associated with the operational phase. The key issues related to the presence of pipeline infrastructure and brine discharges into the marine environment are:

- Altered flows at the intake and discharge resulting in ecological impacts (*e.g.* entrainment and impingement of biota at the intake, flow distortion/changes at the discharge, and affects on natural sediment dynamics);
- Potential for habitat health impacts/losses resulting from elevated salinity in the vicinity of the brine discharge;
- The effect of the discharged effluent potentially having a higher temperature than the receiving environment;
- Biocidal action of residual chlorine (or other alternative biocides) in the effluent;
- The effects of co-discharged constituents and suspended solids in the effluent;
- The removal of particulate matter from the water column where it is a significant food source, as well as changes in phytoplankton production due to changes in nutrients, reduction in light, water column structure and mixing processes; and
- Direct changes in dissolved oxygen content due to the difference between the ambient dissolved oxygen concentrations and those in the discharged effluent, and indirect changes in dissolved oxygen content of the water column and sediments due to changes in phytoplankton production as a result of nutrient input.

Additional engineering design considerations, not strictly constituting issues to be considered within this marine specialist study, include the following:

- Structural integrity of the intake and outfall pipelines (*e.g.* related to shoreline movement);
- Potential impacts associated with the momentum transfer from the discharge and/or the discharge structure itself;
- Potential re-circulation of brine effluent;
- Pipeline maintenance and replacement requirements; and
- Water quality of feed waters that should include consideration of possible deteriorating water quality (particularly sediments that may be stirred up during storms, or large-scale hypoxia in bottom waters), that may require specific mitigation measures or planned flexibility in the operations of the SWRO Plant.

During the scoping phase and public consultation process, the following additional engineering design and operational issues relevant to the marine environment were raised by Interested and Affected Parties:

- flexibility is required in the engineering design and/or the operating procedure should monitoring identify significant negative impacts beyond the sacrificial zone.
- a synopsis of the results of studies conducted elsewhere during the operation of plants of similar size to that proposed, and in similar environments should be included.

6.5.4 Decommissioning Phase

The minimum anticipated life of the SWRO plant is at least 25 years. The individual RO modules will be replaced as and when required during this period. No decommissioning procedures or restoration plans have been compiled at this stage, as it is envisaged that the plant will be refurbished rather than decommissioned after the anticipated 25 year lifespan. In the case of decommissioning the pipelines will most likely be left in place. The potential impacts during the decommissioning phase are thus expected to be minimal in comparison to those occurring during the operational phase, and no key issues related to the marine environment are identified at this stage. As full decommissioning will require a separate EIA, potential issues related to this phase will not be dealt with further in this report.

6.6 ASSESSMENT OF ENVIRONMENTAL IMPACTS

The sources of potential impacts and key issues identified in terms of the construction, commissioning, and operational phases of the proposed SWRO plant relating to potential risks to the marine environment are discussed in detail and assessed below.

6.6.1 Construction of Intake and Discharge Structures

Construction phase impacts are summarised in Table 6.6 and discussed below:

6.6.1.1 Disturbance of the Coastal Zone

The use of intake and discharge pipelines in the engineering designs for the SWRO Plant would involve considerable disturbance of the high-shore, intertidal and shallow subtidal beach habitats during the pipeline construction and installation process. The intake and outfall points of the desalination plant pipelines will be located below the low water mark, beyond the surf zone at depths of 15-20 m.

Offshore, the pipelines at Lovu would be placed on the seabed and with time would settle into the sandy substrate. Where they cross the surf zone, the pipelines would be buried beneath the lowest expected depth of seasonal beach and nearshore erosion to avoid exposure of the pipes and/or damage by wave forces in the surf zone. This would ensure that the pipes are not visible from the beach and would not interrupt the longshore sand movement that occurs in the nearshore zone. The depth of burial would decrease with distance offshore but with sufficient cover to prevent the pipe being exposed by erosion occurring during a one in 100 year storm. Onshore, the pipes would be buried and run underground into the pump station. Installation of the pipelines would require excavation of beach sediments and possible blasting of bedrock, both onshore and offshore. Individual pipeline sections fabricated by the supplier would be transported to site, thus requiring a sufficiently large and relatively flat onshore area (immediately inland of the final pipeline position) where the pipes can be stockpiled and prepared, before being fed down the shore and positioned in the trench. Alternatively, the pipelines may be pre-assembled and floated into position from the seaward side.

The exact offshore construction methodology will be determined at the engineering design phase. If the pipelines are floated into position, once they are in place, the air would be released from the pipes allowing them to fill with water and sink to the bottom. Concrete weight collars would be placed at intervals around the offshore portion of the pipes to provide stability on the seabed.

Trenching of the pipelines through the surf zone would require that a temporary jetty extending from the base of the foredunes to approximately 300-400 m offshore would be constructed to provide a stable platform from which a trench can be excavated. The jetty would comprise two lines of steel piles supporting a steel framework, thereby enabling cranes, dredges and other equipment to operate seaward of the low water mark. For safety reasons, there would be no public access to the jetty, and the beach within a specified distance either side of the jetty would be closed for the period of construction. A marine exclusion zone north and south of the offshore pipeline(s) construction area would also be in place during construction. The presence of the jetty structure in the surf zone would interrupt longshore sediment movement resulting in increased erosion and/or accretion around the construction site. Excavation of the bedrock to a suitable depth to accommodate the pipeline may also require blasting. The trench would be protected from infilling by wave action by rows of sheetpiles. The pipes are then to be placed in the trench and subsequently buried by earth-moving machinery. Excavated material would be disposed of into the surf zone off the side of the jetty and down-current of the construction site.

The beach sediments would be completely turned over (or removed) during the construction process and the associated macrofauna would almost certainly be entirely eliminated. Similarly, the physical removal of sediments or bedrock in the trench would result in the total destruction of the associated benthic biota. Mobile organisms such as fish and marine mammals, on the other hand, would be capable of avoiding the construction area and should therefore not be significantly affected by the excavation activities (unless blasting is involved). Any shorebirds feeding and/or roosting in the area would be disturbed and displaced for the duration of construction activities.

The invertebrate macrofaunal species inhabiting these beaches are all important components of the detritus / beach-cast seaweed-based food chains, being mostly scavengers, particulate organic matter and filter-feeders (Brown & McLachlan 1994). As such, they assimilate food sources available from the detritus accumulations typical of this coast and, in turn, become prey for surf zone fishes and migratory shorebirds that feed on the beach slope and in the swash zone. By providing energy input to higher trophic levels, they are all important in nearshore nutrient cycling, and the reduction or loss of these assemblages may therefore have cascade effects through the coastal ecosystem (Dugan *et al.* 2003). Whilst the construction activities associated specifically with the proposed SWRO desalination plant are unlikely to have a significant effect at the ecosystem level, the cumulative effects of increasing development along those stretches of coast must be kept in mind.

Despite this unavoidable disturbance of the intertidal and shallow subtidal habitats, the activities would remain localised and confined to within a hundred metres of the construction site. Provided the construction activities are all conducted concurrently, the duration of the disturbance should be limited to about two years. Studies on the disturbance of beach macrofauna communities have ascertained that, provided physical changes to the beach morphology are kept to a minimum, and sediment characteristics on the beach are not severely altered, recolonisation following the cessation of disturbance can occur within weeks (Schoeman *et al.* 2000), with recovery to a condition of functional similarity to the original state occurring after two to seven months (Nelson 1985, 1993; Hackney *et al.* 1996). Full recovery of the benthic community and age structure is considered to take between two and five years (USACE 1989; Kenny & Rees 1994, 1996; Rakocinski *et al.* 1996; Essink 1997; Van Dalfsen & Essink 1997; van Dalfsen *et al.* 2000; Nel *et al.* 2003; Newell *et al.* 2004; Pulfrich *et al.* 2004; Boyd *et al.* 2005; Mulder *et al.* 2005; Baptist *et al.* 2009). Biomass therefore often remains reduced for several years. Disturbed subtidal communities within the wave base (<40 m water depth) might recover even more quickly (Newell *et al.* 1998).

6.6.1.2 Pollution and Accidental Spills

Pipeline launching and entrenchment and land-based jetty construction would involve extensive traffic on the beach by heavy vehicles and machinery. There would thus be potential for or accidental spillage or leakage of fuel, chemicals or lubricants, litter, inappropriate disposal of human wastes and general degradation of ecosystem health. Any release of liquid hydrocarbons has the potential for direct, indirect and cumulative effects on the marine environment through contamination of the water and/or sediments. These effects include physical oiling and toxicity impacts to marine fauna and flora, localised mortality of plankton, pelagic eggs and fish larvae, and habitat loss or contamination (CSIR 1998; Perry 2005). Many of the compounds in petroleum products have been known to smother organisms, lower fertility and cause disease in aquatic organisms. Hydrocarbons are incorporated into sediments through attachment to fine dust particles, sinking and deposition in low turbulence areas. Due to differential uptake and elimination rates filter-feeders particularly mussels can bioaccumulate organic (hydrocarbons) contaminants (Birkeland *et al.* 1976).

Concrete work will be required in the intertidal and shallow subtidal zones during construction and installation of the pipelines. As cement is highly alkaline, wet cement is strongly caustic, with the setting process being exothermic. Excessive spillage of cement in the intertidal area may thus potentially increase the alkalinity of the water column with potential sub-lethal or lethal effects on marine organisms.

During construction (and also during operation), litter can enter the marine environment. Inputs can be either direct by discarding garbage into the sea, or indirectly from the land when litter is blown into the water by wind. Marine litter is a cosmopolitan problem, with significant implications for the environment and human activity all over the world. Marine litter travels over long distances with ocean currents and winds. It originates from many sources and has a wide spectrum of environmental, economic, safety, health and cultural impacts. It is not only unsightly, but can cause serious harm to marine organisms, such as turtles, birds, fish and marine mammals. Considering the very slow rate of decomposition of most marine litter, a continuous input of large quantities will result in a gradual increase in litter in coastal and marine environment. Suitable waste management practices should thus be in place to ensure that littering is avoided.

6.6.1.3 Increased Turbidity

Excavating operations would result in increased suspended sediments in the water column and physical smothering of macrofauna by the discarded sediments. The effects of elevated levels of particulate inorganic matter and depositions of sediment would have marked, but relatively predictable effects on the composition and ecology of intertidal and shallow subtidal benthic communities (*e.g.* Zoutendyk & Duvenage 1989, Engledow & Bolton 1994, Iglesias *et al.* 1996, Slattery & Bockus 1997). Increased suspended sediments in the surf zone and nearshore can potentially affect light penetration and thus phytoplankton productivity and algal growth, and could also load the water with inorganic suspended particles thereby affecting the feeding and absorption efficiency of filter-feeders.

The impact of the sediment plume, however, is expected to be relatively localised and of short duration (only for the duration of construction activities below the low water mark). As the biota of sandy and rocky intertidal and subtidal habitats in the wave-dominated nearshore areas of southern Africa are well adapted to high suspended sediment concentrations, periodic sand deposition and resuspension, impacts are expected to occur at a sub-lethal level only.

Rapid deposition of material from the water column and direct deposition of excavated sands on adjacent areas of seabed would have more of an impact on the benthic community due to smothering effects, than gradual sedimentation to which benthic organisms are adapted and able to respond. However, this response depends to a large extent on the nature of the receiving community as some mobile benthic animals inhabiting soft-sediments are capable of migrating vertically through more than 30 cm of deposited sediment (Maurer *et al*. 1979, 1981a, b, 1982; Newell *et al.* 1998; Ellis 2000). In contrast, sedentary communities could potentially be adversely affected by both rapid and gradual deposition of sediment. Sand inundation of reef habitats was found to directly affect species diversity whereby community structure and species richness appears to be controlled by the frequency, nature and scale of disturbance of the system by sedimentation (Seapy & Littler 1982, Littler *et al*. 1983, Schiel & Foster 1986, McQuaid & Dower 1990, Santos 1993, Airoldi & Cinelli 1997 amongst others). For example, frequent sand inundation may lead to the removal of grazers thereby resulting in the proliferation of algae (Hawkins & Hartnoll 1983; Littler *et al*. 1983; Marshall & McQuaid 1989; Pulfrich *et al.* 2003a, 2003b).

Once the pipeline has been laid and sufficient sediment has accumulated, the affected seabed areas would, with time, be recolonised by benthic macrofauna. The ecological recovery of the disturbed sea floor is generally defined as the establishment of a successional community of species, which progresses towards a community that is similar in species composition, population density and biomass to that previously present (Ellis 1996). In general, communities of short-lived species and/or species with a high reproduction rate (opportunists) may recover more rapidly than communities of slow growing, long-lived species. Opportunists are usually small, mobile, highly reproductive and fast growing species and are the early colonisers. Sediments in the nearshore wave-base regime, which are subjected to frequent disturbances, are typically inhabited by these opportunistic species (Newell *et al.* 1998). Recolonisation would start rapidly after cessation of trenching, and species numbers may recover within short periods (weeks) whereas the biomass often remains reduced for several years (Kenny & Rees 1994, 1996).

6.6.1.4 Pile-driving and Blasting

During jetty construction and pipeline trenching operations, noise and vibrations from pile-drivers, and excavation machinery may have an impact on surf zone biota, marine mammals and shore birds in the area. Noise levels during construction are generally at a frequency much lower than that used by marine mammals for communication (Findlay 1996), and these are therefore unlikely to be significantly affected. Additionally, the maximum radius over which the noise may influence is very small compared to the population distribution ranges of surf zone fish species, and resident cetacean species. Both fish and marine mammals are highly mobile and should move out of the noise-affected area (Findlay 1996).

Trenching of the pipeline may require blasting as the sand cover on the beach thins out into the surf zone. As details of the probable blast levels, blasting practice and duration of the blasting required to ensure adequate depth for the sump and suitable burial of the pipeline have not yet been provided, the assessment that follows is generic only. Impacts on the receiving biota can only be confidently graded once blast-effect zones have been calculated. Effects of underwater blasting on marine organisms have received extensive coverage in formal peer-reviewed scientific literature (see Lewis 1996 and Keevin & Hempen 1997 for references), as well as in various assessments for seismic surveys, underwater construction and weapons testing. The following impact description is based on two reviews on the subject provided in Lewis (1996) and Keevin & Hempen (1997).

Explosives generate chemical energy, which is released as physical, thermal, and gaseous products. The most important of these for marine organisms is the physical component which passes into the surrounding medium as a shock wave. Depending on the blasting practice, some of the energy may escape into the water column, and it is this shock wave that is the primary cause of damage to aquatic life at, or some distance from, the shot point. Thermal energy dissipation, in contrast, is generally limited to the immediate vicinity (<10 m) of the exploding material, and in shallow water gaseous products produce minor shock wave amplitudes.

The nature of the shock wave generated by the blast depends on the type of explosive used. Relatively low energy explosives such as black powder are slow burning and produce a shock wave with a shallow rise height. Dynamite and other high explosives have a rapid detonation velocity and produce a more abrupt shock wave. Consequently, high explosives have more dramatic effects on marine organisms.

Two damage zones are associated with an underwater explosion:

- An immediate kill zone of relatively limited extent, but within which all animals are susceptible to damage through disruption of their body tissues by the pressure wave generated by the explosion; and
- A more extensive remote damage zone in which damage is caused by negative pressure pulses, generated when the compression wave is reflected from an air-water interface. The negative pulses act on gas bodies within the organism inducing injuries such as haemorrhaging and contusions of the gastro-intestinal tract (mammals and birds) or rupture of swim bladders in fish.

Lewis (1996) and Keevin & Hempen (1997) provide information on blast effects on a variety of shallow water (<10 m) organisms. Appendix A provides a summary of these effects focussing on the marine macrophytic algae, major invertebrate macrofaunal taxa, fish, turtles and marine mammals that may occur in the blast area off the proposed SWRO plant site.

From this summary, the following can be determined:

- Any effects on macrophytes through blasting would be limited to the immediate vicinity of the charges;
- Marine invertebrates appear to be relatively immune to blast effects in terms of obvious injury or mortalities, suggesting that any blast effects are likely to remain confined to the immediate area of blasting;
- In fish, the swim bladder is the organ most frequently damaged by blasting, potentially leading to high mortality in the immediate area of blasting. In contrast, fish species that do not possess swim bladders seem to be largely immune to underwater explosions. Eggs and fish larvae may also be affected by underwater explosions, but impact ranges seem to be restricted to the immediate vicinity of the blasting. Although injury or mortality of fish and/or their eggs and larvae in the immediate area of the blasting is likely to occur, the probability of the blasting programme having a measurable effect at the population level on fish in the study area is judged to be unlikely, as surf zone and nearshore species along the KZN coastline are widely distributed;
- The limited information available on blasting effects on swimming and diving birds suggests that mortality occurs primarily within the immediate vicinity (< 10 m) of the blast;
- Effects on sea turtles may occur up to a distance of 1 km from the underwater explosion. As turtles occur primarily to the north of the study area, numbers in the shallow nearshore regions off Lovu are expected to be low; and

- Similar to fish, injuries to marine mammals generated by underwater explosions is primarily trauma of various levels to organs containing gas and mortality, which can occur in the immediate area around the blasting. Small cetaceans, sharks and scavenging birds may, however, be attracted to the blasting area by stunned and dead fish following a blast. Although occurring in the study area, whales are infrequent visitors in the shallow nearshore regions, being more common further offshore. However, various dolphin species occur in shallow waters (<50 m) (Table 6.4) and could be vulnerable to detonations. However, cognisance should be taken of the public sensitivity to injury to cetaceans and turtles as a result of blasting.

It is recommended that the area around the blasting site be visually searched before blasting commences and to postpone the blasting should a marine mammal, turtle or flocks of swimming and diving birds be spotted within a 2-km radius around the blasting point. If pratical, blasting should also be scheduled so as to avoid cetacean migration periods or winter breeding concentrations (beginning of June to end of November), and turtle migration and breeding periods (October to end of February). Alternatively, the blasting protocol should include additional mitigation measures such as possibly bubble curtains, acoustic harassment devices or acoustic deterrent devices to warn away species to the presence of danger or small charges (fishing salutes) before the blast to scare away any animals in the area, a watch plan for observers stationed throughout the safety zone (determined based on overpressure calculations), etc. The blasting programme should also be scheduled to allow scavengers feeding on dead fish to have left the area before the next blasting event.

The implementation of Passive Acoustic Monitoring (PAM) is recommended before blasting as a mitigation tool to detect marine mammals through their vocalisations, ***particularly as species of conservation importance are likely to be encountered in the area*** (see Table 6.4), or where a given species or group is difficult to detect by visual observation alone. Such monitoring can provide distance and bearing of the animals from the blast area. Although PAM would only identify animals that are calling or vocal, it has the advantage of 24 hour per day availability as opposed to visual monitoring, which can only be confidently carried out during daylight hours, or under adequate visibility conditions. Ideally, blasting should be restricted to one blast per day during daylight. The probability of the proposed blasting programme having a measurable effect on turtles or marine mammals in the study area is unlikely if these recommendations are strictly adhered to.

6.6.1.5 Installation of Structures

Installation of the intake structure and pipeline would effectively eliminate any (sandy or rocky) biota in the structural footprint, and reduce the area of seabed available for colonisation by marine benthic communities. The loss of substratum as a result of the offshore intake and brine pipelines would, however, be temporary, as the structures them selves would provide an alternative substratum for colonising communities. Assuming that the hydrographical conditions around the structures would not be significantly different to those on the seabed, a similar community to the one on the rocky seabed can be expected to develop. Should the pipelines, however, be located primarily on unconsolidated sediments, biota developing on the structures would be significantly different from the original soft sediment macrobenthic communities. These structures are likely to be left in place on the seabed beyond decommissioning of the plant, and their impacts would thus extend to the post-closure phase.

The composition of the fouling community on artificial structures depends on the age (length of time immersed in water) and the composition of the substratum, and usually differs from the communities of nearby natural rocky reefs (Connell & Glasby 1999; Connell 2001). Colonization of hard substratum goes through successional stages (Connell & Slayter 1977). Early successional communities are characterized by opportunistic algae (*e.g. Ulva* sp., *Enteromorpha* sp.). These are eventually displaced by slower growing, long-lived species such as mussels, sponges and/or coralline algae, and mobile organisms, such as urchins and lobsters, which feed on the fouling community. With time, a consistent increase in biomass, cover and number of species can usually be observed (Bombace *et al.* 1994; Relini *et al.* 1994; Connell & Glasby 1999). Depending on the supply of larvae and the success of recruitment, the colonization process can take up to several years. For example, a community colonizing concrete blocks in the Mediterranean was found to still be changing after five years with large algae and sponges in particular increasing in abundance (Relini *et al.* 1994). Other artificial reef communities, on the other hand, were reported to reach similar numbers of species (but not densities and biomass) to those at nearby natural reefs within eight months (Hueckel *et al.* 1989).

As the pipelines will be trenched below the seabed where they cross the surf zone (and possibly for some further distance offshore) they should not in any way hinder the longshore movement of juvenile or adult fish inhabiting the surf zone or shallow inshore areas. Juvenile surf zone fish can show a remarkably high site fidelity (~100 m along a beach, Ross & Lancaster 2002), but there is also evidence that they might make parallel movements along-shore seeking lower energy runnels for feeding or refuge (Layman 2000).

6.6.1.6 Mitigation Measures

The recommended mitigation measures for the construction phase of the proposed SWRO Plants are:

- Restrict disturbance of the intertidal and subtidal areas to the smallest area possible.
- Lay pipeline in such a way that required rock blasting is kept to a minimum.
- Keep heavy vehicle traffic associated with pipeline construction on the beach to a minimum.
- Restrict vehicles to clearly demarcated access routes and construction areas only. These should be selected under guidance of Ezemvelo KZN Wildlife and the local municipality.
- Conduct a comprehensive environmental awareness programme amongst contracted construction personnel, emphasising compliance with relevant provincial and national legislation and the EMP, pollution control and minimising construction impacts to the intertidal habitat and associated communities.
- For equipment maintained in the field, oils and lubricants must be contained and correctly disposed of off-site.
- Maintain vehicles and equipment to ensure that no oils, diesel, fuel or hydraulic fluids are spilled.
- Vehicles should have a spill kit (peatsorb/ drip trays) onboard in the event of a spill.
- No mixing of concrete in the intertidal zone.
- Regularly clean up concrete spilled during construction.
- No dumping of construction materials, excess concrete or mortar in the intertidal and subtidal zones or on the sea bed.
- Ensure regular collection and removal of refuse and litter from intertidal areas.
- Good housekeeping must form an integral part of any construction operations on the beach from start-up.
- All construction activities in the coastal zone must be managed according to a strictly enforced Environmental Management Plan.
- All blasting activities should be conducted in accordance with recognised standards and safety requirements.

- Use blasting methods which minimise the environmental effects of shock waves through the use of smaller, quick succession blasts directed into the rock.
- Restrict blasting to the absolute minimum required (one blast event per day).
- Avoid onshore blasting during the shore bird breeding season.
- Undertake visual observation prior to blasting to ensure there are no marine mammals and turtles present in the immediate vicinity (approximately 2-km radius). Blasting should only commence once the species have moved out of the impact zone.
- Consider the use of a Passive Acoustic Monitoring (PAM) system to detect the presence of small cetaceans in the impact area prior to blasting.

If these mitigation measures are implemented, all residual impacts are expected to be of low significance with the exception of impacts on subtidal sandy biota, macrophytes, invertebrates and fish communities associated with blasting, which would remain of medium significance.

Table 6.6: Impacts to the marine environment associated with the Construction Phase of the proposed SWRO desalination plant at Lovu.

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
Construction Phase											
1.1. Disturbance and destruction of beach macrofauna during pipeline construction as a result of vehicular traffic, jetty construction, and excavations	**Negative**	**Site Specific,** i.e. within the immediate area of pump station and jetty construction area (1)	**Short,** beach biota is expected to recover within 2-3 years (2)	**Medium,** as sandy biota in the construction footprint will be destroyed (4)	**Definite,** construction is unavoidable if the project is approved (1)	**Reversible** as beach communities will recovery within the short term	**Low**	**Medium (7)**	- Restrict traffic on upper beach to minimum required, - Restrict traffic to clearly demarcated access routes and construction areas only, - Good house-keeping and active rehabilitation following completion of construction activities.	**Low,** since any mitigation measures will reduce the impacts further and rehabilitation will speed-up the recovery of beach biota	**High**
1.2. Accidental spillage or leakage of fuel, chemicals, or lubricants may cause water or sediment contamination and/or disturbance to beach and subtidal biota	**Negative**	**Site Specific,** i.e. within the immediate area of pump station and jetty construction area (1)	**Short,** potentially affected biota is likely to recover in 2-3 years (2)	**High,** hydrocarbons are highly toxic (8)	**Probable,** if 'good-house-keeping' measures are not in place (0.5)	**Reversible** as beach communities will recover within the short term	**Low**	**Medium (5.5)**	- Have good house-keeping practices in place, - Maintain vehicles and equipment to ensure that no oils, diesel, fuel or hydraulic fluids are spilled, - For equipment maintained in the field, oils & lubricants to be contained & correctly disposed of off-site, - Construction vehicles to have a spill kit (peatsorb/ drip trays) onboard in the event of a spill.	**Low,** since good house-keeping measures will reduce the risk of spills	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
1.3. Disturbance and destruction of subtidal sandy biota during pipeline laying, jetty construction, surf-zone excavation and rock blasting	**Negative**	**Site Specific,** i.e. within the immediate area of the pipeline route (1)	**Short,** subtidal sandy biota is expected to recover in 2-3 years (2)	**Medium,** as affected sandy biota will be destroyed (4)	**Definite,** construction is unavoidable if the project is approved (1)	**Reversible** as beach communities will recovery within the short term	**Low**	**Medium** (7)	- Restrict disturbance of the sea bottom to the smallest area possible, - Lay pipeline in such a way that required rock blasting is kept to a minimum, - Active rehabilitation of sandy subtidal substrate is not required as sediment redistribution will be fast in the turbulent surf zone, - Rehabilitation of rocky reefs is not possible but exposed pipeline will serve as new hard-bottom substrate.	**Medium,** since no mitigation measure will eliminate the need for rock blasting or decrease the associated impact magnitude	**High**
1.4. Increased turbidity in surf-zone as a result of excavations and mobilising of sediments	**Negative**	**Local,** within a couple of hundred meters to a few (< 5 km) kilometres (2)	**Temporary,** construction is likely to continue over a 6-12 month period but increased turbidity is expected to last only for a couple of hours to a few days after cessation of excavation activities (1)	**Low,** surf-zone is turbulent and suspended sediment concentra-tions are naturally elevated (1)	**Definite,** construction is unavoidable if the project is approved (1)	**Reversible** over the very short term as plumes will be ephemeral only	**Low**	**Low** (4)	- No mitigation possible other than the no-project alternative	**Low**	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
1.5. Deposition of excavated sediments in the surf-zone will smother benthic communities on both unconsolidated and hard substrata down-current of the construction site	**Negative**	**Local,** within a couple of hundred meters to a few (< 5 km) kilometres (2)	**Temporary,** the surf and wave influenced (<40 m) zone is turbulent and redistribution of deposited sediments will be fast (1)	**Low,** surf-zone is turbulent and suspended sediment concentra-tions are naturally elevated (1)	**Definite,** construction is unavoidable if the project is approved (1)	**Reversible** over the very short term as deposited sediments will be constantly resuspended	**Low**	**Low (4)**	- No mitigation possible other than the no-project alternative	**Low**	**High**
1.6. Disturbance and avoidance behaviour of surf-zone fish communities, shore birds and marine mammals through pylon driving and construction noise	**Negative**	**Local,** within a couple of hundred meters to a few (< 5 km) kilometres (2)	**Temporary,** construction is likely to continue over a 6-12 month period (1)	**Low,** relatively exposed coastline, with moderate densities of shore birds and resident and migratory cetaceans further offshore (2)	**Highly probable** (0.75)	**Reversible** over the very short term as blast/noise impacts will have primarily nuisance value	**Low**	**Low (3.75)**	- No direct mitigation possible, other than to restrict vibration-generating activities to the absolute minimum required - No on shore blasting during breeding season	**Low**	**High**
1.7. Effects of blasting on macrophytes, invertebrates and fish communities	**Negative**	**Site Specific to Local** (2)	**Temporary,** construction is likely to continue over a 6-12 month period (1)	**Medium to High,** most phyla will only be affected in the immediate blasting zone and only fish with swim bladders are more susceptible (8)	**Highly probable** (0.75)	**Reversible** over the very short term as blast/noise impacts will have primarily nuisance value	**Low**	**Medium (8.25)**	- No direct mitigation possible, other than to restrict blasting to the absolute minimum required (one blast per day). - Use blasting methods which minimise the environmental effects of shock waves through the use of smaller, quick succession blasts directed into the rock. - Avoid onshore blasting during the breeding season of shore-birds.	**Medium,** mitigation measures may reduce the frequency of blasting but will not eliminate the need for blasting	**Medium,** blasting schedule (extent and frequency) not known at this stage

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
1.8. Effects of blasting on turtles and marine mammals.	**Negative**	**Local,** within a couple of hundred meters to a few (< 5 km) kilometres (2)	**Temporary,** construction is likely to continue over a 6-12 month period (1)	**Medium,** Exposed open coastline with a wide surf-zone. Resident and migratory cetaceans present further offshore (4)	**Highly Probable** (0.75)	**Reversible** over the very short term as blast/noise impacts will have primarily nuisance value	**Low**	**Medium (5.25)**	- No direct mitigation possible, other than to restrict blasting to the absolute minimum required (one blast per day). - Use blasting methods which minimise the environmental effects of shock waves through the use of smaller, quick succession blasts directed into the rock. - Potential use of bubble curtains - Visual observation limiting blasting to periods when there are no marine mammals present in the immediate vicinity (approximately 2-km radius).	**Low,** mitigation measures will reduce the risk of marine mammals being affected by blasting	**Medium,** blasting schedule (extent and frequency) not known at this stage

6.6.2 Commissioning Phase

Once construction has been completed, it will take some months to commission the new desalination plants. During the commissioning phase, seawater will be pumped into the plant at up to peak production rates. However, any fresh water produced will be combined with the brine and discharged. As the discharge will have a salinity equivalent to that of normal seawater, there will be no significant risk to the marine environment during the commissioning phase.

It may be necessary to discard the membrane storage solution and rinse the membranes before plant start-up. If the storage solution contains a biocide or other chemicals, which may be harmful to marine life and this solution is discharged to the sea, local biota and water quality may be affected. These potential impacts will be discussed in the following section and will not be dealt with separately here.

6.6.3 Operational Phase

The key issues and major potential impacts are mostly associated with the operational phase. The key issues related to the presence of pipeline infrastructure and brine discharges into the marine environment are discussed briefly below, and are summarised in Table 6.9.

6.6.3.1 Feedwater Quality

In determining viable engineering design options for the source water, the main objectives should be to abstract seawater of adequate quantities and of suitable quality to produce desalinated water cost effectively and with minimal impact on the environment. The source water quality analysis undertaken as part of the proposed Lovu SWRO plant as described by Voutchkov (2013) is summarised below.

The quality of the source water may be impacted by:

- **Algal blooms/Red Tide events**, which occur periodically off the KZN coastline in the summer, may result in an increase in algae content of up to 40,000 algal cells/ml. As a result, intake turbidity could increase to up to 15 NTU, total organic carbon (TOC) concentration may increase to 6 mg/l and total suspended solids concentrations may reach 30 mg/l. One or more sequential blooms may occur annually, with each event lasting 6 to 8 weeks during which time the source seawater would have an apparent colour and odour.
- **Wastewater Treatment Plant Discharges**: during heavy rains the feedwater intake in either location is expected to be influenced by freshwater inputs from nearby rivers. The catchment area of the Lovu River receives discharges from wastewater treatment plants. The main anthropogenic contaminants that could reach the plant's intake are heavy metals (*i.e.* copper) and pathogens. Although not as yet detected by source water quality analyses, hydrocarbon contamination from either wastewater treatment plants or from surface runoff also cannot be excluded.
- Increased river runoff during storm events will result in an elevation of **alluvial organics** in the surface waters of the river discharge plume, whereas an **increase in suspended sediment concentrations** in bottom waters occurs in response to resuspension of sediments during rough seas.

At Lovu the best water quality was observed at a depth of 15 m and 1,000 m from shore (Voutchkov 2013. Source water quality variables are provided in Table 6.7.

Table 6.7: Key source water quality variables for the Lovu area.

Parameter	Value
Temperature, °C	19.7 – 21.5
Salinity, psu	35.3 – 35.5
Turbidity, NTU	0.3-4.5
Total Suspended Solids (TSS), mg/l	2 - 24
Chlorophyll a, µg/l	0.28 – 3.40
Total Organic Carbon (TOC), mg/l	< 0.5
pH, Units	8.2
Total Hydrocarbons, mg/l	Non-detectible
Ammonia, TKN, NO_3, Phosphates, mg/l	Non-detectible
Copper, µg/l	3.2
Nickel, µg/l	Non-detectible
Barium, µg/l	5.6
Strontium, µg/l	6.5
Other Heavy Metals	Non-detectible
Volatile Organic Compounds	Non-detectible
Fecal Coliforms, cfu/100 ml	3.3
Total Coliforms, cfu/100 ml	6.4
E. coli, cfu/100 ml	2.9
Fecal *Streptococcus*, cfu/100 ml	9.7
Heterotrophic Plate Count, cfu/100 ml	36.9

6.6.3.2 Impingement and Entrainment

Intake of water directly from the ocean through the submerged intake structure at the end of the intake to the pump station will result in loss of marine species as a result of impingement and entrainment. Impingement refers to injury or mortality of larger organisms (*e.g.* fish, jellyfish, turtles) that collide with and are trapped by intake screens, whereas entrainment refers to smaller organisms that slip through the screens and are taken into the plant with the feedwater. Impingement mortality is typically due to suffocation, starvation, or exhaustion due to being pinned up against the intake screens or from the physical force of jets of water used to clear screens of debris. The significance of impingement is related primarily to the location of the intake structure and is a function of intake velocity. The reduction of the average intake velocity of the feedwater to about 0.1 to 0.15 m/s, which is comparable to background currents in the oceans, will allow mobile organisms to swim away from the intake under these flow conditions (UNEP 2008). The intake of large quantities of seawater may also affect water circulation, especially in areas that are characterized by weak natural currents and waves. However, the use of velocity caps will also drastically reduce this risk.

While using screens and velocity caps reduces the impingement caused by open water intakes, entrainment effects are likely to remain, as most of the entrained organisms are too small to be screened out without significantly reducing the intake water volume. Entrained material includes holoplanktic organisms (permanent members of the plankton, such as copepods, diatoms and bacteria) and meroplanktic organisms (temporary members of the plankton, such as juvenile shrimps and the planktonic eggs and larvae of invertebrates and fish). Mortality rates in SWRO plants are likely to be 100% since the seawater is forced, at high pressure, through filters or membranes to remove particles, including the small organisms that are taken in with the feedwater. Furthermore, the feedwater will be treated with a biocide specifically designed to eliminate and kill entrained biota. The significance of entrainment is related both to the location of the intake, as well as the overall volume of feedwater required.

The mortality caused by entrainment may affect the productivity of coastal ecosystems, but effects are difficult to quantify (UNEP 2008; WHO 2007). Although planktonic organisms show temporal and spatial variations in species abundance, diversity and productivity, it can be assumed that the common native species will be prevalent in coastal surface areas. Furthermore, plankton species have rapid reproductive cycles. Due to these circumstances it seems unlikely that the operation of a desalination facility will have a substantial negative effect on the ability of plankton organisms to sustain their populations. The entrainment of eggs and larvae from common invertebrate and fish species is also unlikely to adversely affect the ability of these species to successfully reproduce. The reproduction strategy of these species is to produce a large number of eggs and larvae, of which only a small percentage reaches maturity due to natural mortality (such as starvation of larvae or failure to settle in a suitable location). For example, an entrainment study for a SWRO Pilot Plant in San Francisco Bay showed that the estimated effects of fish larvae entrainment were minimal and indicated little potential for population-level effects (Tenera Environmental 2007).

The proximity of intakes to estuary mouths potentially increases the significance of entrainment. Estuaries are important nurseries for many marine-spawned fishes and crustaceans, and larvae and juveniles of these species are likely to be concentrated in the vicinity of estuary mouths during critical recruitment periods.

The question is whether entrainment causes a significant additional source of mortality, which may have a substantial negative effect on the ability of a species to sustain its population, *i.e.* cumulative effects such as the existence of other nearby seawater intakes. While it is relatively simple to quantify the levels of entrainment for a specific project, it is difficult and complex to estimate the actual ecosystem impacts, especially when cumulative effects with other projects may occur. Cumulative impacts of entrainment and entrapment are usually only an issue in cases where multiple plants are developed in bays or inlets where water exchange is somewhat reduced. On an open coastline, cumulative impacts are generally unlikely; however, given the absence of information on entrainment and entrapment rates of the existing and proposed plants, actual ecosystem effects remain difficult to estimate. It is therefore recommended that an entrainment study be undertaken to assess the actual entrainment and impingement rates.

An issue of potential concern in large-volume intakes, such as that proposed for this project, is the removal of particulate matter from the water column, where it is a significant source of food for surf zone and nearshore communities (UNEP 2008; WHO 2007). Although the effects are difficult to quantify, this is unlikely to be of significance in the study area, as the surf zone is particularly productive, and particulate organic matter frequently accumulates on the beach as foam and scum.

Algal blooms negatively impact source water quality and may result in elevated organics in the source water and accelerated biofouling of RO installations. Red tides may result in the release of algal toxins of small molecular weight, such as domoic acid and saxitoxin, which may adversely affect product water quality; however, these are removed effectively by desalination treatment. Abstraction of the feedwater at depth and a reduced intake velocity can minimise the entrance of algal material into open water intakes (UNEP 2008).

6.6.3.3 Flow Distortion

The potential of scouring of sediment around the discharge outlet is a serious design issue for an effluent system discharging into a relatively shallow receiving water body (Carter & van Ballegooyen 1998). Despite the comparatively large discharge volumes being considered here (*i.e.* max. of 263 Ml/day or ~11 000 m^3/h), the proposed diffuser configuration should be such that the potential impacts on bottom sediments would be limited.

As the pipelines will be buried where they cross the surf zone, distortion of littoral sediment transport pathways in the nearshore environment are not expected.

6.6.3.4 Desalination Plant Effluents

The effluent water discharged from the desalination plant will constitute a high-salinity brine (expected average salinity 57.6 psu) which contains very low concentrations of chemical residuals from pre-treatment and from the RO membrane cleaning processes. Under current design specifications, the feedwaters will be drawn from ~15 m below the sea surface. At this depth the water column is expected to be well mixed, and no thermocline would be expected. Although no specific heating of the intake water will be done, piping of water prior to it entering the SWRO plant may potentially result in a slight elevation in temperature. This potential increase is assumed to be <3°C above ambient water temperature. Although the brine effluent will have a higher density than the receiving water, discharge through the diffuser system will ensure adequate dispersal throughout the water column, and pooling of the effluent near the seabed, where the receiving water masses may potentially have lower temperatures than the effluent, is unlikely. Insufficient mixing of the effluent with the receiving water may occur only under conditions of extreme calm.

Salinity

There are potential risks to ecosystem health due to the elevated salinity in the vicinity of the brine discharge. All marine organisms have a range of tolerance to salinity, which is related to their ability to regulate the osmotic balance of their individual cells and organs to maintain positive turgor pressure. Marine organisms are commonly classified in relation to their range of tolerance as stenohaline (able to adapt to only a narrow range of salinities) or euryhaline (able to adapt to a wide salinity range), with most organisms being stenohaline.

Salinity changes may affect aquatic organisms in two ways:

- Direct toxicity through physiological changes (particularly osmoregulation); and
- Indirectly by modifying the species distribution.

Salinity changes can also cause changes to water column structure (*e.g.* stratification) and water chemistry (*e.g.* dissolved oxygen saturation and turbidity). For example, fluctuation in the salinity regime has the potential to influence dissolved oxygen concentrations, and changes in the stratification could result in changes in the distribution of organisms in the water column and sediments. Behavioural responses to changes in the salinity regime can include avoidance by mobile animals, such as fish and macro-crustaceans, by moving away from adverse salinity and avoidance by sessile animals by reducing contact with the water by closing shells or by retreating deeper into sediments. Sessile animals are, however, likely to die should hyper-saline conditions persist in the medium to long-term.

In marine ecosystems, adverse effects or changes in species distribution are likely to occur as the result of a reduction, rather than an increase, in salinity (ANZECC 2000), and most studies undertaken to date have investigated effects of a decline in salinity due to an influx of freshwater, or salinity fluctuations in estuarine environments, where most of the fauna can be expected to be of the euryhaline type. As large-scale desalination plants have only been in operation for a short period of time, very little information exists on the long-term effects of hypersaline brine on organisms in coastal marine systems (Al-Agha & Mortaja 2005). However, from the limited studies that have been published, it has been observed that salinity has a toxic effect on numerous organisms dependent on specific sensitivities (Mabrook 1994; Eniev *et al*. 2002), and upsetting the osmotic balance can lead to the dehydration of cells (Kirst 1989; Ruso *et al.* 2007).

Sub-lethal effects of changed salinity regimes (or salinity stress) can include modification of metabolic rate, change in activity patterns, slowing of development and alteration of growth rates (McLusky 1981; Moullac *et al*. 1998), lowering of immune function (Matozzo *el al*. 2007) and increased mortality rates (Fagundez & Robaina 1992). The limited data available include a reported tolerance of adults of the mussel *Mytilus edulis* of up to 60 psu (Barnabe 1989), and successful fertilization (Clark 1992) and development (Bayne 1965) of its larvae at a salinity of up to 40 psu. The alga *Gracilaria verrucosa* can tolerate salinity ranges from 9-45 psu (Engledow & Bolton 1992). The shrimp *Penaeus indicus* is capable of tolerating a salinity range of 1 to 75 psu if allowed an acclimation time of around 48 hours (McClurg 1974), the oyster *Crassostrea gigas* tolerates salinities as high as 44 psu (King 1977), and the shrimp *Penaeus monodon* survived in 40 psu saline water (Kungvankij *et al*. 1986a, b, cited in DWAF 1995). Chen *et al*. (1992) reported a higher moulting frequency in juveniles of the prawn *Penaeus chinensis* at a salinity of 40 psu. Lethal effects were reported for seagrass species: for example, salinities of 50 psu caused 100% mortality of the Mediterranean seagrass *Posidonia oceanica*, 50% mortality at 45 psu, and 27% at 40 psu. Salinity concentrations above 40 psu also stunted plant growth and no growth occurred at levels exceeding 48 psu (Latorre 2005). The high saline concentration can also lead to an increase of water turbidity, which is likely to reduce light penetration, an effect that might disrupt photosynthetic processes (Miri & Chouikhi 2005). The increased salt concentration can reduce the production of plankton, particularly of invertebrate and fish larvae (Miri & Chouikhi 2005). One of the main factors of a change in salinity is its influence on osmoregulation, which in turn affects uptake rates of chemical or toxins. In a review on the effects of multiple stressors on aquatic organisms, Heugens *et al*. (2001) state that, in general, metal toxicity increases with decreasing salinity, while the toxicity of organophosphate insecticides increases with increasing salinity. For other chemicals no clear relationship between toxicity and salinity was observed. Some evidence, however, also exists for an increase in uptake of certain trace metals with an increase in salinity (Roast *et al*. 2002; Rainbow & Black 2002).

Very few ecological studies have been undertaken to examine the effects of high salinity discharges from desalination plants on the receiving communities. One example is a study on the macrobenthic community inhabiting the sandy substratum off the coast of Blanes in Spain (Raventos *et al.* 2006). The brine discharge from this plant was approximately 33,700 m^3/day, approximately a quarter of that considered for the proposed Lovu Plant. Visual census of the macrobenthic communities were carried out at two control points (away from the discharge outlet) and one impacted (at the discharge outlet) location several times before and after the plant began operating. No significant variations attributable to the brine discharges from the desalination plant were found. This was partly attributed to the high natural variability that is a characteristic feature of seabeds of this type, and also to the rapid dilution of the hyper-saline brine upon leaving the discharge pipe. Increase in porewater salinity was thus negligible. Other studies, however, indicated that brine discharges have led to reductions in fish populations, and to die-offs of plankton and coral in the Red Sea (Mabrook 1994), and to mortalities in mangrove and marine angiosperms in the Ras Hanjurah lagoon in the United Arab Emirates (Vries *et al.* 1997). Salinity increases near the outfall of a SWRO plant on Cyprus were reported to be responsible for a decline of macroalgae forests, and echinoderm species vanished from the discharge site (Argyrou 1999 cited in UNEP 2008).

Research conducted on abalone (*Haliotis diversicolor supertexta*) has shown that they experience significant mortality at salinities greater than 38 psu (Cheng & Chen 2000). Cheng *et al.* (2004) demonstrated that salinity stress affects the immune system of abalone, making them more vulnerable to bacterial infection. The immune capabilities in bivalve molluscs (*e.g.* the clam *Chamelea gallina*, Matozzo *et al.* 2007) and crustaceans (*e.g.* the prawn *Allacrobrachium rosenbergii*, Chen & Chen 2000) have also been shown to be compromised by changes in salinity. The Indian spider lobster *Panulirus homarus*, suffered from a depressed immune system when exposed to salinities over 45 psu, subsequently resulting in 100% mortality (Verghese *et al.* 2007). Desalination plants therefore have the potential to impact on the viability of fishing industries if the brine accumulates beyond the optimal range for commercially important species.

The South African Water Quality guidelines (DWAF 1995) set an upper target value for salinity of 36 psu. Measurements of salinity at Lovu indicate that background salinity is typically in the range of 35.3 - 35.5 psu. The paucity of information on the effects of increased salinity on marine organisms makes an assessment of the high salinity plume difficult. However, this guideline seems sufficiently conservative to suggest that no adverse effects should occur for salinity <36 psu. At levels exceeding 40 psu, however, significant effects are expected, including possible disruptions to molluscan bivalves (*e.g.* mussels/oysters/clams) and crustacean (and possibly fish) recruitment as salinities >40 psu may affect larval survival (*e.g.* Bayne 1965; Clarke 1992). This applies particularly to the larval stages of fish and benthic organisms in the area, which are likely to be damaged or suffer mortality due to osmotic effects, particularly if the encounter with the discharge effluent is sudden.

Predictive near-field modelling results identified that initial dilutions of up to 20 (for average and maximum brine flows) would be required to achieve compliance with the South African Water Quality Guidelines, and that these are likely to be realised within a 10-20 m radius from the diffuser discharge ports (WSP Africa Coastal Engineers 2013a). Although required near-field dilutions are not reached in the case of minimum brine flow rates, the dilutions will nonetheless be reached within 50 m of the diffuser. As the plant is expected to only operate at minimum capacity for 4% of the time, this is considered acceptable from an environmental perspective.

Further far-field hydrodynamic dispersion modelling results (WSP Africa Coastal Engineers 2013b) were subsequently used to assess the predicted extent of the impact of the hypersaline effluent and the dilution of a conservative tracer at Lovu for discharge through a diffuser. These results confirmed that:

- Maximum salinity footprints where the salinity above ambient was exceeded for 1% of the time (or approximately 7 hours per month) occurs at the seabed due to the dense nature of the effluent;
- The maximum salinity footprints at the seabed where the salinity exceeded ambient conditions by more than 0.5 psu was 0.2 km^2;
- Salinity footprints at the seabed where the salinity above water quality guideline of 36 psu was exceeded, extended beyond the 20 m sacrificial zone around the diffusers only in the case of minimum discharges. For this worse-case scenario the footprint extended to ~50 m from the diffuser, but this persisted for only 4% of the time per year (15 days);

- Salinity footprints above background values at the surface were discernible for average and maximum discharges only, being limited to a narrow band no more than a few hundred metres wide but extending alongshore to the north and south of the discharge point thereby being consistent with the dominant NE-SW wind regime;
- Persistence of elevated salinities above 36 psu for more than a day was primarily evident in bottom waters and within a 60 m radius of the discharge. For the worst-case brine discharge scenario, this increased to 200 m; a level of 1 psu above ambient, or ~36.5 psu, was found not to be exceeded;
- Elevated salinities at the surface was transient, rarely persisting for more than a day; and
- Difference between winter and summer footprints were negligible.

Temperature

Generally, there is no heating process of the intake water in SWRO desalination plants. However, the temperature of the feedwater may increase slightly during its passage through the pipelines and the plant. Such an increase is not expected to exceed 3°C. In nearshore regions coastal winds and swell typically ensure thorough mixing of the water column such that the bottom waters usually have similar water temperatures to the surface waters. The discharged brine will not be heated above this naturally occurring maximum temperature and therefore no thermal effects on local biota are expected. For the sake of completeness, however, thermal effects on marine biota are provided below.

Bamber (1995) defined four categories for direct effects of thermal discharges on marine organisms:

- Increases in mean temperature;
- Increases in absolute temperature;
- High short term fluctuations in temperature; and
- Thermal barriers.

Increased mean temperature

Changes in water temperature can have a substantial impact on aquatic organisms and ecosystems, with the effects being separated into two groups:

- Influences on the physiology of the biota (*e.g.* growth and metabolism, reproduction timing and success, mobility and migration patterns, and production); and
- Influences on ecosystem functioning (*e.g.* through altered oxygen solubility).

The impacts of increased temperature have been reviewed in a number of studies along the West Coast of South Africa (*e.g.* Luger *et al*. 1997; van Ballegooyen & Luger 1999; van Ballegooyen *et al.* 2004, 2005). A synthesis of these findings is given below.

Most reports on adverse effects of changes in sea water temperature on Southern African West Coast species are for intertidal (*e.g.* the white mussel *Donax serra*) or rocky bottom species (*e.g.* abalone *Haliotis midae*, kelp *Laminaria pallida*, mytilid mussels, and Cape rock lobster *Jasus lalandii*). Cook (1978) specifically studied the effect of thermal pollution on the commercially important rock lobster *Jasus lalandii*, and found that adult rock lobsters appeared reasonably tolerant of increased temperature of +6°C and even showed an increase in growth rate. The effect on the reproductive cycle of the adult lobster female was, however, more serious as the egg incubation period shortened and considerably fewer larvae survived through the various developmental stages at +6°C above ambient temperature. Zoutendyk (1989) also reported a reduction in respiration rate of adult *J. lalandii* at elevated temperatures.

Other reported effects include an increase in biomass of shallow water hake *Merluccious capensis* and West Coast sole *Austroglossus microlepis* at 18°C (MacPherson & Gordoa 1992) but no influence of temperatures of <17.5°C on chub-mackerel *Scomber japonicus* (Villacastin-Herroro *et al*. 1992). In contrast, 18°C is the lower lethal limit reported for larvae and eggs of galjoen *Distichius capensis* (Van der Lingen 1994).

Internationally, a large number of studies have investigated the effects of heated effluent (cooling water discharges) from coastal power stations on open coasts. These concluded that at elevated temperatures of <5°C above ambient sea water temperature, little or no effect on species abundances and distribution patterns was discernible (van Ballegooyen *et al*. 2005). On a physiological level, however, some adverse effects were observed, mainly in the development of eggs and larvae (*e.g.* Cook, 1978, Sandstrom *et al*. 1997; Luksiene *et al*. 2000).

The South African Water Quality Guidelines recommend that the maximum acceptable variation in ambient temperature should not exceed 1°C (DWAF 1995), which is an extremely conservative value in view of the negligible effects of thermal plumes on benthic assemblages reported elsewhere for a ΔT of +5°C or less.

All benthic species have preferred temperature ranges and it is reasonable to expect that those closest to their upper limits (*i.e.* boreal as opposed to temperate) would be negatively affected by an increase in mean temperature. The sessile biota in the KZN region are, however, naturally exposed to wide temperature ranges due to surface heating and rapid vertical mixing of the water column and intrusions of cold bottom shelf water into the system. It can thus be assumed that the biota in these waters are relatively robust and well-adapted to substantial natural variations in temperature.

The ANZECC (2000) water quality guideline requires that the median temperature in the environment with an operational discharge should not lie outside the 20 and 80 percentile temperature values for a reference location or ambient temperatures observed prior to the construction and operation of the proposed discharge. This guideline is, however, more appropriate for areas characterised by high temperature variability conditions in the bottom waters.

As temperature differences between the brine and receiving waters are expected to be <1°C, there is compliance with both, the ANZECC (2000) as well as the South African Water Quality Guidelines (DWAF 1995).

Increased absolute temperature

The maximum observed sea surface temperature in the region typically is 28°C. Strong wind events are likely to mix the water column to such an extent that the bottom waters usually have similar water temperatures to the surface waters. The discharged brine will not be heated above this naturally occurring maximum temperature and therefore an increase in absolute temperature is not expected and is not further assessed here.

Short term fluctuations in temperature and thermal barriers

Temperature fluctuations are typically caused by variability in flow or circulation driven by frequently reversing winds or tidal streams. For example, Bamber (1995) described faunal impoverishment in a tidal canal receiving hot water effluent where the temperature variability was ~12°C over each tidal cycle.

For thermal barriers to be effective in limiting or altering marine organism migration paths they need to be persistent over time and cover a large cross-sectional area of the water body. The predictions for the brine plume distributions indicate that neither condition will be met in the study area. Although various fish species undertake annual migrations along the KZN coastline, the anticipated temperature increases due to the effluent are negligible and this effect can therefore be considered insignificant.

Dissolved Oxygen

Dissolved oxygen (DO) is an essential requirement for most heterotrophic marine life. Its natural levels in sea water are largely governed by local temperature and salinity regimes, as well as organic content. Coastal upwelling regions are frequently exposed to hypoxic conditions owing to extremely high primary production and subsequent oxidative degeneration of organic matter. Although topographically induced upwelling occurs along the edge of the Natal Bight, productivity is comparatively low and consequently near-bottom hypoxia has not been reported from the area. However, ambient water temperatures are relatively high and a reduction in dissolved oxygen can thus be expected as a result of a combination of temperature and the elevated salinity of the brine. The biological consequences of hypoxia are discussed briefly below.

Hypoxic water (<2 mℓ O_2/ℓ) has the potential to cause mass mortalities of benthos and fish (Diaz & Rosenberg 1995). Marine organisms respond to hypoxia initially by attempting to maintain oxygen delivery (*e.g.* increases in respiration rate, number of red blood cells, or oxygen binding capacity of haemoglobin), then by conserving energy (*e.g.* metabolic depression, down-regulation of protein synthesis and down-regulation/modification of certain regulatory enzymes), and upon exposure to prolonged hypoxia, organisms eventually resort to anaerobic respiration (Wu 2002). Hypoxia reduces growth rates and feeding, which may eventually affect individual fitness. The effects of hypoxia on the reproduction and development of marine animals remains almost unknown. Many fish and marine organisms can detect, and actively avoid, hypoxia (*e.g.* rock lobster "walk-outs"). Some macrobenthic organisms may leave their burrows and move to the sediment surface during hypoxic conditions, rendering them more vulnerable to predation. Hypoxia may eliminate sensitive species, thereby causing changes in species composition of benthic, fish and phytoplankton communities. Decreases in species diversity and species richness are well documented, and changes in trophodynamics and functional groups have also been reported. Under hypoxic conditions, there is a general tendency for suspension feeders to be replaced by deposit feeders, demersal fish by pelagic fish and macrobenthos by meiobenthos (see Wu 2002 for references). Further anaerobic degradation of organic matter by sulphate-reducing bacteria may result in the production of hydrogen sulphide which is detrimental to marine organisms (Brüchert *et al*. 2003).

Because oxygen is a gas, its solubility in sea water is dependent on salinity and temperature, whereby temperature is the more significant factor. Increases in temperature and/or salinity result in a decline of dissolved oxygen levels. The temperature in the effluent is not significantly elevated in relation to the intake water temperature, and a reduction in dissolved oxygen is thus only expected as a result of the elevated salinity of the brine. The South African Water Quality Guidelines for Coastal Marine Waters (DWAF 1995) stipulate that for the East Coast, the dissolved oxygen should not fall below 5 mg/l (99% of the time) and below 6 mg/l (95% of the time). As the receiving water body in the discharge area is relatively shallow and likely to be well mixed, the potential for a reduction in dissolved oxygen levels will reduce rapidly within a few metres of the outlet. However, indirect changes in dissolved oxygen content of the water column and sediments due to changes in hydrodynamic and ecosystem functioning in the area are also possible. For example, oxygen concentrations may change (particularly in the bottom waters and in the sediments) due to changes in phytoplankton production as a result of changes in nutrient dynamics (both in terms of changes in nutrient inflows and vertical mixing of nutrients) and subsequent deposition of organic matter. As KZN coastal waters are nutrient poor and productivity is low, should they occur, such effects are likely to be negligible.

Several of the scale control additives typically used in SWRO desalination plant operations have the potential to act as nutrients for plants (*e.g.* sodium tripolyphosphate and trisodium phosphate). In principle, the phosphate can act as a plant nutrient and thus increase algal growth (Lattemann & Höpner 2003), however phosphate generally is not limiting in marine environments, unless there are significant inputs of nitrogen (nitrates, ammonia), which is the limiting nutrient in such systems.

A critical factor that needs to be observed is that oxygen depletion in the brine might also occur through the addition of sodium metabisulphite, an oxygen scavenger, which is commonly used as a neutralizing agent for chlorine (Lattemann & Höpner 2003) (see below). If not properly dosed, sodium metabisulphite can severely deplete the dissolved oxygen in the discharged water. In this case, aeration of the effluent is recommended prior to discharge. If this is indeed undertaken, the brine may in fact have a higher DO concentration than the receiving water body during natural low oxygen events.

Pre-treatment of Intake Waters

Chemical pre-treatment of the intake water and periodical cleaning of the reverse osmosis membranes is essential for the effective operation of desalination plants. Pre-treatment and cleaning include treatment against biofouling, suspended solids and scale deposits. The type of pre-treatment system used will depend primarily on the intake type (*e.g.* pre-treatment for an open water intake is generally more complex and comprehensive than that for sub-surface intakes) and the feedwater quality.

The main proposed components of the pre-treatment system for the proposed Lovu desalination plant are:

- Tretament against biofouling by chlorination;
- Removal of suspended material by coagulation (ferric sulphate or ferric chloride) or flocculation (involving sedimentation, filter beds and/or Dissolved Air Flotation), followed by membrane filtration (*e.g.* ultrafiltration membrane);
- Control of scaling by acid addition (lowering the pH of the incoming sea water) and/or dosing with special 'antiscalant' chemicals; and
- Cartridge filters as a final protection barrier against suspended particles and microorganisms before the reverse osmosis units.

With the feedwater intakes located at 15 m depth this will reduce the intake of unicellular algae, floating debris, grease and oil. Chlorination of the intake water would nonetheless need to be undertaken to ensure that the pumping systems (*e.g.* intake pipe and membranes) are maintained free of biofouling organisms. For example, larvae of sessile organisms (*e.g.* mussels, barnacles) can grow in the intake pipe, and impede the flow of the feedwater. Biofouling of the membranes by algae, fungi and bacteria can rapidly lead to the formation and accumulation of slimes and biofilms, which can increase pumping costs and reduce the lifespan of the membranes.

Sodium hypochlorite (NaOCl) is typically used as an oxidising agent added intermittently at the offshore intake structure as shock dosages to prevent marine growth. The exact chlorine shock dosing regime (*e.g.* dosing schedule and concentration) is not known at this stage. As RO membranes are typically made from polyamide materials, which are sensitive to oxidising chemicals, residual chlorine needs to be neutralised with sodium bisulfite (SBS) before the feed-water enters the RO units. As a consequence, the chlorine concentration will be very low to undetectable in the brine effluent from the plant and is thus assumed to be below the 3 µg/ℓ limit as permitted by ANZECC (2000), which provides the most conservative guideline value (Table 6.2).

Compliance with the guidelines is thus expected, but for the sake of completeness a summary of chlorine chemistry and its potential effects on the receiving environment is provided in Appendix A. This serves to highlight the importance of assuring that chlorine is at all times sufficiently neutralised before discharge of the brine.

Sodium metabisulphite is a powerful reducing agent that reduces hypobromous acid (HOBr) to hydrobromic acid (HBr) and is in turn oxidized to sulphate. Although the reaction products are non-hazardous, sodium metabisulphite may cause oxygen depletion if the dosing is not adjusted properly. However, sodium metabisulphite rapidly reacts with free chlorine but has a much slower reaction with naturally occurring dissolved oxygen. The reaction chemistry involved also means that sodium metabisulphite can remove less oxygen from the sea water than the quantity of chlorine it is capable of removing. In case of overdosing with sodium metabisulphite and resultant low oxygen levels, aeration of the effluent, prior to discharge may be necessary.

A major disadvantage of chlorination is the formation of organohalogen compounds (*e.g.* THMs, see Appendix A). However, as only a few percent of the total added chlorine is recovered as halogenated by-products, and as by-product diversity is high, the environmental concentration of each substance can be expected to be relatively low. Dechlorination will further considerably reduce the potential for by-product formation. Nonetheless, there is some evidence that chlorinated-dechlorinated sea water increased mortality of test species and chronic effects of dechlorinated sea water were observed, which were assumed to be as a result of the presence of halogenated organics formed during chlorination (see UNEP 2008 for references).

A further concern is excessive bacterial regrowth in the brine after chlorination, as was for example recorded for a reverse osmosis desalination plant in Egypt (Diab 2002). Bacterial counts in the brine were 7-10 times higher than those in the feedwater thereby posing potential health risks to marine biota as well as users of the marine environment (*e.g.* swimmers, surfers, divers). Besides inadequate maintenance of the plant and an ineffective cleaning-in-place (CIP) process, excessive bacterial after-growth is also being attributed to the use of continuous levels of chlorine. The reason for this ineffectiveness is that chlorination results in the breakdown of high molecular dissolved organics into nutrients thus forming assimilable organic carbon (AOC). In addition, microorganisms subject to low levels of biocides often exude extracellular polysaccharides as a protective biofilm that increases their survival rate. Both the availability of surplus nutrients and the survival of some microorganisms can cause a heavy regrowth in desalination systems following chlorination (UNEP 2008). For most large reverse osmosis facilities, continuous chlorination has proven ineffective and has been replaced by intermittent shock chlorination, which is also proposed for this project. In severe cases of biogrowth, additional shock treatment may be necessary from time to time to reduce bacterial numbers to a low level. Sodium metabisulphite is most commonly used for this purpose, with a typical application of 500-1 000 mg/ℓ for 30 minutes (Redondo & Lomax 1997). It has to be noted though that sodium metabisulphite reduces bacterial numbers by oxygen depletion and is, therefore, only effective against aerobic microorganisms, while some other bacteria might survive in anaerobic conditions.

Co-discharged Waste-water Constituents

In addition to the biocide dosing, the pre-treatment of the feedwater includes the removal of suspended solids, the control of scaling and the periodical cleaning of the reverse osmosis membranes. As different chemicals are suited for different types of membranes, exact specifications for some of the additives (*e.g.* the antiscalant) will only be known once the reverse osmosis plant operator has been appointed and the membrane type decided on. Manufacturers of reverse osmosis membranes will provide relevant information in product manuals and are likely to offer consultation with regard to pre-treatment and CIP chemicals. This section thus describes the use and effects of cleaning chemicals that are used *conventionally* in reverse osmosis plants with open water intake structures. It can generally be said that a sub-surface intake design would considerably reduce the need for, and volume of, any of these cleaning agents.

Ferric chloride ($FeCl_3$) will be used as primary coagulant or flocculant in the pre-treatment system. When added to water, a hydrolysis reaction produces an insoluble ferric hydroxide precipitate that binds non-reactive molecules and colloidal solids into larger aggregations that can then be more easily settled or filtered from the water before it passes through to the reverse osmosis membranes. Dosing with sulphuric acid to establish slightly acidic pH values and addition of coagulant aids such as polyelectrolytes can enhance the coagulation process. Polyelectrolytes are organic substances with high molecular masses (like polyacrylamide) that help to bind particles together. The dosage of coagulants and coagulant aids is normally correlated with the amount of suspended material in the intake water. It can range between < 1 and 30 mg/ℓ for coagulants and between 0.2 and 4 mg/ℓ for polyelectrolytes. The resulting ferric hydroxide floc is retained when the sea water passes through filter beds. The filters are backwashed on a periodic basis (a few times every day), using filtered sea water or permeate water, to clean the particulate material off the filters. This produces a sludge that contains mainly sediments and organic matter, and filter coagulant chemicals. If co-discharged to the sea, ferric hydroxide may cause discoloration of the receiving water, and the sludge discharge may lead to increases in turbidity and suspended matter and has blanketing effects (Sotero-Santos *et al.* 2007, Lattemann & Höpner 2003). The sludge will be gradually blended into, and co-discharged with, the brine effluent. Residual ferric hydroxide in the brine will thus be minimal to undetectable.

After passing through the filter beds, the feedwater may be put through a Dissolved Air Flotation (DAF) tank. DAF is a water treatment process that clarifies waters by the removal of suspended matter such as oil or solids. The removal is achieved by dissolving air in the water under pressure and then releasing the air at atmospheric pressure in a flotation tank or basin. The released air forms tiny bubbles which adhere to the suspended matter causing the suspended matter to float to the surface of the water where it may then be removed by a skimming device. The supernatant water (943 m^3/h) would be kept combined with other cleaning wastewater and treated in the retention discharge tank prior to discharge with the brine.

Scaling on the inside of tubes or on reverse osmosis membranes impairs plant performance. Antiscalants are commonly added to the feedwater in desalination plants to prevent scale formation. Antiscalants mainly comprise organic, carboxylic-rich polymers such as polyacrylic acid and polymaleic acid. Acids and polyphosphates are still used on a limited scale but their use is decreasing as they can cause eutrophication, which results in algal blooms and excessive macroalgal growth (DWAF, 2007). Phosphonate and organic polymer antiscalants have a low toxicity to aquatic invertebrate and fish species, but some substances exhibit an increased toxicity to algae (see UNEP 2008 for reference). The typical antiscalant dosing rate in desalination plants (1–2 mg/ℓ), however, is a factor of 10 lower than the level at which a chronic effect was observed (20 mg/ℓ), and it is 10 to 5 000 times lower than the concentrations at which acutely toxic effects were observed. Predicted antiscalant concentration in the brine for this project is 4 mg/ℓ, which is still far below chronic effects level. Due to the antiscalant's capability of binding nutrients they may, however, interfere with the natural processes involving dissolved metals in sea water following discharge (see UNEP, 2008 for reference). Some of these metals may be important micronutrients for marine algae.

Polyphosphate antiscalants are easily hydrolysed to orthophosphate which is an essential nutrient for primary producers. The use of polyphosphates may cause a nutrient surplus and an increase in primary production at the discharge site, which may lead to oxygen depletion when the organic material decays. Eutrophication was reported at the outlets of some larger thermal desalination plants that used polyphosphates for scale control (Shams *et al.,* 1994). The type of antiscalant to be used may vary depending on the membrane type, but it is recommended that the use of a polyphosphate antiscalant be avoided.

Despite feedwater pre-treatment, membranes may become fouled by biofilms, accumulation of suspended matter and scale deposits, necessitating periodic cleaning. The cleaning intervals for reverse osmosis membranes are typically three to six months depending on the quality of the plant's feedwater (Einav *et al*., 2002). The cleaning interval currently suggested for the proposed desalination plant is three times per year. The chemicals used are mainly weak acids and detergents. Alkaline cleaning solutions (pH 11-12) (*e.g.* sodium hydroxide) are used for removal of silt deposits and biofilms, whereas acidified solutions (pH 2-3) (*e.g.* citric acid) remove metal oxides and scales. Further chemicals such as detergents, oxidants, complexing agents and/or non-oxidising biocides for membrane disinfection, are often added to improve the cleaning process. These additional chemicals are usually generic types or special brands recommended by the membrane manufacturers. Common cleaning chemicals include sulphuric acid, ethylenediaminetetra-acetic acid (EDTA), sodium tripolyphosphate (STPP), and trisodium phosphate (TSP), and dibromonitrilopropionamide (DBNPA) as non-oxidising biocide. Appendix A provides a short summary of the environmental fates and effects of these chemicals.

After the cleaning process is complete and the cleaning agents have been circulated through the membranes, the membranes are rinsed with product water several times. The residual membrane cleaning solution and rinse water will be blended with the other residual streams from the filtration systems and will be sent to a mixing tank prior to be discharged with the brine effluent.

Generally, the toxicity of the various chemicals used in the pre-treatment and CIP process (aside from biocides) is relatively low (see Appendix A), and none of the products is listed as tainting substances (DWAF, 1995). Of more concern is the likelihood of eutrophication (*e.g.* antiscalant, STPP, TSP) or elimination of micronutrients (*e.g.* antiscalant).

The waste brine often contains small concentrations of heavy metals that pass into solution when the plant's interior surfaces corrode. In reverse osmosis desalination plants, non-metal equipment and stainless steels are typically used. The brine from a reverse osmosis desalination plant may, therefore, contain traces of iron, nickel, chromium and molybdenum, but contamination levels are generally low (Hashim & Hajjaj, 2005; Lattemann & Höpner, 2003). Heavy metals tend to become enriched in suspended material and finally in sediments, so that areas of restricted water exchange and soft bottom habitats impacted by the discharge could be affected by heavy metal accumulation. Many benthic invertebrates feed on this suspended or deposited material, with the risk that the heavy metals accumulate in their bodies and are passed on to higher trophic levels. At this stage, no assessment of the potential concentration of heavy metals can be provided, as it is an incidental by-product of the reverse osmosis desalination processes. It is recommended, therefore, that limits are established for heavy metal concentrations in the brine discharges (see Table 6.2 for guideline values), and the brine be monitored regularly to avoid exceedance of these limits.

The Impact Assessment table below provide an assessment of potential impacts associated with the operational phase of the proposed SWRO desalination plant at Lovu, based on the initial dilution and far-field brine dispersion model results currently available. The initial dilutions (near-field) model required target values of up 16-times dilution during maximum and average plant operations, and 23-times dilution during minimum plant operations, under the assumption that this would be sufficient to meet the relevant water quality guidelines. These required dilutions are conservative and also provided indicative results for potential co-discharges. When the plant is operating at average or maximum capacity, the achievable dilutions are reached within a 10 m radius of the discharge ports. Due to the variance in ambient salinity and possible discrepancies between the numerical model and actual dilutions, inclusion of a buffer area beyond the radius at which the maximum dilution is reached, is typically recommended. In this case, a 20 m horizontal distance (both directions) as measured from the discharge ports was recommended as constituting the sacrificial zone (WSP Africa Coastal Engineers, 2013a). As the diffuser ports discharge to both sides of the diffuser pipe, the sacrificial zone would thus be in the order of 40 m wide by about 80 m long (the length of the 60 m-long diffuser, plus 20 m buffer beyond last port). When the plant is operating at minimum capacity, the width of the zone would extend to 50 m either side of the pipeline, but this is estimated to occur only 4% of the time (15 days per year) (WSP Africa Coastal Engineers, 2013a).

Further far-field hydrodynamic dispersion modelling results (WSP Africa Coastal Engineers, 2013b) were subsequently used to assess the predicted extent of the impact of the brine effluent and associated co-discharges at Lovu for discharge through a double diffuser (each 30 m long) during winter (July) and summer (December) conditions (Table 6.8). Although the design taken forward is for a single outfall pipe and diffuser, the diffuser would have a length of 60 m and thus the same effective length as two 30-m diffusers. The modelling results indicated that:

- Salinity footprints above background values at the surface were discernible for average and maximum discharges only, being limited to a narrow band no more than a few hundred metres wide but extending alongshore to the north-east and south-west of the discharge point due to the dominant NE-SW wind regime;
- Elevated salinity at the surface was transient, rarely persisting for more than a day;
- Maximum salinity footprints where the salinity above ambient was exceeded for 1% of the time (or approximately 7 hours per month) occurs at the seabed due to the dense nature of the effluent;
- Persistent elevated salinities not exceeding 36.5 psu (or 1 psu above ambient) at the seabed are localised to within <50 m of the diffuser at depths between -5 m to -15 m;
- Salinities primarily remain below 0.5 psu above ambient and rarely persisted for more than a day (in total) during a simulated season. Although a level of 1 psu above ambient is NOT reached at Lovu, a maximum salinity of 0.8 psu is attained, but persists for less than 1% of the time;
- Concentrations rapidly decrease with distance from the discharge location;
- The maximum salinity footprints at the seabed where the salinity exceeded ambient conditions by more than 0.5 psu was 0.2 km^2;
- Persistence of elevated salinities of 1 psu or more above ambient for more than a day was only evident in bottom waters for the cases of minimum discharge flow and within 30 m of the diffuser;
- Although negligible, difference between winter and summer footprints (Table 6.8) indicate that brine dispersion at Lovu is sensitive to seasonal changes, particularly under minimum flow conditions; during prolonged periods of minimum brine discharge diffuser ports would be closed off thereby increasing the port velocities and raising the effective outflow.

- The plume distribution patterns for a conservative tracer reflect the footprints obtained for salinity. Under the worst-case maximum discharge scenario, tracer concentrations at the surface exceed 10% concentration only 1% of the time. Concentrations of >1% are limited to within 150 m from the diffuser;
- Near the seabed, high tracer concentrations occur most frequently in close proximity to the diffuser, exceeding 1% at a distance of >1 km from the diffuser <1% of the time.

Table 6.8: Areas of the brine footprints (in km^2) under various flow scenarios for a salinity of 0.5 psu above ambient. This is achieved only 1% of the time.

Scenario	Winter	Summer
Minimum Flow	0.201	0.145
Average Flow	0.118	0.112
Maximum Flow	0.159	0.145

The recent assessment framework for the management of effluent discharged from land-based sources to the marine environment (Anchor Environmental Consultants 2015), recommended that in a nearshore open coast environment, the combined size of the mixing zone around a multiple-port diffuser should not exceed the total area permitted by the applicable single mixing zone of 282 743 m^2 (0.3 km^2). For a diffuser with 15 discharge ports as proposed for the Tongaat RO Plant, this amounts to a radius not exceeding 26 m around each diffuser port.

Interpretation of the modelling results from an ecological perspective indicate that:

- Achievable dilutions are reached within the permissible radius of 26 m around each diffuser port in most cases, the exception being during minimum discharges when the footprint extends to a radius of ~50 m. However, this is likely to occur over a cumulative period of only 15 days per year.
- A level of 0.5 psu above ambient (or 36 psu as specified by the DWAF guidelines) was exceeded at the seabed over a maximum area of 0.165 km^2, but this occurs only 1% of the time. Discharges will therefore be compliant with legal requirements for 99% of the time.
- Salinities occurring beyond the sacrificial zone did not reach 1 psu above ambient (36.6 psu) at any time. As scientific studies have shown that effects on marine biota are primarily observed for increases of >4 psu above ambient level, the concentrations beyond the sacrificial zone are unlikely to negatively affect the marine communities in the area.

6.6.3.5 Mitigation Measures

Virtually all the impacts identified for the operational phase of the proposed SWRO Plant at Lovu can, and would be mitigated by the implementation of appropriate engineering designs. For example, the use of screens at the intake and intermittent sodium hypochlorite dosing as part of the proposed design will ensure that impingement and entrainment, and bacterial regrowth, respectively are minimised, and diffusers will ensure adequate dilution and dispersal of the brine discharge. Further recommended mitigation measures include:

- Suitably neutralise residual chlorine with sodium bisulfite (SBS); in an emergency when intake water needs to be bypassed directly to the brine outfall, residual chlorine in the brine discharge must be below 3 µg/ℓ.

- Monitor the brine for dissolved oxygen levels potentially caused by overdosing of sodium bisulfite, and aerate if necessary.
- Use only antiscalants with low toxicity to aquatic invertebrate and fish species; avoid the use of a polyphosphate antiscalant.
- Collect residual cleaning solutions and membrane filter washes and neutralize in the retention discharge tank before discharge into the brine stream. If practicable, remove solids and dispose of those at an accredited landfill site (It must however be noted that the disposal of sludge originating from the marine environment on land would also have potential impacts on the terrestrial ecology).

Table 6.9: Impacts to the marine environment associated with the Operational Phase of the proposed SWRO desalination plants at Lovu.

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
Operational Phase											
3.1. Permanent loss of habitat under submerged intake and discharge pipelines	**Negative**	**Site Specific,** i.e. within the immediate area of the submerged structures (1)	**Permanent,** if pipelines are left in place after decommissioning of the plant (5)	**Medium,** a portion of the original benthic habitat is lost (4)	**Definite,** impact will occur if this alternative is chosen (1)	**Irreversible** as structures will be left in place on de-commissioning	**Low**	**High (10)**	- No mitigation possible other than the no-project alternative, - Impact will be ameliorated by the fact that the submerged structures offer a new settling substrate for hard bottom species (see 3.2), - Leave pipeline in place post closure to prevent unnecessary disturbance of the seabed and associated communities.	**Low,** impact will be ameliorated by the fact that the submerged structures offer a new settling ground for hard bottom species (see 3.2.)	**High**
3.2 Submerged pipelines and associated structures act as artificial reefs	**Positive**	**Site Specific,** i.e. within the immediate area of the submerged structures (1)	**Permanent,** if pipelines are left in place after de-commissioning of the plant (5)	**Low,** a new settling habitat for reef dwellers is created but this community might be different to the original one prior to the construction of the pipelines (1)	**Definite,** impact will occur if this alternative is chosen (1)	**Irreversible** as structures will be left in place on de-commissioning	**Low**	**Medium (7)**	- Leave pipeline in place post closure to prevent unnecessary disturbance of the seabed and associated communities.	**Medium,** community on submerged structures is likely to be different from the original community prior to the construction of the pipelines	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.3. Changes in water circulation at the inlet structure due to the abstraction of large volume of seawater	**Negative**	**Site Specific,** i.e. within the immediate area of the intake (1)	**Long,** over the entire operational life time of the plant (4)	**Low,** natural environment is turbulent and realised changes in water circulation should thus be minimal (1)	**Improbable,** will only happen when natural currents are very weak (0.1)	**Irreversible** during operational life time of plant	**Low**	**Very Low,** since unlikely to happen (0.6)	- Adjust intake velocities, - Ensure installation of velocity caps.	**Very Low,** mitigation measures will reduce the possibility of the impact occurring even further	**High**
3.4. Impingement and entrainment of organisms at the intake structure	**Negative**	**Site Specific,** i.e. within the immediate area of the intake pipeline (1)	**Long,** over the entire operational life time of the plant (4)	**Medium,** a small proportion of plankton, larvae and eggs will be taken in with the feed water and killed during the desalination process (4)	**Low Probability** (0.25) assuming velocity caps and screens form part of engineering design	**Irreversible** during operational life time of plant	**Low**	**Low** (2.25)	- Adjust intake velocities, - Ensure installation of velocity caps and screens.	**Very Low,** low intake velocities and screens will reduce impingement and entrainment drastically	**High**
3.5. Flow distortion at the discharge, and effects of pipeline on natural sediment dynamics	**Negative**	**Site Specific,** i.e. within the immediate area of the pipelines (1)	**Long,** over the entire operational life time of the plant (4)	**Low** (2)	**Improbable** (0.1)	**Irreversible** during operational life time of plant	**Low**	**Very Low,** since it is unlikely to happen (0.7)	- No additional mitigation possible	**Very Low**	**Medium**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversibility	Irreplaceability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.6. Discharge of high density saline brine may cause sinking of the plume, seafloor spreading and increases in porewater salinity beyond the sacrificial mixing zone	**Negative**	**Site Specific,** i.e. worst case scenario footprint for 0.5 psu above ambient is 0.165 km^2 (2)	**Long,** over the entire operational life time of the plant (4)	**Medium,** increased salinity may be harmful to some biota (4)	**Low,** elevated salinities beyond the mixing zone expected only when opeartional at minimum capacity (0.25)	**Irreversible** during operational life time of plant	**Low**	**Low (2.25)**	- Ensure sufficient mixing of the discharged brine with the receiving water body by adjusting the discharge configuration appropriately, - Limit increased salinity to mixing zone.	**Low,** an appropriate discharge configuration will reduce the risk of seafloor spreading considerably	**High**
3.7. Increased salinity beyond the sacrificial mixing zone affects biota	**Negative**	**Site Specific,** i.e. worst case scenario footprint for 0.5 psu above ambient is 0.165 km^2 (1)	**Long,** over the entire operational life time of the plant (4)	**Medium,** increased salinity may be harmful to some biota (4)	**Low,** elevated salinities beyond the mixing zone expected only when opeartional at minimum capacity (0.25)	**Irreversible** during operational life time of plant	**Low**	**Low (2.25)**	- Ensure sufficient mixing of the discharged brine with the receiving water body by adjusting the discharge configuration appropriately, - Limit increased salinity to mixing zone.	**Low,** an appropriate discharge configuration will reduce the size of the mixing zone even under calm weather conditions	**High**
3.8. Increased temperature in the mixing zone affects biota	**Negative**	**Site Specific,** i.e. worst case scenario footprint would be confined to the mixing zone (1)	**Long,** over the entire operational life time of the plant (4)	**Low** temperature differences lie within the range defined by the 20%ile and 80%ile of the seasonal distribution of the ambient temperature for the system (2)	**Highly probable,** the feed water will not be externally heated but its temperature may increase during its travelling time through the plant (0.75)	**Reversible** as temperature differences lie within the tolerances of marine biota	**Low**	**Low (4.5)**	- Ensure sufficient mixing of the discharged brine with the receiving water body by adjusting the discharge configuration appropriately, - Confirm the performance of the discharge system in limiting increased temperature in mixing zone by sampling.	**Low**	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.9. Effects of biocide plume on marine communities in the mixing zone	**Negative**	**Local,** i.e. the worst case scenario footprint is 0.165 km^2 (2)	**Long**, over the entire operational life time of the plant (4)	**High**, biocides are highly toxic to aquatic life (8)	**Improbable** Effluent will be dechlorinated (0.1)	**Irreversible** biocides are highly toxic to aquatic life	**Low**	**Very Low (1.4)**	- If biocide dosing proves ineffective in controlling marine growth then undertake pigging of intake and discharge pipelines.	**Very Low**, the dechlorination process will reduce residual chlorine in the brine to below detectable level if SBS dosing is done properly	**High**
3.10. Reduction in dissolved oxygen concentrations of the receiving water as a result of dechlorination with sodium bisulphate	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Temporary,** dechlorination will be done over the entire operational life time of the plant but overdosing may occur only intermittently (1)	**Medium**, low-oxygen events are uncommon in the area (4)	**Probable,** if overdosing with SBS occurs (0.5)	**Reversible** as biota adapted to natural fluctuations in dissolved oxygen concentrations	**Low**	**Low (3)**	- Aeration of the effluent prior to discharge, if necessary	**Low,** aeration of brine will increase dissolved oxygen to acceptable level	**High**
3.11. Effects of discharged co-pollutants (e.g. ferric hydroxide sludge) with backwash water	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Long,** over the entire operational life time of the plant (4)	**Medium-Low,** ferric hydroxide is non-toxic but causes discolouration and blanketing effects (2)	**Probable,** if discharged gradually with brine effluent (0.5)	**Reversible** over the very short term as deposits will be constantly resuspended	**Low**	**Low (3.5)**	Additional measure: If practicable, treat backwash sludge in sludge handling facility, neutralize, and remove solids for alternative disposal on land	**Very Low,** removal of the solids from the backwash will avoid discharge of ferric chloride	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.12. Effects of discharged antiscalants (assuming required dilution of 23x during the worst-case scenario of minimum flows during winter)	**Negative**	**Site Specific to local,** i.e. worst case scenario footprint is 0.2 km^2 (2)	**Long,** over the entire operational life time of the plant (4)	**Medium,** antiscalants are non toxic at the concentra-tions used but may bind nutrients and ions needed for plant growth. Polyphosphonate antiscalants may cause a nutrient surplus potentially leading to algal blooms (4)	**Probable** (0.5)	**Reversible** over the very short term as micro-nutrients unlikely to be limited	**Low**	**Medium** (5)	- Avoid antiscalants that increase nutrient levels (e.g. polyphosphate antiscalants), - Select antiscalant that has relevant eco-toxicological testing, - Conduct Whole Effluent Toxicity (WET) testing of the brine effluent.	**Low**	**High**
3.13. Effects of discharge of other residual cleaning solutions used during periodical RO membrane maintenance cleaning (assuming required dilution of 23x during the worst-case scenario of minimum flows during winter)	**Negative**	**Site Specific to local,** i.e. worst case scenario footprint is 0.2 km^2 (2)	**Temporary,** RO membrane maintenance cleaning (CIP) to be undertaken ~3 x per year. The cleaning solutions will be blended into and discharged with the brine (1)	**Low,** cleaning solutions have low toxicity but may have lower pH values (see 3.14) (1)	**Definite** (1)	**Reversible** over the very short term as effects of chemicals benign at the concentra-tions discharged	**Low**	**Low** (4)	- Collect residual cleaning solutions and membrane filter washes and neutralize before discharge	**Low,** treatment of the residual cleaning solutions will reduce the impact	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.14. Discharge of acidic or alkaline cleaning solutions may affect the ambient pH seawater	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Temporary,** RO membrane maintenance cleaning (CIP) to be undertaken ~3 x per year. The cleaning solutions will be blended into and discharged with the brine (1)	**Low,** buffering capacity of seawater will neutralize surplus acidity quickly (1)	**Probable** (0.5)	**Reversible** over the very short term as effects of chemicals benign at the concentra-tions discharged	**Low**	**Very Low (1.5)**	- Collect residual cleaning solutions and membrane filter washes and neutralize before discharge	**Very Low,** neutralizing of the cleaning solutions will avoid the impact	**High**
3.15. Heavy metals (if present in the brine from corrosion processes) may affect dissolved metal concentrations in the receiving water	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Long,** if corrosion occurs (4)	**High,** heavy metals are toxic and may accumulate in sediments (8)	**Probable,** if corrosion occurs (0.5)	**Irreversible** during operational life time of plant as heavy metals may accumulate in the sediments	**Low**	**Medium (6.5)**	- Design plant properly, e.g. by eliminating dead spots and threaded connections, to reduce corrosion to a minimum, - Corrosion resistance is considered good when the corrosion rate is <0.1 mm/a (UNEP 2008), - Monitor corrosion rate in the plant and monitor brine for metal concentrations.	**Low,** reduction of corrosion rate will reduce the risk of heavy metal contamination	**High**
3.16. Excessive bacterial regrowth in the brine after chlorination	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Long,** over the entire operational life time of the plant (4)	**Low,** heavy bacterial loading may cause human health risk but water quality in area around discharge is already compromised (2)	**Probable,** depends on the bacteria naturally occurring in the feed water (0.5)	**Irreversible** during operational life time of plant	**Low**	**Low (3.5)**	- Use intermittent shock dosing with a biocide to avoid bacterial resistance to the biocide - Monitor the brine for excessive bacterial regrowth and if necessary use sodium bisulfite shock dosing to reduce bacteria numbers (note that the brine will be oxygen depleted after this treatment and needs to be aerated before discharge)	**Low,** mitigation measures will reduce the risk of bacterial regrowth in the brine	**High**

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Reversi-bility	Irreplace-ability	Signifi-cance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
3.17. Chlorinated-dechlorinated brine may still have chronic effects due to the presence of halogenated by-products	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Long,** over the entire operational life time of the plant (4)	**High,** chlorination by-products are also powerful biocides (8)	**Improbable,** only a very small % of chlorine will transform into toxic by-products that are not eliminated by dechlorination (0.1)	**Irreversible** during operational life time of plant	**Low**	**Very Low (1.3)**	- No mitigation possible as chlorine chemistry is very complex and type and concentrations of by-product formation cannot be predicted	**Very Low**	**Medium,** chlorine chemistry is very complex and type and concentrations of by-product formation cannot be predicted
3.18. Avoidance behaviour by fish and marine mammals of the discharge area	**Negative**	**Site Specific,** i.e. within the immediate area of the brine outlet (1)	**Long,** over the entire operational life time of the plant (4)	**Medium,** mobile biota will avoid area but this may result in loss of potential feeding or breeding grounds (4)	**Probable,** depends on species sensitivity (0.5)	**Irreversible** during operational life time of plant	**Low**	**Low (4.5)**	- Ensure sufficient mixing of the discharged brine with the receiving water body by adjusting the discharge configuration appropriately, - Confirm the performance of the discharge system in limiting spread in mixing zone by sampling.	**Low, an appropriate discharge configuration will reduce the size of the mixing zone**	**High**

Although all residual impacts associated with the brine discharge are expected to be of low significance, the following monitoring programmes are recommended:

- Once in operation, conduct a study to ensure that the diffuser is performing to the expected specifications and that required dilution levels are achieved.
- Confirm brine and thermal footprints by sampling with a conductivity-temperature-depth (CTD) probe to confirm the performance of the discharge system and the numerical model predictions.
- Undertake toxicity testing of the discharged effluent for a full range of operational scenarios (*i.e.* shock dosing, etc) to ensure complete confidence in the potential effects of co-discharged constituents and the antiscalant to be used.
- Continuously monitor the effluent for residual chlorine and dissolved oxygen levels.
- Periodically assess bacterial regrowth.
- Regularly monitor the effluent for heavy metals until a profile of the discharge in terms of heavy metal concentrations is determined.
- Check corrosion levels of plant constituent parts and the physical integrity of the intake and outlet pipes and diffuser and replace or modify components if excessive corrosion is identified or specific maintenance is required.
- Implement a monitoring program to study the effects of the discharged brine on the receiving water body, which is associated with the validation of the model results, and use the information to develop a contingency plan that examines the risk of contamination, and considers procedures that must be implemented to mitigate any unanticipated impacts.

6.6.4 Decommissioning Phase

The minimum anticipated life of the SWRO plant is at least 25 years. The individual RO modules will be replaced as and when required during this period. No decommissioning procedures or restoration plans have been compiled at this stage, as it is envisaged that the plant will be refurbished rather than decommissioned after the anticipated 50 year lifespan. In the case of decommissioning, the pipeline will most likely be left in place, although this presently accepted practice might change. The potential impacts during the decommissioning phase are thus expected to be minimal in comparison to those occurring during the operational phase, and no key issues related to the marine environment are identified at this stage.

6.6.5 Cumulative Impacts

Anthropogenic activities in the coastal zone can result in complex immediate and indirect effects on the natural environment. Effects from disparate activities can combine and interact with each other in time and space to cause incremental or cumulative effects. Cumulative effects can also be defined as the total impact that a series of developments, either present, past or future, will have on the environment within a specific region over a particular period of time (DEAT IEM Guideline 7, Cumulative effects assessment, 2004).

From a coastal and marine environmental perspective, the proposed intake/discharge sites cannot be considered particularly “pristine”. The coastline is relatively uniform over the 1-1.5 km stretch under consideration at each location, has undergone substantial developments over the past decades and is already impacted by seasonally high visitor numbers who utilize the area primarily for coastal recreation, rock- and surf-angling and kite-surfing. Water and sediment quality have no doubt already been compromised by the various marine outfalls along the coast. Likewise, the river water shows measurable anthropogenic contamination due to discharges from wastewater treatment plants within the river's catchment areas. Therefore, given the current past and future proposed development along the coastline of the project area, cumulative impacts as well as further disturbances to marine or coastal systems or features can be expected. The magnitude and significance of these to the nearshore benthic ecosystem and potential cascade effects on higher order consumers are, however, difficult to predict and impossible to quantify. Of importance is the recognition that cumulative effects may occur and this should be kept in mind during any monitoring studies undertaken as part of this (or any other similar) project.

6.7 CONCLUSIONS AND RECOMMENDATIONS

The main marine impacts associated with the proposed desalination plant at Lovu are related to the construction of the intake and outfall structures during the construction phase, the intake of feed water from, and consequent discharge of a high-salinity brine back into the ocean during the operational phase.

6.7.1 Environmental Acceptability

The environmental acceptability of the proposed development is outlined below.

6.7.1.1 Construction Phase

At Lovu, the preferred option for the intake and outfall conduits across the wide beach and through the surf zone comprise trenched pipelines extending 1,220 m and 630 m offshore, respectively. Installation of the pipelines would require the construction of a temporary jetty through the surf zone from which excavation and pipe laying would take place. Construction activities would severely impact the intertidal and nearshore habitats and their associated communities, but the impacts will be highly localised and confined to the immediate construction area. The installation of the intake and discharge structures will result in considerable disturbance of the high-shore, intertidal and shallow subtidal habitats at the construction site. The construction will involve substantial excavation activities in the intertidal beach and in the surf-zone, as well as extensive traffic on the shore by heavy vehicles and machinery, and the potential for associated hydrocarbon spills. Although the activities in the intertidal zone will be localised and confined to within a hundred metres of the construction site, the boulders and sediments will be completely turned over in the process and the associated macrofauna will almost certainly be entirely eliminated. The steep beach profile and coarse sediments characterising the beaches suggest that macrofaunal communities inhabiting the beaches are likely to be relatively depauperate and it is unlikely that the site provides habitat for new, unique or rare or endangered species.

Rock blasting may be necessary to remove existing bedrock to the required depth, resulting in disturbance of coastal and marine biota. The physical removal of sediments or bedrock in the trench will result in the total destruction of the associated sessile benthic biota. Excavating operations will also result in increased suspended sediments in the water column and physical smothering of macrofauna by the discarded sediments.

However, provided construction activities are not phased over an extended period, the shoreline is not repeatedly disturbed through persistent activities and suitable post-construction rehabilitation measures are adopted (*e.g.* track rehabilitation, removal of foreign construction materials which may hamper recovery of biota, backfilling excavations above mean sea level with the excavated material as trenching progresses, so as to maintain the original shore profile as far as possible), construction impacts may be considered to be environmentally acceptable, as the macrofaunal communities are likely to recover in the short-to medium-term. The benthic communities of these shores are highly variable, on both spatial and temporal scales, and subject to dramatic natural fluctuations, particularly as a result of episodic disturbances such as unusual storms, and natural sediment movement. As a consequence, the benthos is considered to be relatively resilient, being well-adapted to the dynamic environment, and capable of keeping pace with rapid biophysical changes (McLachlan & De Ruyck 1993). The highly localised, yet significant impacts (medium significance) over the short term thus need to be weighed up against the long-term benefits of the desalination plant.

6.7.1.2 Operational Phase

The key potential impacts on the marine environment of the proposed desalination plant are mostly associated with the operational phase. The impacts involve impingement and entrainment of biota at the intake point, and impacts associated with water quality due to pre-treatment of feed-water and discharge of the brine effluent.

The open water intake considered for this project will result in impingement and entrainment of biota. Careful designing of the intake with appropriate screens will reduce impingement substantially and has already been catered for in the proposed design. The entrainment of biological matter and suspended matter, however, cannot be eliminated and will require substantial pre-treatment of the feed-water, which has environmental as well as operational cost consequences for the desalination plant.

The need for pre-treatment of the feed water will also result in the use of chlorination to prevent biofouling of the pipelines and screens, and the use of other cleaning materials, which will be co-discharged with the reject brine. Impacts associated with the brine discharge thus include:

- the effect of elevated salinities in the discharged effluent;
- the effect of the effluent potentially having a higher temperature than the receiving environment;
- biocidal action of residual chlorine in the effluent (residual chlorine will be neutralized with sodium metabisulfite before the feed-water reaches the RO membranes);
- the effects of co-discharged constituents in the brine;
- the removal of particulate matter from the water column where it is a significant food source, as well as changes in phytoplankton production due to changes in nutrients, water column structure and mixing processes; and
- direct changes in dissolved oxygen content due to the difference between the ambient dissolved oxygen concentrations and those in the discharged effluent (especially if sodium bisulfate is used to neutralize residual chlorine), and indirect changes in dissolved oxygen content of the water column and sediments due to changes in phytoplankton production as a result of nutrient input.

It is particularly important that the development of a coherent density flow of brine along the seabed is avoided by ensuring complete mixing in the surf-zone at the point of discharge. Consequently, the effluent must be discharged through a diffuser in an area of relatively high wave energy where regular mixing of the water column can be expected as a result of the exposed nature of the coastline. Careful consideration of available technologies and processes in the plant design for the proposed desalination plant is thus the key issue that will allow the selection of the least environmentally damaging option for feed-water treatment, cleaning of plant components and brine disposal, thereby reducing discharges of hazardous components into the environment and ensuring adequate and rapid dilution of the effluent in the receiving water.

The hydrodynamic modelling results indicate that under average sea conditions, the predicted plume footprint is limited in spatial extent to no more than 20 m from the discharge point, thereby falling within the permitted 26 m radius sacrificial zone. Although this may extend to up to 50 m from the discharge point under minimum discharge conditions, these will be transient only and are predicted to occur only 1% of the time. The discharge would thus largely comply with legal requirements and guidelines, and given the proposed diffuser design would be acceptable from a marine ecological perspective.

6.7.2 Recommendations

6.7.2.1 Mitigation Measures

The essential mitigation measures are listed below for both the construction and operational phases of the desalination plant.

Construction Impacts

Heavy vehicle traffic associated with construction and pipeline installation must be kept to a minimum, and be restricted to clearly demarcated access routes and construction areas only. All construction activities in the coastal zone must be managed according to a strictly enforced Environmental Management Plan. Good house-keeping must form an integral part of any construction operations on the beach from start-up, including, but not limited to:

- drip trays under all vehicles parked on the beach;
- no vehicle maintenance or refuelling on beach;
- oil spill contingency plan for accidental oil spills;
- accidental diesel and hydrocarbon spills to be cleaned up accordingly; and
- no concrete mixing on the shore.

All blasting activities must be conducted in accordance with recognised standards and safety requirements. The area around the blasting site should be visually searched before blasting commences, and the blasting postponed should a marine mammal, sea turtle and/or flocks of swimming and diving birds be spotted within a 2-km radius around the blasting point. Following a previous blast, stunned or dead fish may attract seals and scavenging birds. The blasting programme should be scheduled to allow seals to have left the area before the next blasting event. The number of blasts should be restricted to the absolute minimum required, and should consist of smaller, quick succession blasts directed into the rock using a time-delay detonation.

Operational Impacts

Seawater Intake

There are several alternative design or mitigation measures that can completely avoid or reduce the impact of impingement. Intake velocities should be kept below ~0.15 m/s to ensure that fish and other organisms can escape the intake current. This can be achieved through a combination of pumping rates and intake design as is the case for the proposed desalination plant at Lovu. The use of screens, which are part of the proposed design, will prevent the intake of fish and wrack while still allowing adequate water flow.

Furthermore, manual cleaning of the intake structure and seawater delivery pipelines will be necessary as marine growth, scaling and sediment settlement will occur. Most marine pipelines employ a pigging system for regular maintenance cleaning, in which a ‘pig’ (bullet-shaped device with bristles) is introduced into the pipeline to mechanically clean out the structure. The pigging device is introduced at the intake structure and allowed to travel to the pump station, from where it is retrieved. For the discharge pipeline, it is introduced in the desalination plant, and is removed again on the seaward side.

Chlorination of the intake water is undertaken intermittently to ensure that the intake pipeline and feed-water pumping systems remain free of biofouling organisms. However, as the RO membranes are sensitive to oxidizing chemicals, neutralisation of residual chlorine, with sodium metabisulfite (SMBS), is necessary if membrane damage is to be avoided.

Scaling of the plant pipelines and RO membranes is controlled by the addition either of acid or specific antiscalant chemicals. Acids and polyphosphates cause eutrophication through formation of algal blooms and macroalgae, and should therefore be avoided. The preferred alternative would be to use phosphonate and organic polymer antiscalants, which have a low toxicity to aquatic invertebrate and fish species. These are proposed for the Lovu desalination plant. Depending on the membrane type, the antiscalant product should preferably be one for which relevant eco-toxicological testing has already been undertaken.

The recommendations provided above are in line with best practice for desalination plants of the capacity proposed at Lovu. Essential mitigation measures would comprise the use of low toxicity phosphonate and organic polymer antiscalants.

Discharges

During commissioning of the desalination plant, it may be necessary to discard the membrane storage solution and rinse the membranes before plant start-up. If the membrane storage solution contains a biocide or other chemicals these must either be neutralised before being discharged to sea, or the storage solution disposed of at an appropriate waste disposal facility.

Umgeni Water have specified that traces of residual chlorine in the brine discharge will be below 3 µg/ℓ (ANZECC (2000) guideline levels) as chlorine will be neutralised with SMBS. As marine organisms are extremely sensitive to residual chlorine, it is vital to ensure that the residual chlorine concentration in the discharged brine is at all times reduced to a level below that which may have lethal or sublethal effects on the biota, particularly the larval stages. Should the exceedance of the recommended guideline (<3 µg/ℓ) be a more persistent or recurrent event, there could be serious implications for marine biota in the discharge gully and the plant would need to be closed down until the problem has been rectified.

The use of SMBS during dechlorination is, however, associated with oxygen depletion in the effluent if overdosing occurs, as the substance is an oxygen scavenger. Shock dosing with SMBS is also an effective way of eliminating regrowth of aerobic bacteria in the discharge pipelines. Aeration of the effluent prior to discharge is therefore recommended, preferably with a permanent aeration system. Alternatively, if a permanent *in situ* effluent monitoring system is in place, aeration can be undertaken intermittently when monitoring results detect unacceptably low dissolved oxygen levels in the effluent.

If DBNPA were to be used as alternative to chlorine, mitigation measures to ensure low residuals of DBNPA in any discharge to the marine environment include appropriate design of the brine basin so as to ensure greater and sufficient dilution of the DBNPA residuals in the effluent stream and higher degradation rate before discharge. A better option would be carefully monitored dosing to ensure minimal DBNPA concentrations in the discharge.

If practical, it is recommended that the solids generated by the filtration, backwash and CIP processes be diverted to a sludge handling facility where solids are removed and the supernatant neutralised before being discharged to sea with the brine.

6.7.2.2 Monitoring

Monitoring plays a key role in ensuring that plant operations function as intended and achieve the provision of water with minimal environmental impacts. It includes validation, operational monitoring, verification and surveillance. Validation is the process of obtaining evidence that control measures are capable of operating as required, in other words it should confirm that specific pieces of equipment achieve accepted performance standards. Operational monitoring is the planned series of observations or measurements undertaken to assess the ongoing performance of individual control measures in preventing, eliminating or reducing hazards. Operational monitoring will normally be based on simple and rapid procedures such as measurement of turbidity and chlorine residuals or inspection of the distribution system integrity. Verification provides assurance that a system as a whole is providing safe water while surveillance reviews compliance with identified guidelines standards and regulations.

Recommendations for Validation

International guidelines (WHO 2007; UNEP 2008) recommend that, prior to the design and construction of the desalination plant, a study be conducted on the chemical and physical properties of the raw water. A thorough raw water characterisation at the proposed intake site should include an evaluation of physical, microbial and chemical characteristics, meteorological and oceanographic data, and aquatic biology. Seasonal variations should also be taken into account. The study should consider all constituents that may impact plant operation and process performance including water temperature, total dissolved solids (TDS), total suspended solids (TSS), membrane scaling compounds (calcium, silica, magnesium, barium, etc.) and total organic carbon (TOC). Many of these data were collected for the area during the pre-feasibility phase of the project.

As an open-water intake is planned, an entrainment study is recommended. A widely used and recognised study for determining entrainment effects of open ocean water intakes is known as the "316(b)" study, named after a section of US EPA Federal Clean Water Act (US EPA 1977, Seawater desalination and the California Coastal Act 2004). The protocol for this study was designed to evaluate the impacts of once-through cooling systems used by thermal power plants but can also be used for desalination intakes. Ideally, an entrainment study should form part of the pilot project for a small-scale pilot plant (Seawater desalination and the California Coastal Act 2004). Basically, the study requires sampling at various depth of the water column over the course of a year at both the intake site and a control site to identify the types and concentrations of species that would be entrained. The study then uses any of several models to determine what effect the entrainment has on adult fish population or broader marine community of the source water. This study should also take into consideration the potential cumulative effect of other sea water intakes in the Lovu area.

Once the desalination plant is in full operation, a monitoring program should be implemented to ensure that the required level of dilution (as predicted by the numerical modelling) is in fact achieved. Typical brine and thermal footprints should ideally be confirmed, both to assess the performance of the discharge system and validate the numerical model predictions. This should be done for a suitably representative range of "conservative" environmental conditions, *i.e.* conditions for which dispersion of the effluent is likely to be the most limited. It is envisaged that two to three field surveys of one to two days duration would be adequate to confirm the performance of the discharge system and the accuracy of model predictions. It is likely, that most of these measurements would in any case be needed to be included in the monitoring programmes developed to study the impact of the brine on potentially affected communities, particularly the subtidal benthic communities. If field observations and monitoring fail to mirror predicted results, the forecasted impacts will need to be re-assessed.

To ensure complete confidence in the potential effects of the antiscalant to be used in the desalination plant and that the co-discharged wastewater constituents are being managed to concentrations that will not have significant environmental impacts, it will be necessary to undertake toxicity testing of the discharge for a full range of operational scenarios (*i.e.* shock dosing, etc.). Such sampling and Whole Effluent Toxicity (WET) testing need only be undertaken for the duration and extent necessary to determine an effluent profile under all operational scenarios.

Recommendations for Operational Monitoring

To quantify the full impact of the brine discharge on the marine environment, all affected habitats and/or communities should be monitored before and during the discharge. However, prior research has indicated that this is impractical, impossible or simply unnecessary. Monitoring should rather focus on what are likely to be the most sensitive, significantly affected and/or representative species, communities or resources. The proposed discharge area includes two principal kinds of habitat - subtidal unconsolidated sediments and reefs. In both cases a suite of standard and widely accepted techniques have been developed for the monitoring of invertebrate communities associated with these habitats. It is strongly recommended that a well-designed monitoring plan be developed as part of the SWRO Plant environmental requirements. This would involve establishing a baseline of shallow subtidal invertebrate macrofaunal communities before any construction commences, followed by regular monitoring thereafter to assess recovery of the impacted communities following construction, as well as responses of the communities to a continuous hypersaline discharge.

Although it is predicted that residual chlorine levels in the discharge will be below guideline levels, continuous monitoring of the effluent for residual chlorine and dissolved oxygen levels is essential. Should residual chlorine be detected in the brine, SMBS dosing should immediately be increased. This may in turn lead to reduced oxygen levels in the effluent requiring aeration of the brine before discharge. Furthermore, bacterial regrowth should be periodically assessed (every 6 months) and if high bacterial numbers are encountered in the brine, shock dosing with SMBS should be undertaken. Continuous monitoring of oxygen levels would then indicate whether aeration of the effluent is necessary.

To ensure complete confidence in the controls of the dosing regime and that the consequent residual biocides in the discharge are being managed to concentrations that (together with possible synergistic effects of other co-discharges) will not have significant environmental impacts, it will be necessary to undertake toxicity testing of the discharge for a full range of operational scenarios (*i.e.* shock dosing, etc). Such sampling and toxicity testing need only be undertaken for the duration and extent necessary to determine an effluent profile under all operational scenarios.

The waste brine often contains low amounts of heavy metals from corrosive processes, which tend to enrich in suspended material and finally in the marine sediments. It is recommended that the effluent be monitored regularly (every 6-12 months) for heavy metals until a profile of the discharge in terms of heavy metal concentrations is determined. These heavy metal concentrations in the brine effluent would then need to be assessed based on existing guidelines (DWAF 1995; ANZECC 2000). A summary of these guidelines is provided in Table 6.2. An inspection program at similar intervals (6-12 months) to check corrosion levels of plant constituent parts and the physical integrity of the intake and outlet pipes and diffuser should be implemented and components replaced or modified if excessive corrosion is identified or specific maintenance is required.

Recommendations for Surveillance Reviews

A monitoring program should be developed to study the effects of the discharged brine on the receiving water body, particularly as monitoring of the affected subtidal benthic communities is in this case not feasible. This recommendation is reinforced by the *National Guideline for the Discharge of Effluent from Land-based Sources into the Coastal Environment* (DWAF 2014), in which it is stated that it is essential that the effects of an effluent discharged into the coastal zone be monitored according to an accepted monitoring programme. This monitoring programme would build on the programme designed to assess diffuser performance and validate numerical modelling results (see above). As a minimum, this monitoring should include measurement of the main water quality parameters such as temperature, salinity and dissolved oxygen as a minimum. It is further recommended that every effort be made to publish the results in a peer-reviewed journal, and in annual company reports that includes triple bottom line reporting.

This information should be used to develop a contingency plan that examines the risk of contamination, and considers procedures that must be implemented to mitigate any unanticipated impacts (*e.g.* mixing zone larger than expected under certain conditions).

6.7.3 Conclusions

The impact assessment (Section 6) identified that the marine environment will be impacted to some degree during both the construction and operational phases of the proposed SWRO Desalination Plant at Lovu.

Five negative impacts of medium significance (before mitigation) associated with the construction phase were identified:

- Disturbance and destruction of intertidal beach macrofauna during pipeline construction as a result of vehicular traffic and excavations.
- Accidental spillage or leakage of fuel, chemicals, or lubricants that may cause water or sediment contamination and/or disturbance to beach and subtidal biota.
- Disturbance and destruction of subtidal sandy and rocky reef biota during laying of the intake and discharge pipelines, jetty construction, surf-zone excavation and rock blasting.
- Effects of blasting on macrophytes, invertebrates and fish communities.
- Effects of blasting on marine communities, particularly turtles and marine mammals.

Only one negative impact of high significance (before mitigation) associated with the operational phase was identified:

- Permanent loss of habitat under submerged intake and discharge pipelines.

Three negative impacts of medium significance (before mitigation) associated with the operational phase were identified:

- Effects of discharged antiscalants.
- Heavy metals (if present in the brine from corrosion processes) may affect dissolved metal concentrations in the receiving water.

One positive impact of medium significance associated with the operational phase was identified:

- Intake structure and submerged pipelines act as artificial reefs.

With few exceptions, recommended management actions and mitigation measures will reduce the negative impacts of medium to high and of medium significance to low.

Ideally, a small-scale pilot plant should be developed to facilitate detailed assessments of expected impacts and validate the predictions of the brine dispersion studies. An entrainment study should form part of this approach.

The recommended mitigation measures for the construction phase of the SWRO Plant are:

- Keep heavy vehicle traffic associated with pipeline or breakwater construction on the beach to a minimum.
- Restrict vehicles to clearly demarcated access routes and construction areas only.
- All construction activities in the coastal zone must be managed according to a strictly enforced Environmental Management Plan.
- Good house-keeping must form an integral part of any construction operations on the beach from start-up.
- Maintain vehicles and equipment to ensure that no oils, diesel, fuel or hydraulic fluids are spilled.
- For equipment maintained in the field, oils & lubricants to be contained & correctly disposed of off-site.
- Construction vehicles to have a spill kit (peatsorb/ drip trays) onboard in the event of a spill.
- Restrict disturbance of the sea bottom to the smallest area possible.
- Lay pipeline in such a way that required rock blasting is kept to a minimum.
- Restrict vibration-generating activities to the absolute minimum required.
- All blasting activities should be conducted in accordance with recognised standards and safety requirements.
- Search the area around the blasting area and postpone blasting if turtles, marine mammals or flocks of diving or swimming birds are spotted within a 2-km radius of the blasting point.
- Restrict the number of blasts to the absolute minimum required, and to smaller, quick succession blasts directed into the rock using a time-delay detonation.
- Undertake only one blast per day.
- Avoid onshore blasting during the breeding season of shore-birds.

The recommended mitigation measures for the operational phase of the SWRO Plant are:

- Design plant properly, e.g. by eliminating dead spots and threaded connections, to reduce corrosion to a minimum (corrosion resistance is considered good when the corrosion rate is <0.1 mm/a (UNEP 2008).
- Keep intake velocities below ~0.15 m/s to ensure that fish and other organisms can escape the intake current.
- Install screens to prevent fish from entering the system while still allowing adequate water flow.
- If biocide dosing proves ineffective in controlling marine growth then undertake regular pigging of the intake pipelines.
- Undertake intermittent chlorination of the intake water to prevent bacterial regrowth in the brine.
- Ensure that residual chlorine is suitably neutralised with sodium bisulfite (SBS); residual chlorine in the brine discharge must be below No Observed Effect Concentration (NOEC) and/or the relevant water quality target values.
- Monitor the brine for decreased dissolved oxygen levels potentially caused by overdosing of sodium bisulfite, and aerate if necessary.

- Avoid the use of nutrient-enriching antiscalants, and use antiscalants with low toxicity to aquatic invertebrate and fish species.
- If practical, treat backwash sludge in a sludge handling facility and remove solids as far as practical and dispose of at an accredited landfill site or recycle.
- Collect residual cleaning solutions and membrane filter washes and neutralize and remove solids before discharge.

Monitoring recommendations include:

- Conduct a study on the chemical and physical properties of the raw water at the proposed intake site prior to the design and construction of the desalination plant.
- Conduct an entrainment study.
- Once in operation, conduct a study to ensure that the diffuser is performing to the expected specifications and that required dilution levels are achieved.
- Confirm brine and thermal footprints by sampling with a conductivity-temperature-depth (CTD) probe to confirm the performance of the discharge system and the numerical model predictions.
- Undertake WET testing of the discharged effluent for a full range of operational scenarios (*i.e.* shock dosing, etc.) to ensure complete confidence in the potential effects of co-discharged constituents and the antiscalant to be used.
- Continuously monitor the effluent for residual chlorine and dissolved oxygen levels.
- Periodically assess bacterial regrowth.
- Regularly monitor the effluent for heavy metals until a profile of the discharge in terms of heavy metal concentrations is determined.
- Check corrosion levels of plant constituent parts and the physical integrity of the intake and outlet pipes and diffuser and replace or modify components if excessive corrosion is identified or specific maintenance is required.
- Implement a monitoring program to study the effects of the discharged brine on the receiving water body, which is associated with the validation of the model results, and use the information to develop a contingency plan that examines the risk of contamination, and considers procedures that must be implemented to mitigate any unanticipated impacts.

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6.9 APPENDIX A:

6.10 A.1 POTENTIAL EFFECTS OF BLASTING

The laying of the intake and discharge pipeline and/or the construction of the breakwater will require blasting. Keevin & Hempen (1997) and Lewis (1996) provide information on blast-effects on a variety of shallow water (<10 m) organisms. Below follows a summary of these effects focussing on the marine macrophytic algae, major invertebrate macrofaunal taxa, fish, turtles and marine mammals that may occur in the blast area off the SWRO plant site.

Macrophytes

Smith (1996) measured blast effects on three species of algae, and found that both physical and physiological damage can occur within 10.5 m of a 2 kg explosive charge. Mortality (=biomass loss) was limited to within 8.5 m whilst depressions in photosynthetic rates post-blast occurred at all distances observed: 2.5 m – 10.5 m from the blast. This indicates that any disruptions to algal beds through blasting would be limited to the immediate vicinity of the charges.

Invertebrates

Due to the lack of gas bodies, marine invertebrates appear to be relatively immune to blast effects in terms of obvious injury or mortalities. Keevin & Hempen (1997) reported that oysters (*Ostrea virginica*) exposed to a 136.1 kg charge of TNT (high explosive) in open water had 100% survival at distances ranging from 7.6 - 122 m from the blast. Crabs (*Callinectes sapidus*) also showed high survival rates when exposed to a 90.7 kg open water charge, with mortalities ranging from 28% at a distance of 15.2 m from the blast, to 11% at a distance of 75 m. At 110 m from the charge, crab mortalities were zero. In a study by CSIR (1997) in Saldanha Bay, mud prawns (*Upogebia capensis*) suspended in perforated, thin walled plastic bags at 0.5 m, 30 m, 70 m and 120 m from six short interval (millisecond) 22.5 kg high explosive blasts in stemmed shot holes, showed no mortalities, and were actively swimming immediately after the blasts. In contrast, Keevin & Hempen (1997) reported 55% mortality in crabs exposed within 38 m - 15 m to a 13.6 kg blast in open water. Sublethal injuries in crabs, including carapace rupture, have been observed within metres to similarly moderately sized blasts (Keevin & Hempen 1997). This suggests that the blast-effects on invertebrates are likely to remain confined to the construction area and minimal far-field effects are likely to occur. Consequently deleterious impacts of underwater blasting on the invertebrate macrofauna in the vicinity of the pipeline are considered to be insignificant should they occur.

Fish

The swim bladder in fish is the organ most frequently damaged by shock (pressure) waves generated by underwater explosions (Lewis 1996, and authors cited therein). Post-mortem examinations of fish killed by underwater explosions generally show traumatic rupture of swim bladders and associated damage to adjacent organs including kidney, liver and spleen (Keevin & Hempen 1997). Further evidence of the role of the swim bladder in blast trauma is offered by the different apparent sensitivities to underwater explosions of physoclistous and physostomus fish species. The former have their swim bladder attached to the circulatory system and it consequently responds slowly to pressure changes, whereas the latter have the swim bladder ducted to the oesophagus with a relatively rapid pressure equalization response. Consequently physoclistic fish species, such as white bass (*Morone chrysops*) appear to be more sensitive to blasts than physostomus species such as trout (*Salmo* sp). Further factors moderating susceptibility to mortality and injury due to blast effects include body shape and overall size. In general thick bodied cylindrical fish, *e.g. Sphyraena* spp.

(barracuda), are less susceptible to injury than more laterally compressed species such as Sparidae (Fitch & Young 1948). Furthermore, Yelverton *et al.* (1975) found that higher shock wave intensity was required to kill larger than smaller fish of the same species.

Fish species that do not possess swim bladders (*e.g.* sharks and rays, some bony fish such as sea chub *Girella* spp, scorpion fish *Scorpaena* and *Scorpaenicthys* sp., and soles such as *Trinectes* sp.) appear to be largely immune to underwater explosions. For example, Goertner *et al.* (1994) found that *Trinectes* were not killed beyond a distance of 1 m from an open water charge of 4.5 kg of the high explosive pentolite.

Hill (1978) has developed equations predicting lethal ranges and safe distances for fish exposed to open water explosions. Input information for these includes:

- Typical size (weight) of the fish species likely to be exposed to the charges;
- Depth of the target fish in the water column;
- Depth of the detonation; and
- Weight of the charge.

Keevin & Hempen (1997) provide nomograms based on Hill's (1978) equations for estimating ranges from these variables. Following Hill's (1978) recommendations ranges calculated from the nomograms should be doubled to account for possible energy focusing effects of shallow water. Given the fact that surf-zone and nearshore species along the KZN coastline are widely distributed, the probability of the blasting programme having a measurable effect at the population level on fish in the study area is judged to be unlikely and therefore of low impact.

Based on exposures of anchovy eggs and larvae to a small charge size of 50 g TNT, Kostyuchenko (1973) concluded that fish eggs and pre-air bladder inflation fish larvae suffer pathological injury from underwater explosions, but effect ranges appear to be relatively small (< 20 m). The 'Guidelines for the use of explosives in Canadian Fisheries waters' (Wright, cited in Keevin & Hempen 1997) utilise a wider range of data and define a peak particle velocity of 13 mm/s as the critical threshold. These data allow the calculation of setback distances for fish spawning areas according to the regression equation:

Setback distance (m) = 1.806 (charge wt in kg) + 34.61

It is assumed that fish eggs and larvae will be widely distributed along the KZN coastline. Given the small area in which effects would possibly be generated, the probability of the proposed blasting programme having a measurable effect on fish eggs and larvae on a population level in the study area is unlikely.

Birds

Information on the effects of underwater blasting on swimming and diving birds is limited to experiments on ducks (Lewis 1996). Mortality occurred primarily within the immediate vicinity (< 10 m) of the blast, as a result of extensive pulmonary haemorrhaging and ruptured livers, kidneys, airsacs and eardrums. Birds beyond 20 m from the blast were largely uninjured. Lewis (1996) presents underwater blast criteria for birds on and beneath the water surface, from which safe and lethal ranges can be estimated.

In the case of underwater explosions, shock waves above the water surface are considered highly unlikely (O’Keeffe & Young 1984), and impacts on shore-birds can therefore be expected to be insignificant. Blasting on the shoreline, however, are likely to result in flight responses in nesting birds

(Wambach *et al.* 2001), and resting or feeding flocks on the shore. For a more detailed assessment of the effects of blasting on shore birds and other terrestrial organisms, the reader is referred to the Noise and Birds Specialist Studies also contained in this EIA report.

Turtles

A number of studies have demonstrated that sea turtles are killed and injured by underwater explosions (Duronslet *et al.* 1986; Gitschlag 1990; Gitschlag & Herozeg 1994; Gitschlag & Renaud 1989; Klima *et al.* 1988; O'Keeffe & Young 1984). Experiments undertaken to document the effects of underwater explosions on sea turtles, found that animals placed at intervals between 200-900 m from an explosive removal of an oil platform suffered averted cloaca and vasodilation, and in extreme cases lost consciousness, and if left in the water may have drowned. Carapace fractures in Loggerhead turtles which surfaced within minutes of a detonation have also been reported, as have extensive internal damage, particularly to the lungs.

Young (1991) developed the following equation to estimate sea turtle safe ranges, but as there has been no study establishing the relationship between underwater explosive pressures and mortality, this should be used for preliminary planning purposes only.

$R = 222\ W^{1/3}$

Where R = range in m and W = charge weight in kg.

There are no data on non-lethal damage from underwater explosions or delayed mortality, both of which may have a greater impact on sea turtle populations than immediate death from explosions.

Although occurring in the study area, turtles are infrequent visitors in the shallow nearshore regions. It is recommended that the area around the blasting area be searched before blasting commences, and to postpone blasting if a sea turtle is spotted. Given the small area in which effects would possibly be generated, the probability of the proposed blasting programme having a measurable effect on turtles in the study area is unlikely if the above recommendation is adhered to.

Marine Mammals

Similar to fish, injuries to mammals generated by underwater explosions are primarily trauma of various levels to organs containing gas, such as lungs, ears, and the intestinal tract. Empirical evidence on seals suggests that close proximity to charges can result in mortality, with observations of seals being killed by an 11.4 kg dynamite charge exploded 23 m away (Hanson 1954, cited in Keevin & Hempen 1997). Empirical observations on blast effects on other mammals have allowed the formulation of quantitative relationships between explosive charge size and safe distances. Keevin & Hempen (1997) provide such relationships derived from Young (1991) and Hill (1978). Using three input variables, namely depth of the target animal, depth of detonation and weight of the charge, the safe distances from the predicted maximum charges can be estimated in terms of seal mortality and sub-lethal injury. Note that seals outside of the lethal range but within zero effect range limit may suffer blast injuries such as lung haemorrhaging or ear drum rupture (Hill 1978). However, animals are expected to recover unaided; *i.e.* no human intervention should be required.

Given the relatively small lethal range and the generally low numbers of seals in the study area relative to the overall population size any population level mortality effects, or injuries that may be caused are judged to be insignificant.

Although occurring in the study area, whales and dolphins are infrequent visitors in the shallow nearshore regions, being more common further offshore. Because of their large sizes the risk of pathological injuries that may be caused by the proposed blasting appears to be constrained because of limited effect ranges. Young (1991) gives the following safe ranges for dolphins and whales, the equations indicating a reduction in sensitivity to underwater explosions with increasing size:

Juvenile dolphin	$R = 576\ W^{0.28}$
Dolphin	$R = 434\ W^{0.28}$
6 m Whale	$R = 327\ W^{0.28}$

Where R = range in m and W = charge weight in kg.

Due to the limited effect ranges and the distributions of whales and dolphins in the region any effects of the proposed blasting programme at the respective population levels are considered to be insignificant. The Marine Living Resources Act, 1998 (No. 18 of 1998) states that no whales or dolphins may be harassed[2], killed or fished. If whales are present in the blast area, disturbance cannot be ruled out. Consequently mitigation of the possible disturbance effect is required. It is recommended to visually search the area around the blasting area before blasting commences and to postpone the blasting should a whale be spotted.

6.11 A.2. SEAWATER CHLORINE CHEMISTRY AND ASSOCIATED POTENTIAL IMPACTS

The chemistry associated with seawater chlorination when using chlorine-based products is complex and only a few of the reactions are given below, summarised from ANZECC (2000), Lattemann & Höpner (2003) and UNEP (2008). Chlorine does not persist for extended periods in water but is very reactive. Its by-products, however, can persist for longer. The addition of sodium hypochlorite to seawater results in the formation of hypochlorous acid:

$$NaOCl + H_2O \rightarrow HOCl + Na^+ + OH^-$$

Hypochlorous acid is a weak acid, and will undergo partial dissociation as follows:

$$HOCl \rightarrow H^+ + OCl^-$$

In waters of pH between 6 and 9, both hypochlorous acid and hypochlorite ions will be present; the proportion of each species depending on the pH and temperature of the water. Hypochlorous acid is significantly more effective as a biocide than the hypochlorite ion.

In the presence of bromide (Br-), which like chloride is a natural component of seawater (average bromide concentration in seawater is 67 mg/ℓ), chlorine instantaneously oxidises bromide to form hypobromous acid and hypobromite (HOBr):

$$HOCl + Br^- \rightarrow HOBr + Cl^{--}$$

Hypobromous acid is also an effective biocide. It is worth noting that, for a given pH value, the proportion of hypobromous acid relative to hypobromite is significantly greater than the

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[2] In the Regulations for the management of boat-based whale watching and protection of turtles as part of the Marine Living Resources Act of 1998 the definition of "harassment" is given as "behaviour or conduct that threatens, disturbs or torments cetaceans".

corresponding values for the hypochlorous acid - hypochlorite system. Thus, for example, at pH 8 (the pH of seawater), hypobromous acid represents 83% of the bromine species present, compared with hypochlorous acid at 28%. Hypobromous acid can also disproportionate into bromide and bromated, which is accelerated by sunlight.

In natural waters, chlorine can undergo a range of reactions in addition to those discussed above, leading to the formation of a range of by-products. The reaction of chlorine with organic constituents in aqueous solution can be grouped into several types:

(a) Oxidation,

where chlorine is reduced to chloride ion, *e.g.* $RCHO + HOCl \rightarrow RCOOH + H^+ + Cl^-$

(b) Addition,

to unsaturated double bonds, *e.g.* $RC = CR' + HOCl \rightarrow RCOHCClR'$

(c) Substitution,

to form N-chlorinated compounds, *e.g.* $RNH_2 + HOCl \rightarrow RNHCl + H_2O$

or C-chlorinated compounds, *e.g.* $RCOCH_3 + 3HOCl \rightarrow RCOOH + CHCl_3 + 2H_2O$

Chlorine substitution reactions can lead to the formation of organohalogen compounds, such as chloroform, and, where HOBr is present, mixed halogenated and brominated organic compounds. The number of by-products can hardly be determined due to many possible side reactions. A major component, however, are the trihalomethanes (THMs) such as bromoform. Concentrations of other halogenated organics are considerably lower and usually in the nanogram per liter range. Substances of anthropogenic origin in coastal waters, especially mineral oil or diesel fuels, may give rise to compounds like chlorophenols (some of which can taint fish flesh at concentrations as low as 0.001 mg/ℓ (DWAF 1995)) or chlorobenzenes. However, THMs such as bromoform account for most of the compounds.

A number of other source water characteristics are likely to have an impact on the concentrations of organic by-products present in brine water discharges: natural organic matter in water is the major precursor of halogenated organic by-products, and hence the organic content of the source water (often measured as total organic carbon, TOC) may affect the concentration of by-products formed. In general, the higher the organic content of the source water, the higher the potential for by-product formation. The ammonia concentration is likely to affect the extent of by-product formation, through reaction with chlorine to form chloramines. Although seawater generally contains low concentrations of ammonia than freshwater, under certain conditions (dependent on chlorine dose: ammonia nitrogen concentration) it can compete with bromide for the available chlorine to form monochloramine. In addition, hypobromous acid can react with ammonia to form bromamines. Although the sequence of reactions is complex, it is likely that the reaction of either hypochlorous or hypobromous acid with ammonia to form halamines will reduce organic by-product formation during the chlorination of seawater. Chlorine can also react with nitrogen-containing organic compounds, such as amino acids to form organic chloramines. The pH of the incoming feed-water water could also affect the nature of the by-products formed. In general, while variations in pH are likely to affect the concentrations of individual by-products, the overall quantity formed is likely to remain relatively constant. Little is known about the biocidal properties of these compounds.

Paradoxically, chlorine chemistry thus establishes that no free chlorine is found in chlorinated seawater where bromide oxidation is instantaneous and quantitative. However, the chlorinated compounds, which constitute the combined chlorine, are far more persistent than the free chlorine.

After seawater chlorination, the sum of free chlorine and combined chlorine is referred to as total residual chlorine (TRC).

Marine organisms are extremely sensitive to residual chlorine, making it a prime choice as a biocide to prevent the fouling of marine water intakes. Many of the chlorinated and halogenated by-products that are formed during seawater chlorination (see above) are also carcinogenic or otherwise harmful to aquatic life (Einav *et al.* 2002, Lattemann & Höpner 2003). Values listed in the South African Marine Water Quality Guideline (DWAF 1995) show that 1500 µg/ℓ is lethal to some phytoplankton species, 820 µg/ℓ induced 50% mortality for a copepod and 50% mortality rates are observed for some fish and crustacean species at values exceeding 100 µg/ℓ (see also ANZECC 2000). The lowest values at which lethal effects are reported are 10 – 180 µg/ℓ for the larvae of a rotifer, followed by 23 µg/ℓ for oyster larvae (*Crassostrea virginica*). Sublethal effects include valve closure of mussels at values <300 µg/ℓ and inhibition of fertilisation of some urchins, echiuroids, and annelids at 50 µg/ℓ. Eppley *et al.* (1976) showed irreversible reductions in phytoplankton production, but no change in either plankton biomass or species structure at chlorine concentrations greater than 10 µg/ℓ. Bolsch & Hallegraeff (1993) showed that chlorine at 50 µg/ℓ decreased germination rates in the dinoflaggelate *Gymnodinium catenatum* by 50% whereas there was no discernable effect at 10 µg/ℓ. This indicated that particularly the larval stages of some species may be vulnerable to chlorine pollution. The minimum impact concentrations reported in the South African Water Quality Guidelines are in the range 2 to 20 µg/ℓ at which fertilisation success in echinoderm (*e.g.* sea urchin) eggs is reduced by approximately 50% after 5 minute exposures.

6.12 A.3. ENVIRONMENTAL FATE OF CLEANING CHEMICALS USED IN THE CIP PROCESS

The membranes in the SWRO plant will need periodical cleaning (CIP = Cleaning in Place) to remove any biofouling. The currently suggested cleaning interval for the proposed desalination project is three times per year. Typical cleaning chemicals include weak acids, detergents, oxidants, complexing agents and/or non-oxidising biocides for membrane disinfection. These chemicals are usually generic types or special brands recommended by the membrane manufacturers. The exact list of chemicals used will only be known once the SWRO plant operator has been appointed. Common cleaning chemicals, however, include Sulphuric acid, Ethylenediaminetetra-acetic acid (EDTA), Sodium tripolyphosphate (STPP), and Trisodium phosphate (TSP), and Dibromonitrilopropionamide (DBNPA) as non-oxidising biocide. Below follows a short summary of the environmental fates and effects of these chemicals.

Sulphuric acid (H_2SO_4) is used for pH adjustment in the desalination process to reduce the pH for the acid-wash cycle. It is a strong mineral acid that dissociates readily in water to sulphate ions and hydrated protons, and is totally miscible with water. At environmentally relevant concentrations, sulphuric acid is practically totally dissociated, sulphate is at natural concentrations and any possible effects are due to acidification. This total ionisation also implies that sulphuric acid, itself, will not adsorb on particulate matters or surfaces and will not accumulate in living tissues (http://www.chem.unep.ch/irptc/sids/oecdsids/7664939.pdf). Sulphuric acid can be acutely toxic to aquatic life *via* reduction of water pH. Most aquatic species do not tolerate pH lower than 5.5 for any extended period. No guideline values are available for this substance but *No Observed Effect Concentration* (NOEC) values were developed from chronic toxicity tests on freshwater organisms and range from 0.058 mg/ℓ for fish populations to 0.13 mg/ℓ for phytoplankton and zooplankton populations, respectively (http://www.chem.unep.ch /irptc/sids/oecdsids/7664939.pdf). As seawater is highly buffered, the limited sulphuric acid discharges are not expected to have significant impacts in the marine environment. The pH of the effluent is predicted to be between 7.3 and 8.2.

EDTA is an aminopolycarboxylic salt that is used as a chelating agent to bind or capture trace amounts of iron, copper, manganese, calcium and other metals. In water treatment systems, EDTA is used to control water hardness and scale-forming calcium and magnesium ions to prevent scale formation. Because of the ubiquitous presence of metal ions, it has to be assumed that EDTA is always emitted as a metal complex, although it cannot be predicted which metal will be bound. EDTA will biodegrade very slowly under ambient environmental conditions but does photodegrade. EDTA is not expected to bioaccumulate in aquatic organisms, adsorb to suspended solids or sediments or volatilize from water surfaces (European Union Risk Assessment Report 2004). Toxicity tests on aquatic organisms have shown that adverse effects occur only at higher concentrations (the lowest concentrations at which an adverse effect was recorded is 22 mg/ℓ) (European Union Risk Assessment Report 2004). On the other hand, if trace elements like Fe, Co, Mn, and Zn are low in the natural environment, an increased availability of essential nutrients caused by the complexing agent EDTA is able to stimulate algal growth. Heavy metal ions in the water are complexed by free EDTA, and a comparison of the toxicity of those compared to the respective uncomplexed metals and free EDTA have shown a reduction in toxicity by a factor of 17 to 17000 (Sorvari & Sillanpää 1996). Experiments (albeit with significantly higher trace metal concentrations than are typically observed in the environment) indicate that EDTA decreases the accumulation of metals such as Cd, Pb and Cu, however the absorption of Hg by mussels is seemingly promoted through complexation with EDTA (Gutiérrez-Galindo 1981, as cited in the European Union Risk Assessment Report 2004). Potential promotion of the accumulation of metals in sediments is unlikely to be a concern as in high concentrations EDTA prevents the adsorption of heavy metals onto sediments and even can remobilise metals from highly loaded sediments (European Union Risk Assessment Report 2004). Within the framework of marine risk assessment, the European Union has published a risk assessment report in which a *Predicted No Effect Concentration* (PNEC) of 0.64 mg/ℓ was calculated (European Union Risk Assessment Report 2004). The EDTA concentration expected in the brine is 0.013 mg/ℓ and lies thus under the PNEC value.

Sodium tripolyphosphate (STPP, $Na_5P_3O_{10}$) is the sodium salt of triphosphoric acid. It is a typical ingredient of household cleaning products, and is thus commonly present in domestic waste-waters. STPP is an inorganic substance that when in contact with water (waste-water or natural aquatic environment) is progressively hydrolysed by biochemical activity, finally to orthophosphate. Acute aquatic ecotoxicity studies have shown that STPP has a very low toxicity to aquatic organisms (all EC/LC_{50} are above 100 mg/ℓ) and is thus not considered as environmental risk (HERA 2003). The final hydrolysis product of STPP, orthophosphate, however, can lead to eutrophication of surface waters due to nutrient enrichment. However, phosphate as a nutrient is not limiting in marine environments unless there are significant inputs of nitrogen (nitrates, ammonia), which is the limiting nutrient in the marine environment. Depending on the presence of cationic ions, STPP can, in addition to the hydrolysis into orthophosphate, precipitate in the form of insoluble calcium, magnesium or other metal complex species (HERA 2003).

Trisodium phosphate (TSP) (Na_3PO_4) is a highly water-soluble cleaning agent. When dissolved in water it has an alkaline pH. The phosphate can act as a plant nutrient, and can thus increase algal growth, however, as noted above, phosphate as a nutrient is not limiting in marine environments unless there are significant inputs of nitrogen.

The non-oxidising biocide DBNPA, which could potentially be added during the RO cleaning process, has extremely fast antimicrobial action and rapid degradation to relatively non-toxic end products (US EPA 1994). The ultimate degradation products formed from both chemical and biodegradation processes of DBNPA include ammonia, carbon dioxide, and bromide ions. Exposure to sunlight further increases the degradation rate. While the degradation end-products will not be problematic in the marine environment, the specific biocidal action of residual DBNPA in the effluent streams could be of concern. Due to the fast degradation of DBNPA, however, acute toxic effects generally occur within 24 hours of exposure, and chronic effects will not occur. Some risk assessment studies have concluded that the use of DBNPA in cooling systems (once through and recirculating sytems) does not pose an unacceptable risk to the environment (Klaine *et al.* 1996). If used, DBNPA is likely to remain in the process stream long enough to ensure sufficient degradation and will occur in such small concentration that it should not pose a threat to the receiving marine environment.

6.13 A.4. REFERENCES

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