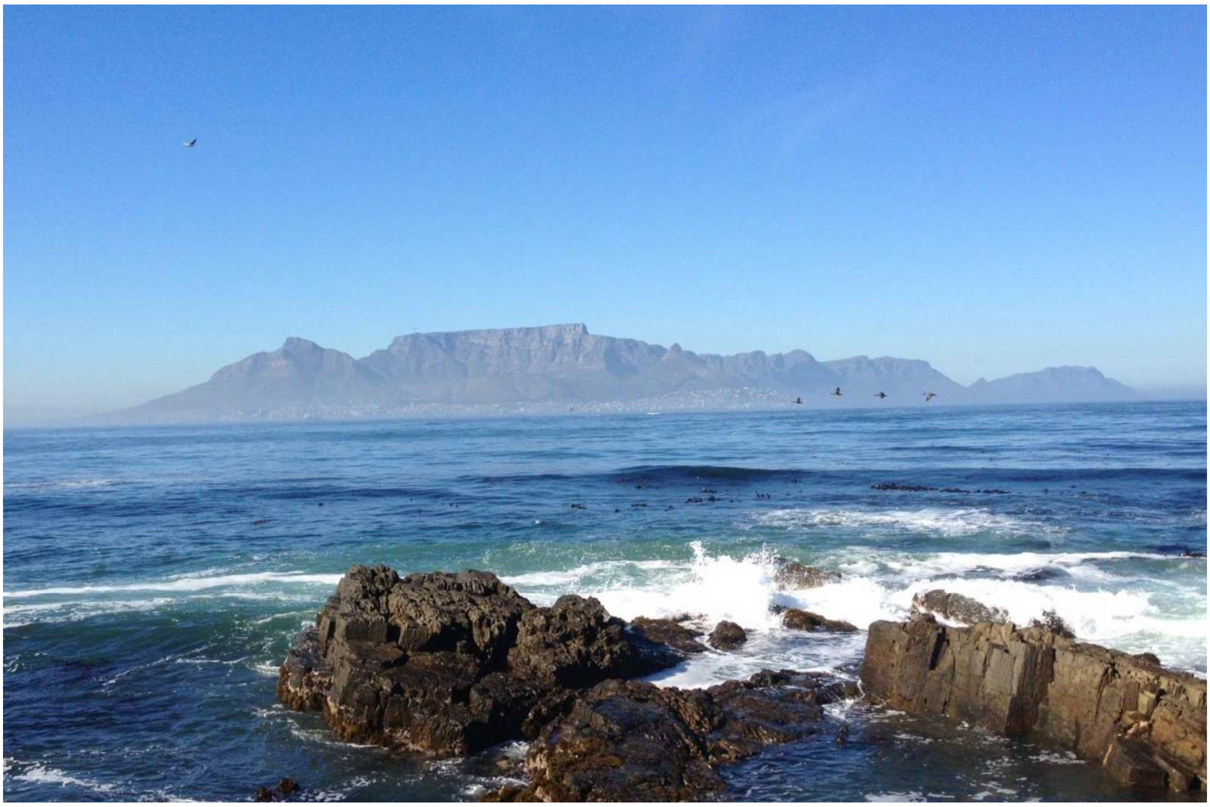
WSP IN AFRICA

# ROBBEN ISLAND WASTEWATER TREATMENT WORKS

## WWTW EFFLUENT DISPERSION MODELLING STUDY

17 NOVEMBER 2021

PUBLIC



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TYPE OF DOCUMENT (VERSION)
PUBLIC

PROJECT NO.: WSP - 43101910-R01
DATE: SEPTEMBER 2021

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Your ref.: 43101910 - Robben Island Outfall Modelling

Our ref.: WSP - 43101910-R01

PUBLIC

Jacqui Fincham
WSP in Africa
Pavilion First Floor
Corner of Portswood and Beach Road
Waterfront
Cape Town 8001

Dear Sir/Madam:

**Subject: Robben Island WWTW: WWTW effluent dispersion modelling study**

Herewith the updated WWTW effluent dispersion modelling specialist study for the Robben Island WWTW BAR.

Yours sincerely,

Roy van Ballegooyen
Associate

RvB/01
cc: Marthinus Retief, Geoff Smith
Encl.

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# QUALITY MANAGEMENT

| ISSUE/REVISION | FIRST ISSUE | REVISION 1 | REVISION 2 | REVISION 3 |
|---|---|---|---|---|
| Remarks | | Revised draft | Final | |
| Date | 10 Sep 2021 | 30 Sep 2021 | 18 Nov 2021 | |
| Prepared by | Roy van Ballegooyen | Roy van Ballegooyen | Roy van Ballegooyen | |
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| Authorised by | Marthinus Retief | Marthinus Retief | Geoff Smith | |
| Signature | - | - | Digitally signed by Smith, Geoff (ZAGS00142)<br>DN: cn=Smith, Geoff (ZAGS00142), ou=Active, email=Geoffrey.Smith@wsp.com<br>Date: 2021.11.19 09:21:12 +02'00' | |
| Project number | 431 01910 | 431 01910 | 431 01910 | |
| Report number | 431 01910-R01 | 431 01910-R01.Rev02 | 431 01910-R01.Rev03 | |
| File reference | | | | |

# SIGNATURES

PREPARED BY

Roy van Ballegooyen, Associate
Mr

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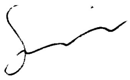

Geoff Smith, Coastal Engineer
Title

REPORT REFERENCE:

van Ballegooyen, R.C. (2021) Robben Island Wastewater Treatment Works: WWTW effluent dispersion modelling. WSP Report No. 431001910-.R01.Rev03, 48pp + 6pp App., Stellenbosch, South Africa.

# PRODUCTION TEAM

## CLIENT

| | |
|---|---|
| Environmental Assessment Practitioner | Jacqui Fincham |

## WSP

| | |
|---|---|
| Dispersion Modelling | Roy van Ballegooyen |

# EXECUTIVE SUMMARY

## INTRODUCTION

Currently there is no formal wastewater treatment works (WWTW) on Robben Island. A decision was made to upgrade the existing facilities by constructing a Sewage Package Plant (SPP) on Robben Island, the intention being to improve the *status quo*, *i.e.* changing from the discharge of an essentially untreated effluent to the discharge of an effluent complying with General Limit Values (GLV) (GN 665 of 2013). The requisite Environmental Authorisations for such a project were obtained in March 2015; however, this authorisation has subsequently lapsed.

WSP in Africa has been contracted to undertake a renewed Basic environmental impact assessment for the proposed waste water treatment works (WWTW) and obtain the necessary environmental authorisations. As part this process the original specialist dispersion modelling study undertaken in 2014 has been reviewed and updated.

## OBJECTIVE OF THE STUDY & SCOPE OF WORK

The purpose of this study is to provide an updated specialist dispersion modelling report to inform both the updated specialist marine ecology assessment and Basic Assessment Report (BAR) to be submitted as part of the Environmental Authorisation process presently being undertaken for the proposed Robben Island WWTW.

WSP in Africa: Water and Maritime has been tasked to review and update the original specialist dispersion modelling study undertaken for the 2014 BAR, taking into account any changed requirements in terms of guidance documents as well as any changes in water quality guidelines and/or the CWDP regulations issued in 2019.

## PROJECT DESCRIPTION

The Robben Island Museum (RIM) proposes to upgrade the existing sewage handling system on Robben Island with the construction of a WWTW.


**The location of proposed WWTW (red polygon) and the existing marine outfall in relation to Murray's Bay harbour.**

The plant, which will be located adjacent to the existing sewage collection unit ~600 m south of Murray's Harbour. The WWTW will have a treatment capacity of 108,000 $m^3$ per annum (or ~300 $m^3$ /day) and will treat all sewage and domestic wastewater generated on the island, resulting in a wastewater effluent that will comply with General Limit Values effluent quality standards (GN 665 of 2013). The treated effluent will be transported via an existing pipeline to the existing sea outfall pipeline and discharged to sea (see figure above).

The outfall is 465m long and discharges effluent via a 10 m long diffuser in an approximate -8 m CD water depth. The outfall diffuser comprises three ports spaced approximately 3.5 apart and discharging in alternate directions. The proposed effluent discharge comprises an intermittent discharge with a flow rate of 25 ℓ/s, occurring for an estimated cumulative total duration of approximately 3 hours and 20 minutes each day.

An estimated 120 $m^3$ of sludge produced annually as part of the treatment process will be dried on drying beds on the island, and either used as fertiliser or disposed of via the normal refuse system.

## ENVIRONMENTAL QUALITY OBJECTIVES

The Environmental Quality objectives used for the dispersion modelling study are determined by both the sensitivity of the natural environment and beneficial uses in the area potentially impacted by proposed WWTW effluent discharge.

Robben Island is located within the West Coast Rock Lobster Sanctuary which extends from Melkbos Point to "Die Josie" near Chapmans Peak and extend 12 nautical miles seawards of the high water mark. In addition, the marine environment around Robben Island within a one nautical mile buffer zone around the island, is legally protected as a National Heritage Site through the National Environmental Management Act (Act No 107 of 1998); National Environmental Management: Biodiversity Act (Act No 10 of 2004); and the National Environmental Management: Protected Areas Act (Act No 57 of 2003) (amongst others).

The environmental guidelines and target values deemed relevant to this study are the existing South African Water Quality guidelines for the natural environment and recreational activities, including the interim guidelines for recreational waters produced in 2012.

## ASSESSMENT APPROACH

Based on these guidelines, required dilutions where calculated for all relevant constituents in the effluent for the proposed new WWTW on Robben Island. Using both a near-field and an (analytical) far-field model, achievable dilutions were estimated for a representative range of environmental conditions (current speeds only as it was not deemed necessary to include water column stratification in the modelling assessments).

## MODEL RESULTS

The predicted achievable dilution in the near-field are summarised in the table below. The achievable dilutions reported in the table are those attained at the end of the near-field. The plume is predicted to reach the sea surface under all environmental conditions modelled. Thus, for all environmental conditions modelled, the end of the near-field is the location where the effluent reached the sea surface.

**Near-field model predicted minimum achievable dilutions for a representative range of environmental conditions.**

| Ambient Condition | Current speed (m/s) | |
|---|---|---|
| | Minimum initial dilutions | Horizontal distance from the diffuser |
| Stagnant | 66 | 3 |
| Average | 79 | 5 |
| 20% exceedance | 250 | 8 |
| 5 % exceedance | 756 | 18 |

Estimations of the total dilution comprising both initial and secondary dilutions have been determined for specified distances from the diffuser for all of the environmental conditions assessed. These are summarised in the table below. However, where necessary, actual concentrations of effluent constituents have been calculated, *i.e.* where there is not compliance with the relevant water quality guidelines within the near-field.

**Predicted near and far-field dilutions for a representative range of environmental conditions.**

| PREDICTED ACHIEVABLE DILUTIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model Type** | **Near-field** | **Far-field** | | | | | | |
| **Distance from Diffuser** | **< 10 m** | **20 m** | **30 m** | **50 m** | **100 m** | **200 m** | **300 m** | **400 m** |
| Stagnant conditions | 66 | 335 | 530 | 1 000 | 2 575 | 6 900 | 12 450 | 19 000 |
| Average conditions | 79 | 95 | 115 | 155 | 280 | 600 | 990 | 1 440 |
| 20% exceedance | 250 | 270 | 30 | 370 | 595 | 1 140 | 1 800 | 2 540 |
| 5% exceedance | 756 | 770 | 810 | 925 | 1 310 | 2 245 | 3 245 | 4 580 |

Assuming a minimum achievable dilution of 65, almost all effluent constituents have required dilutions less than the predicted minimum dilution. The only exceptions are possible residual concentrations of free chlorine, SS concentrations, nutrient concentrations (specifically Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) and Phosphate ($PO_4$-P)).

A compliance summary for all effluent constituents are summarised in the table below.

**Compliance summary for the wastewater effluent from the proposed new Robben Island WWTW.**

| | **Constituent** | **Compliance Distance** | **Comment** |
|---|---|---|---|
| **Protection of Marine Ecosystem (Natural Environment)** | Oil, soap and grease (mg/ℓ) | < 10 m | - |
| | Temperature (ºC) | < 10 m | - |
| | Salinity (psu) | < 10 m | - |
| | pH | < 10 m | - |
| | Suspended Solids (mg/ℓ) | < 10 m | - |
| | $BOD_5$ (mg/ℓ) | < 10 m | - |
| | COD (mg/ℓ) | < 10 m | - |
| | **Nitrate, Nitrite, Ammonia and Phosphate as nutrients-** | | |
| | Ammonium ($NH_4^+$-N) | < 10 m | - |
| | Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) | < 10 m | Provided the ambient Nitrate/Nitrite as Nitrogen concentrations remain below 0.14 mg/ℓ |
| | Dissolved inorganic nitrogen ($NH_4$-N + $N0_3$-N + $NO_2$-N) | < 10 m | - |
| | $PO_4$-P (mg/ℓ P) | < 30 m<br>< 100m | assuming an effluent concentration of 4 to 6 mg/ℓ<br>assuming an effluent concentration of 10 mg/ℓ |
| | **Ammonia, Fluoride, chlorine and metals as toxicants** | | |

| | Constituent | Compliance Distance | Comment |
|---|---|---|---|
| | Total Ammonia (mg/ℓ) ($NH_3$-N + $NH_4^+$-N) | < 10 m | - |
| | Cyanide (mg/ℓ) | < 10 m | - |
| | Fluoride (mg/ℓ) | Compliant at point of discharge | - |
| | Chlorine as Free Chlorine | < 10 m | Does not comply in the near-field but does comply within 10 m of the outfall diffuser |
| | Arsenic (mg/ℓ) | < 10 m | - |
| | Boron (mg/ℓ) | < 10 m | - |
| | Cadmium (mg/ℓ) | < 10 m | - |
| | Chromium (VI) (mg/ℓ) | < 10 m | - |
| | Copper (mg/ℓ) | < 10 m | - |
| | Iron (mg/ℓ) | - | - |
| | Lead (mg/ℓ)[8] | < 10 m | - |
| | Manganese (mg/ℓ) | < 10 m | - |
| | Mercury (mg/ℓ) | < 10 m | - |
| | Nickel (mg/ℓ) | < 10 m | - |
| | Selenium (mg/ℓ) | < 10 m | - |
| | Silver (mg/ℓ) | Compliant at point of discharge | |
| | Zinc (mg/ℓ) | < 10 m | - |
| **Contact Recreation** | F. Coli (MPN/100 m ℓ) | < 10 m | Complies with all of the relevant guidelines for contact recreation |
| **Collection of Filter Feeders** | F. Coli (MPN/100 m ℓ) | < 10 m | Complies with all of the relevant guidelines for collection of filter feeder |

## Conclusions and Recommendations

There is compliance with the existing water quality guidelines within a predicted 10 m of the outfall diffuser for all effluents constituents other than Phosphate. Phosphate is predicted to comply within between 30 m and 100 m of the outfall diffuser, depending on the assumed phosphate concentration in the wastewater effluent from the proposed new WWTW. However this non-compliance beyond a 10 m radius of the outfall could be considered non-substantive as phosphate is generally not a limiting nutrient in the environment under consideration.

It should be noted that the non-compliances or marginal compliances predicted are generally for quiescent (stagnant conditions) that are unlikely to be a common occurrence for the marine outfall location. Furthermore, the discharge of effluents from the WWTW will be intermittent (*i.e.* a cumulative 3 hours and 20 minutes per day for the sewage flow volumes envisaged). The “no-flow” periods between the intermittent discharges will give the effluent time to disperse, suggested a very low likelihood of the accumulation of effluent around the outfall diffuser.

It is recommended that the actual phosphate concentration in the WWTW effluent be monitored. Should it be higher than anticipated there may be a need to introduce mitigation measures. However, as phosphate is generally not a limiting nutrient in the environment under consideration, such mitigation measures may not be necessary especially if the phosphate concentration is restricted to 4 to 6 mg/ℓ (as is expected for the new WWTW). While the capital costs of such mitigation measures are modest, the operational costs are unlikely to be so.

It is further recommended that the condition of the outfall be assessed either directly (*e.g.* diver surveys) or indirectly (performance assessment via monitoring activities), to confirm that it is indeed operating as specified (and as simulated in this modelling study).

# GLOSSARY & ABBREVIATIONS

| | |
|---|---|
| Achievable Dilution | The total achievable dilution ($S_t$) which can be expected at a distant location is the product of the initial dilution ($S_i$), secondary or eddy dilution ($S_e$) and, to the extent that it exists, dilution due to the die-off of non-conservative parameters such as microbiological organisms ($S_d$). The total achievable dilution, $S_t$, at a distance location therefore is given by:<br>$S_t = S_i \times S_e$ for conservative substances<br>$S_t = S_i \times S_e \times S_d$ for microbiological indicators where there is die-off or other parameters where transformation processes lead to "decay".<br>where<br>$S_i$ = initial dilution<br>$S_e$ = secondary dilution<br>$S_d$ = "dilution" due to decay. |
| ADWF | Average Dry Weather Flow comprises the average sewage flow that is not influenced by rainfall. |
| AWWF | Average Wet Weather Flow comprises the ADWF flow plus any storm water inflows / infiltration into the sewer systems. |
| BAR | Basic Assessment Report required for the application for Environmental Authorisation based on the Basic Assessment rather than a full Environmental Impact Assessment process. |
| Baseline | Information gathered at the beginning of a study which describes the environment prior to development of a project and against which predicted changes (impacts) are measured. |
| Benthic | Pertaining to the environment inhabited by organisms living on or in the ocean bottom. |
| $BOD_5$ | The 5-day biological oxygen demand that is a measure of the biodegradable organic matter contained in an effluent. $BOD_5$ is measured by evaluating the oxygen consumed by the microorganisms involved in natural degradation processes. |
| CD | Chart Datum is a vertical datum corresponding with the Lowest Astronomical Tide (LAT). |
| COD | Chemical oxygen demand is a measure of the oxygen consumption associated with the chemical decomposition of organic and inorganic contaminant, dissolved or particulate, in water. |
| Contact recreation | Contact recreation is defined as recreational activities involving a significant risk of ingestion of water, including wading by children, swimming, water skiing, diving, and surfing. |
| Cumulative impacts | Direct and indirect impacts that act together with current or future potential impacts of other activities or proposed activities in the area/region that affect the same resources and/or receptors. |
| CWDP | Coastal Waters Discharge Permit, necessary requisite for the discharge of all effluents not authorised under the General Authorisation process. The relevant requirements are outlined in the CWDP Regulations (DEA, 2019b), promulgated in 2019. |
| DEA | The former Department of Environmental Affairs, presently the Department of Forestry, Fisheries and the Environment (DFFE). |

| | |
|---|---|
| DFFE | Department of Forestry, Fisheries and the Environment. |
| DFFE: O&C | Department of Forestry, Fisheries and the Environment: Branch Oceans and Coasts (responsible for CWDP authorisations). |
| Desalination | Removal of salt (sodium chloride) and other minerals from the sea water to make it suitable for human consumption and/or industrial use. The most common desalination methods employ reverse-osmosis in which salt water is forced through a membrane that allows water molecules to pass but blocks the molecules of salt and other minerals. |
| Desalination reject brine | The wastewater from a reverse osmosis desalination process that has an elevated salinity compared to the intake waters. For seawater and an assumed plant efficiency of 40%, the reject brine effluent stream is expected to have a salinity of ~ 60 mg/ℓ (or psu). |
| DWA | The former Department of Water Affairs, presently the Department of Water and Sanitation (DW&S). |
| DWAF | The former Department of Water Affairs and Forestry, presently the Department of Water and Sanitation (DW&S). |
| E. coli | Escherichia coli (*E. coli*) are bacteria found in the environment but usually in the lower intestine of warm-blooded organisms (*i.e.* people and animals). They are used as an indicator of bacteriological contamination that could lead to illness. |
| Environment | The external circumstances, conditions and objects that affect the existence of an individual, organism or group. These circumstances include biophysical, social, economic, historical and cultural aspects. |
| Environmental Authorisation | Permission granted by the competent authority for the applicant to undertake listed activities in terms of the NEMA EIA Regulations, 2014. |
| Environmental Impact Assessment | A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project. |
| Faecal coliforms | Faecal coliforms (*f. coli*) are microscopic organisms that live in the intestines of warm-blooded animals. They are used as an indicator of pathogenic organisms in the water that could lead to illness. |
| Far-field | The far-field is the region beyond the near-field. In the far-field secondary dilution processes associated with ambient conditions dominate. The dilution in the far-field is not directly influenced by the diffuser design (*i.e.* no of ports, port exits velocities, *etc.*) but rather are determined by ambient conditions (vertical mixing processes, flows, eddy diffusivity, *etc.*). |
| Filter feeders | Filter feeders are a sub-group of suspension feeding animals that feed by straining suspended matter and food particles from water, typically by passing the water over a specialized filtering structure. Typically, filter feeders refer to shellfish (mollusca) such as mussels and oysters. |
| General Authorisation (GA) | General Authorisation, a simplified process for providing Environmental Authorisation for smaller volume and "cleaner" effluents. Depending on the nature of the discharge and the sensitivity of the receiving environment, the discharge will need to comply with the General Value Limits or Special Value Limits as outlined in (DWA, 2013). |
| GLV | General Limit Values (GN 665 of 2013) as described in (DWA, 2013). |
| Impact | A change to the existing environment, either adverse or beneficial, that is directly or indirectly due to the development of the project and its associated activities. |
| IMT | Institute for Maritime Technology, Simonstown. |

| | |
|---|---|
| Initial dilution | Initial dilution is the process) in which a buoyant plume rises from the diffuser or an open-ended pipeline towards the surface of the sea (or a dense plume descends towards the seabed). As the buoyant (or dense) plume rises (or descends) through the water column there is entrainment of seawater at the periphery of the rising (or descending) plume. |
| Initial mixing zone | The initial mixing zone defines a limited area or volume of the receiving water where the initial dilution of a discharge occurs. |
| Macrofauna | Animals larger than 0.5 mm. |
| Marine Protected Area | An area of sea and coastline that is dedicated to the protection of biodiversity and natural and cultural resources and is managed in a structured and legal manner. Different levels of MPAs exist, ranging from complete no-take zones (where nothing may be disturbed, caught or removed) to partial-take MPAs which have a suite of regulations that determine what activities may take place in which zone. |
| Meiofauna (meiobenthos) | Small benthic invertebrates that are larger than microfauna but smaller than macrofauna. |
| Mitigation Measures | Design or management measures that are intended to minimise or enhance an impact, depending on the desired effect. These measures are ideally incorporated into a design at an early stage. |
| Mixing zone | This comprises a zone around an outfall within which it is acceptable for relevant water and/or sediment quality guidelines to be exceeded. The spatial extend of this zone will be determined by the relevant regulatory authority based primarily on beneficial uses and the environmental sensitivity of the receiving environment. |
| MLD | megalitres per day. |
| MSL | Mean Sea Level. |
| MPN/100 mℓ | Most Probable Number of coliforms per one hundred millilitres of sample water, a statistically estimated measure of contamination of water by coliforms. |
| *n*%tile | the $n^{th}$ percentile value. |
| Near-field | The near-field is the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux, the outfall geometry and ambient flows and water column stratification determine the jet trajectory and mixing of an effluent discharge. Where the buoyant and momentum flux of the effluent plume have been largely dissipated, is considered the outer edge of the near-field. |
| Nearshore | The zone extending seawards from the low water mark to well beyond the surf-zone, typically into water depths of -10 m to -15 m CD. |
| NEMA | South African National Environmental Management Act (No. 107 of 1998, as amended) |
| PDWF | Peak Dry Weather Flow comprising the highest hourly sewage inflow during a period not influenced by rainfall. |
| ppt | parts per thousand. |
| psu | practical salinity units (roughly equivalent to ppt or mg/ℓ). |
| Peak Wet Weather Flow | The PDWF with stormwater inflows/ infiltration added. |
| Preliminary treated effluent | Preliminary treatment generally refers to screening/grit removal (in some cases maceration of the raw sewage effluent) with limited additional treatment technology. |

| | |
|---|---|
| Primary treated Effluent | Primary treatment refers to screening/grit removal with at least primary clarification (*i.e*. settlement of suspended solids (largely physical but sometimes chemically assisted primary clarification). During this primary treatment process approximately 25% to 50% of the biological oxygen demand (BOD) in the incoming wastewater, 50% to 70% of the suspended solids (SS), and 65% of the oil and grease are removed (van Ballegooyen *et al*., 2003; DWAF, 2004b). Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation, but colloidal and dissolved constituents typically are not affected (DWAF, 2004b). |
| Required Dilution | The Required Dilution of an effluent is the number of dilution necessary to ensure that there is compliance with the relevant water quality guidelines. |
| Sacrificial mixing zone | Defines a limited area or volume of the receiving water around the discharge that is non-compliant with the relevant water quality guidelines, target values or standards. In practice, compliance with the relevant water quality guidelines may occur within the near-field or only in the far-field of a hydrodynamic mixing process, as such compliance depends on the nature of the discharge and conditions in the receiving environment, as well as regulatory constraints. |
| Secondary treated effluent | Secondary treatment refers to biological treatment (activated sludge and/or trickling filtration) followed by polishing treatment including disinfection (chlorination, maturation ponds, wetlands). During secondary treatment, 85% to 95% of the suspended solids and the BOD load can be removed (DWAF, 2004b). |
| Secondary dilution | Secondary dilution (Se) (after dissipation of the discharge energy / momentum during the initial dilution phase) is considered to occur when turbulence, eddies and velocity shears result in further entrainment/mixing of the plume with surrounding waters resulting in the further dilution of the effluent plume. In contrast to the initial dilution process, secondary dilution cannot be influenced by the design of the outfall and is primarily dependent on the ambient oceanographic conditions. |
| SPP | Sewage Package Plant |
| Suspended Solids (SS) | Particulate material (biological and non-biological) suspended in the water column. |
| Subtidal | The marine habitat that lies below the level of mean low water for spring tides. |
| Supratidal | The area above the spring high tide mark that is not submerged by seawater. Seawater penetrates these elevated areas only at high tide during storms. |
| Surficial Sediments | Conservatively defined as the upper 20 cm of sediments in the marine environment. |
| Surf zone | Zone extending seawards of the high water mark to a point where the largest waves begin to break. |
| TAN | Total ammonia nitrogen ($NH_3$-N + $NH_4^+$-N) |
| Total suspended solids (TSS) | Total particulate material (biological and non-biological) suspended in the water column. |
| Toxicity | The inherent potential or capacity of a material to cause adverse effects in a living organism. |
| WWTW | Wastewater Treatment Works. |
| Zone of non-compliance | This is a zone surrounding an outfall where water and/or sediment quality guidelines are exceeded. Whether the spatial extent of this zone is environmentally acceptable will be determined by the relevant regulatory authority that will define a mixing zone (or sacrificial zone) within which it is acceptable for water and/or sediment quality guidelines to be exceeded. |

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# 1 INTRODUCTION

## 1.1 BACKGROUND

Robben Island, located approximately 10 km north of the V & A Waterfront in Cape Town. It has a relatively small permanent population of approximately 200 residents and is visited by as many as 3 200 people during the peak tourist season.

Currently there is no formal wastewater treatment works (WWTW) on Robben Island. All sewage is pumped via 6 pump stations to a central collection sump where it is macerated and pumped along the marine outfall sewer pipeline to discharge via a diffuser located approximately 465 m offshore (Elemental, 2021). The outfall was constructed in 2001 following an upgrade to the island's wastewater handling facilities (WSP|PB, 2014a).

Subsequently, a decision was made to upgrade the existing facilities by constructing a Sewage Package Plant (SPP) on Robben Island, the intention being to improve the *status quo, i.e.* changing from the discharge of an essentially untreated effluent to the discharge of an effluent complying with General Limit Values (GLV) (GN 665 of 2013 – DWA, 2013). A Basic Assessment process was followed for the Environmental Authorisation of the proposed upgrade (WSP|PB, 2014a). The requisite Environmental Authorisation for the proposed SPP was received on 25 March 2015 (DEA, 2015). A Coastal Waters Discharge Permit (CWDP) application was made on 14 May 2014 for the effluent discharge from the proposed new SPP.

WSP|Parsons Brinckerhoff was appointed by the Coega Development Corporation in 2016 to design and implement a new WWTW for Robben Island, however this did not include any upgrading of the existing marine outfall infrastructure as this was not deemed necessary as the effluent to be discharged did not exceed the existing design capacity of the marine outfall (WSP, 2017a,b). Infrastructure proposals were made during the concept and viability stage of the project (WSP, 2016, 2017a,b). However, due to a lack of available funding at that time, the project was not able to progress to the design development stage. The 25 March 2015 Environmental Authorisation for the project subsequently lapsed. Upon request, an extension of the Environmental Authorisation was granted on 27 March 2018. However, this extension to the Environmental Authorisation also lapsed on 27 March 2020.

WSP in Africa (Environmental) has been contracted to undertake a renewed Basic environmental impact assessment for the proposed WWTW. As part this process WSP in Africa: Water and Maritime has been asked to review and update the original specialist dispersion modelling study (WSP|PB, 2014b), based on existing policy and legislation and the presently proposed WWTW design (Elemental, 2021).

## 1.2 OBJECTIVE OF THE STUDY

The purpose of this study is to provide an updated specialist dispersion modelling report to inform both the updated specialist marine ecology assessment and BAR to be submitted as part of the Environmental Authorisation process presently being undertaken for the proposed Robben Island WWTW.

## 1.3 SCOPE OF WORK

WSP in Africa: Water and Maritime has been tasked to review and update the original specialist dispersion modelling study (WSP|PB, 2014b) undertaken for the 2014 BAR, taking into account any changed requirements in terms of guidance documents (Anchor Environmental, 2015; DEA, 2014), as well as any changes water quality guidelines (DEA, 2019a) and/or the CWDP regulations issued in 2019 (DEA, 2019b).

## 1.4 STRUCTURE OF THE REPORT

The background and context to this study is outlined in Section 1, while Section 2 provides a more detailed project description. Included in this description is brief overview of the proposed WWTW plant and the wastewater effluent volumes and quality expected from the plant, as well as a high-level description of the existing Robben Island marine outfall infrastructure.

The environmental policy, legislation and regulations of relevance to the study are provided in Section 3. Also provided in this section are the applicable water quality guidelines and required dilutions necessary to ensure compliance of the various effluents constituents with these water quality guidelines. Section 3 also includes a discussion of the concept of achievable dilution in both the near- and far-field surrounding the Robben Island marine outfall.

A description of the receiving environment and the relevant processes determining the dispersion and ultimate fate of the proposed effluent discharge from the WWTW, is provided in Section 4. This includes a characterisation of the representative current flows that is used in the model predictions of achievable dilutions of the effluent.

The modelling approach and relevant model parameters are described in Section 5. The resultant model results are presented in Section 6 where a detailed assessment is provided of the compliance of the effluent from the proposed new Robben Island WWTW with the relevant water quality guidelines.

The conclusion and recommendations of this study are provided in Section 7, the final section of this report.

# 2 PROJECT DESCRIPTION

## 2.1 GENERAL

The Robben Island Museum (RIM) proposes to upgrade the existing sewage handling system on Robben Island with the construction of a WWTW. The plant, which will be located adjacent to the existing sewage collection unit ~600 m south of Murray's Harbour. The WWTW will have a treatment capacity of 108,000 $m^3$ per annum (or ~300 $m^3$ /day) and will treat all sewage and domestic wastewater generated on the island, resulting in a wastewater effluent that will comply with General Limit Values effluent quality standards (GN 665 of 2013). The treated effluent will be transported via an existing pipeline to the existing sea outfall pipeline and discharged to sea (Figure 2-1). An estimated 120 $m^3$ of sludge produced annually as part of the treatment process will be dried on drying beds on the island, and either used as fertiliser or disposed of via the normal refuse system (Elemental, 2021).


**Figure 2-1: The location of proposed WWTW (red polygon) and the existing marine outfall in relation to Murray's Bay Harbour on Robben Island.**

A modular treatment plant, comprising relatively large chambers and based on a flow-through system is proposed. The system enables long retention times thereby allowing the biological action of the bacterial colonies in the chambers to reduce sludge production to minimal levels, thus virtually eliminating the need for sludge removal. Following initial screening and solids removal, the treatment process involves a number of inter-linked processes (see Figure 2-2):

- An anaerobic primary settler containing facultative bacterial colonies that initiate contamination reduction of the raw product through anaerobic oxidation and gross removal of organic material by settlement.

— An anoxic second settler, which promotes de-nitrification and releases nitrogen to the atmosphere in undetectable quantities. Nitrate-rich sludge returned from the final settler enhances the efficiency of the de-nitrification process thereby improving the quality of the effluent.
— An aerobic bio-reactor in which further organic reduction and ammonia nitrification is achieved under aerobic conditions using Rotating Biological Contactors (RBCs) within the aerobic reactor. The aerobic conditions are achieved by the rotation of discs, on which the micro-organism are attached and growing, at a low speed of approximately 3 to 4 RPM. This generates an oxygen-rich effluent flow, which completes the process of de-nitrification to nitrates. There will be six rotors, each capable of treating 30 kℓ of domestic sewage per day.
— A secondary settling tank (humus tank) in which de-nitrification is completed. Removal of the settled nitrate-rich sludge and return thereof to the anaerobic primary settler for digestion.
— Final disinfection by chlorine dosing at 1 – 2 ppm with HTH calcium hypochlorite. This ensures that any remaining microorganisms or pathogens are destroyed before the treated water is released into the environment.

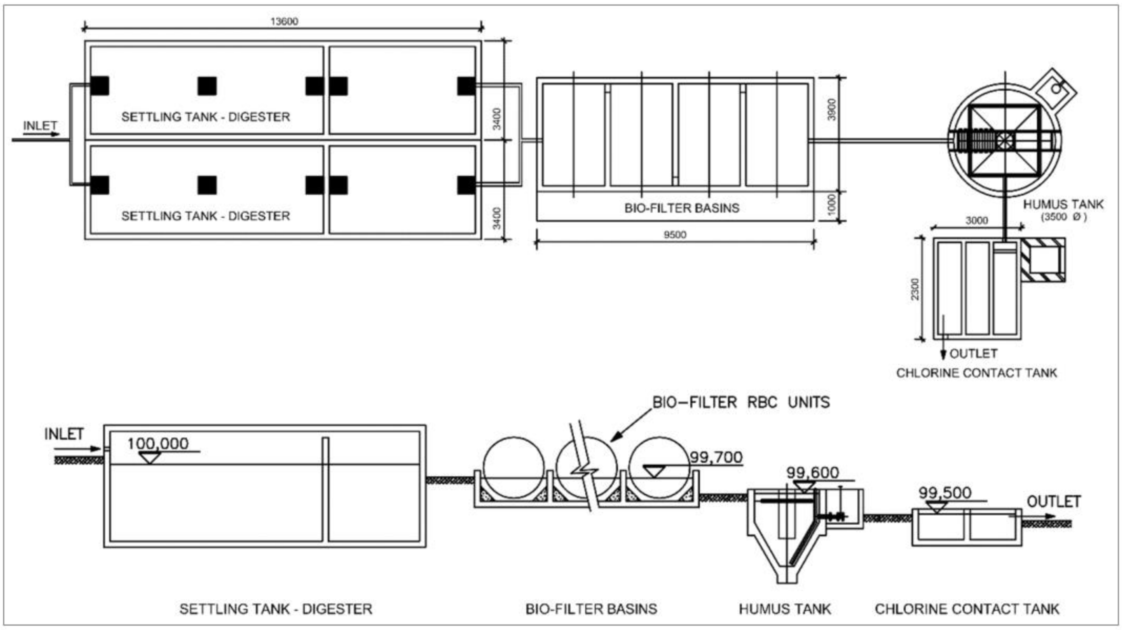



**Figure 2-2: Schematic of the proposed modular wastewater treatment process (Source: Elemental, 2021).**

The Schematic in Figure 2-2 above is for a 200 kℓ/day plant which should be sufficient for the likely wastewater flows generated on the island, however the preliminary design report indicated that a WWTW with a 300 kℓ/day should be provided to compensate for reduced biological activity in the WWTW due to the expected elevated saline conditions in the influent water to the WWTW. This is consistent with the 2014 BAR and associated Environmental Authorisations. The present Environmental Authorisation process thus also will be for a WWTW with a 300 kℓ/day capacity, despite the final recommendation (Elemental, 2021) that a WWTW with only a 200 kℓ/day capacity be built[1].

[1] This recommendation is based on the view that the saline conditions observed in the influent to the WWTW are due to the flushing of the sewer pipelines with brine from the desalination plant rather than major infiltration of saline groundwater into the system and the fact that, at some future date, maintenance can and will be undertaken to prevent infiltration into the sewer pump stations and infiltration of groundwater by replacement of sewer pipelines.

## 2.2 EFFLUENT DISCHARGE SCENARIOS

The effluent discharge scenarios of relevance to this modelling dispersion study are described below.

### 2.2.1 EFFLUENT QUANTITY

The existing marine outfall was designed for the discharge of an effluent comprising both untreated sewerage and a brine effluent from the desalination plant (Wamtech and Rossouw, 1999). When commissioned, the outfall operated under an environmental exemption authorisation (Exemption number 2098B) issued by the Department of Water affairs and Forestry on 2 November 2000 (see Appendices to WSP, 2014c). The exemption allowed the discharge of 223 000 $m^3$ per annum comprising 400 $m^3$/day of sewage and a "storm water" (presumably mostly groundwater) ingress of an additional 15% (~60 $m^3$/day) during 365 days per annum, plus a further 150 $m^3$ per day of (reject) brine from the desalination plant. The initial design of the marine outfall considered peak dry weather flows (PDWF) of sewage of 25 ℓ/s and 7 ℓ/s of brine effluent. Although the average dry weather flow (ADWF) was not specified in the report, based on the assumed effluent quality to be discharged under ADWF conditions, the inferred ADWF is ~ 18 ℓ/s. This is consistent with the assumption that the effluent typically would be discharged intermittently at a rate of 25 ℓ/s though the marine outfall but inconsistent with expected peaking factors for small sewage works (*e.g.* Noziac and Freeze, 2010; DPW, 2012). (Note that the design included the option of a 50 ℓ/s discharge to flush any deposited sediments from the outfall.) Given the daily flow limits in the exemption (*i.e.* a total of 610 $m^3$/day), implies that discharge at these flow rates (a total of 25 ℓ/s) would occur for a total duration of approximately 6 hours and 45 minutes daily.

For the 2014 BAR specialist wastewater dispersion study (WSP|PB, 2014b), a wastewater effluent discharge of discharge 300 $m^3$/day was assumed. However, the effluent being discharged comprised only the wastewater from the proposed Sewage Package Plant (SPP) and excluded any desalination brine effluent. A design flow rate of 25 ℓ/s was used in in the dispersion modelling study. This comprised an intermittent discharge, occurring for an estimated cumulative total duration of approximately 3 hours and 20 minutes each day.

The expected wastewater flow volumes to be discharged via the marine outfall after the commissioning of the presently proposed WWTW, are discussed in the design reports for the proposed WWTW (WSP, 2017a,b and Elemental, 2021). Based on the number of residents and visitors to the island, together with a number of assumptions on water usage and infiltration into the sewer system, an initial estimate of 82.74 $m^3$/day was made for the total daily wastewater flow likely to enter the WWTW (WSP, 2016). However, in the subsequent preliminary design report, this estimate was increased to an average of ~ 156 $m^3$/day, comprising about 136 $m^3$/day of wastewater plus an additional estimated 20 $m^3$/day of infiltration of (saline) groundwater (WSP, 2017a).

<u>Assuming that the elevation in salinity was due to solely groundwater infiltration</u>, available total dissolved solids concentration data[2] indicated that the inflows to the WWTW would comprise 72.15% sewage and 27.85% groundwater (WSP, 2017a). Based on these observations, the total wastewater inflows to the WWTW again

[2] Initial measurements indicated elevated total dissolved solids (TDS) concentrations in the sewage inflows of between 2 000 mg/ℓ (a salinity of ~ 2 ppt) in the day-time and a TDS = 7 000 (a salinity ~ 7 ppt) in the night-time (WSP, 2017a). Subsequent more detailed measurements (n=19) indicated that the TDS concentrations varied between 1 000 mg/ℓ (during high sewage inflow periods) to 22 000 mg/ℓ (during little / no sewage inflow periods). The TDS concentrations were highly variable with a mean TDS value of ~7 000 mg/ℓ (salinity ~7 ppt). Assuming these /elevations in salinity to be solely due to groundwater infiltration, groundwater infiltration volumes were inferred from these data (WSP, 2017b).

were revised upwards to an estimated ~ 136 $m^3$/day of sewage and 52 $m^3$/day of saline groundwater, suggesting a combined flow of ~188 $m^3$/day[3].

While these estimates suggested that a 200 $m^3$/day WWTW capacity would be sufficient in terms if these inflows, it was proposed by WSP to design the plant with a 50% overcapacity to compensate for the effects that the elevated salinities in these inflows are likely to have on the plant efficiency (WSP, 2017b). The resultant proposed capacity of 300 $m^3$/day is consistent with the capacity suggested in the 2014 BAR (WSP|PB, 2014a).

As noted above, the present Environmental Authorisation process will be for a WWTW with a 300 kℓ/day capacity, despite the final recommendation that only a WWTW with only a 200 kℓ/day be built (Elemental, 2021). Consequently, this study thus assumes a daily wastewater effluent flow of 300 $m^3$/day that is intermittently discharged at a rate of 25 ℓ/s via the existing marine outfall. The wastewater effluent flows will comprise only effluent from the WWTW as it is recommended that the practise of flushing the sewer and marine outfall pipelines with (reject) brine from the desalinations plant will need to cease to avoid possible compromising of the biological processes within the WWTW and the resultant risk of generating wastewater effluent that does not meet the required water quality standards, *i.e*. the General Limit Values (GN 665 of 2013).

### 2.2.2 EFFLUENT QUALITY

As noted above, the existing marine outfall was designed in 1999 assuming a combined effluent comprising both a sewage effluent and desalination (reject) brine effluent (Wamtech and Rossouw, 1999). The effluent characteristics and quality assumed in that study, is summarised in Table 2-1 below.

Based on the relevant South African Water Quality Guidelines (DWAF (1995a-b), required dilutions of < 60 were required for all constituents of the combined preliminary treated sewage and brine effluent, other than suspended solids and F. coli, the required dilutions for these two parameters being significantly higher. The near-field modelling showed that initial dilutions exceeded 60 dilutions for a discharge depth of 7 m for all prevailing environmental conditions.

Far-field predictions using the analytical methods of Brookes (1960) that applies the so-called "4/3 law" as described in Botes and Taljaard (1996), were used to assess the suspended solids and F. coli components of the effluent as these did not comply with the relevant water quality guidelines in the near-field. The results showed that there would be compliance with the suspended solids water quality criterion within 200 m of the outfall. Using a bacterial die-off rate ($T_{90}$) of 1.5 hours it was demonstrated that for a discharge depth of 7.0 to 7.5 m there would be compliance with the direct contact and collection of filter feeder guidelines within 1 000 m of the discharge for a representative range of environmental conditions. No comment was made on the compliance for expected bacterial die-off rates under night-time conditions when $T_{90}$ values of 24 hours or greater are expected (van Ballegooyen *et al*., 2016), suggesting a more extensive area of non-compliance under night-time and early morning conditions.

The SPP proposed in 2014 was designed to generate a wastewater effluent that would be compliant with the General Limit Values (GN 665 of 2013 – DWA, 2013), a much improved effluent compared to the preliminary treated effluent for which the marine outfall was originally designed. This is the same effluent quality that will be generated by the presently proposed WWTW.

The General Limit Values (GN 665 of 2013) proposed for the effluent from the WWTW are summarised in Table 2-2 below.

3 There is significant uncertainty related to the estimates of groundwater infiltration as this was inferred from TDS monitoring data (WSP, 2017a,b). The most recent design reports suggest that the high salinities in the influent to the WWTW are more likely a consequence of residual salinity from the present practice of flushing the sewer pipelines with the (reject) brine from the desalination plant, rather than infiltration of saline groundwater. This suggests that the groundwater infiltration volumes may have been overestimated in the orginal design reports (WSP, 2017a, b).

**Table 2-1: Design flow and effluent composition (for ADWF) used to design the existing Robben Island marine outfall.**

| Parameter | Value | | | |
|---|---|---|---|---|
| | Wamtech & Rossouw (1999) | | | WSP\|PB (2014b) |
| Design flow during (intermittent) discharge) | 18ℓ/s | 7 ℓ/s | 25 ℓ/s | 25 ℓ/s |
| Effluent density | 1 000 kg/m³ | 1 020 kg/m³ | 1 007 kg/m³ | 1 007 kg/m³ |
| Effluent Quality | | | | |
| | Sewage | Brine | **Combined** | **Combined** |
| pH | 7.4 | 7.4 | 7.4 | 7.4 |
| BOD | 400 mg/ℓ | 50 mg/ℓ | 300 mg/ℓ | 344 mg/ℓ |
| COD | - | - | - | 442 mg/ℓ |
| Suspended solids | 350 mg/ℓ | 5 mg/ℓ | 250 mg/ℓ | 308 mg/ℓ |
| Total Phosphate | 8 mg/ℓ | 0.1 mg/ℓ | 6 mg/ℓ | 6 mg/ℓ |
| Total Kjeldahl Nitrogen (TKN) | | | 51.8 mg/ℓ | 51.8 mg/ℓ |
| Total $NH_4$ - N | 18 mg/ℓ | 0.1 mg/ℓ | 18 mg/ℓ | 18 mg/ℓ |
| Copper (Cu) | 0.27 mg/ℓ | 0.000 8 mg/ℓ | 0.25 mg/ℓ | 0.27 mg/ℓ |
| Lead (Pb) | 0.16 mg/ℓ | 0.000 5 mg/ℓ | 0.15 mg/ℓ | 0.16 mg/ℓ |
| Zinc (Zn) | 0.42 mg/ℓ | 0.006 mg/ℓ | 0.40 mg/ℓ | 0.42 mg/ℓ |
| F. coli | 7.2 x $10^6$ | 0 | 7 x $10^6$ | 7.2 x $10^6$ |

* Discrepancies exist between the values reported in Wamtech and Rossouw (1999) and those reported in WSP|PB (2014b) thus both sets of data are reported in the table above.

**Table 2-2: General and Special Wastewater Limit Values (DWEA, 2013), and effluent composition of existing marine outfall (WAMTECH & Rossouw 1999). For context, the special limits and the presently existing wastewater effluent quality also are provided.**

| Substance/Parameters | Unit | General Limit Value | Special Limit Value*2 | Existing Discharge |
|---|---|---|---|---|
| Faecal Coliforms | per 100 mℓ | 1,000 | 0 | 7,200,000 |
| Chemical Oxygen Demand (COD) | mg/ℓ | 75 (after removal of algae) | 30 (after removal of algae) | |
| Biological Oxygen Demand (BOD) | mg/ℓ | - | - | 344 |
| pH | | 5.5 - 9.5 | 5.5 - 7.5 | 7.4 |
| Ammonia (ionised & unionised) as Nitrogen ($NH_3$-N + $NH_4^+$-N) | mg/ℓ | 6 | 2 | 18 |
| Nitrate/Nitrite as Nitrogen ($NO_3$-N and $NO_2^-$-N) | mg/ℓ | 15 | 1.5 | ~ 18 |
| Chlorine as Free Chlorine | mg/ℓ | 0.25 | 0 | |
| Suspended Solids (SS) | mg/ℓ | 25 | 10 | 308 |
| Electrical Conductivity (mS/m)*1 | mS/m | 70 mS/m above intake to a maximum of 150 mS/m | 70 mS/m above intake to a maximum of 150 mS/m | |

| Substance/Parameters | Unit | General Limit Value | Special Limit Value*[2] | Existing Discharge |
|---|---|---|---|---|
| Ortho-Phosphate as phosphorous ($PO_4$-P) | mg/ℓ | 10 | 1 (median) and 2.5 (maximum) | 6 |
| Fluoride | mg/ℓ | 1 | 1 | |
| Soap, oil or grease | mg/ℓ | 2.5 | 0 | |
| Dissolved Arsenic | mg/ℓ | 0.02 | 0.01 | |
| Dissolved Cadmium | mg/ℓ | 0.005 | 0.001 | |
| Dissolved Chromium (VI) | mg/ℓ | 0.05 | 0.02 | |
| Dissolved Copper | mg/ℓ | 0.01 | 0.002 | 0.27 |
| Dissolved Cyanide | mg/ℓ | 0.02 | 0.01 | |
| Dissolved Iron | mg/ℓ | 0.3 | 0.3 | |
| Dissolved Lead | mg/ℓ | 0.01 | 0.006 | 0.16 |
| Dissolved Manganese | mg/ℓ | 0.1 | 0.1 | |
| Mercury and its compounds | mg/ℓ | 0.005 | 0.001 | |
| Dissolved Selenium | mg/ℓ | 0.02 | 0.02 | |
| Dissolved Zinc | mg/ℓ | 0.1 | 0.04 | 0.42 |
| Boron | mg/ℓ | 1 | 0.5 | |

*[1] Given that the discharge will occur into a marine environment, the upper limitation on conductivity is only relevant in terms of its effect on outfall performance. Note 70 mS/m ≈ salinity of 0.4 ppt and 150 mS/m ≈ salinity of 1.0 ppt.

*[2] A more restrictive guideline used for effluent discharges into listed water resources.

The (ortho-) phosphate concentrations in the existing sewage flows (*i.e.* in the expected influent to the WWTW) mostly are lower than the 10 mg/ℓ limit in the General Limit Values. While the average phosphate concentrations in domestic sewage or wastewater with a high domestic component are expected to range between 10 mg/ℓ and13 mg/ℓ, measurements for the Robben Island sewage during Feb 2017 indicated a < 10% exceedance of this value.

It is expected that the wastewater effluent from the proposed new WWTW will be in the region of 4 to 6 mg/ℓ (email from Elemental – 18 Aug 2021). Phosphate removal therefore does not form part of the process design for the proposed WWTW. Should phosphate removal be required, it will not be too costly in terms of capital costs but will be so in terms of operational costs (Elemental, 2021).

WSP (2017b) considered using gas or liquid sodium hypochlorite for the disinfection of the final effluent before discharge via the marine outfall. However, the disinfection was not recommended due to the concern that it may do more harm than good (*i.e.* the presence of chlorine in an old pipeline and the fact that the effluent would possibly contain a significant chlorine residual when exiting the marine outfall diffuser). The final design (Elemental, 2021) proposes a chlorine contact channel where the wastewater effluent will be dosed with a disinfectant, through the installation of a pod system using chlorine tablets. The likely chlorine residual in the effluent is uncertain but is expected to be < 0.1 mg/ℓ (*e.g.* van Ballegooyen *et al*., 2007) which is lower than the General Limit Value of 0.25 mg/ℓ specified for the effluent from the proposed new WWTW.

As noted in Section 2.2.1, the wastewater effluent flows will comprise only the wastewater effluent from the WWTW as it is recommended that the practise of flushing the sewer and marine outfall pipelines with (reject) brine from the desalinations plant will need to cease to avoid possible compromising of the biological processes within the WWTW and the resultant risk of generating wastewater effluent that does not meet the required water quality standards, i.e. the General Limit Values (GN 665 of 2013).

Alternatives to such flushing operations using brine effluent to prevent clogging of the pipelines due to low flow conditions were suggested in the most recent design report (Elemental, 2021), however a final solution is yet to be decided upon. The two alternatives of flushing the pipes with existing WWTW final effluent or potable water from the desalination plant (Elemental, 2021) will not result in a poorer quality effluent than presently is being assessed in this study. These flow conditions (effluent volumes and quality) used in the present study are the same as those assumed in the 2014 specialist effluent dispersion modelling study (WSP|PB, 2014b) for the 2014 BAR environmental authorisation process (WSP|PB, 2014a).

## 2.3 ENGINEERING CONCEPT AND DESIGN

It is proposed that the existing marine outfall and diffuser structures be utilised to discharge the wastewater effluents from the proposed new WWTW. The existing pipeline was designed by ZLH Consulting Engineers and constructed by Sea and Shore Contractors in 2000. The installation and commissioning of the marine outfall in 2001 was part of the construction of the current sewage collection and disposal facility. Based on effluent dilution studies (Wamtech and Rossouw, 1999), the outfall was designed with a 10 m long diffuser comprising three sections tapering from 200 mm diameter, through 160 mm to 110 mm. The first diffuser section was fitted with a single 100 mm and the second and third sections each with a single 110 mm port discharging horizontally to alternate sides of the main diffuser pipe thereby ensuring optimum diffusion of the effluent. The design details are summarised in Table 2-3 with the relevant drawing provided in Appendix A of this report.

**Table 2-3: Existing outfall configuration (Wamtech and Rossouw, 1999 and Drawing numbers 512-140 and C4833).**

| | |
|---|---|
| **Marine Pipeline** | |
| Pipeline length | 465 m |
| Pipeline Material | HDPE |
| Pipe diameter (ID) | 200 mm (PIPE CLASS 16) |
| **Diffuser** | |
| Diffuser depth | 8 m |
| Diffuser length | 10 m |
| No of ports | 3 |
| Port Height | 780 mm above main pipeline |
| Port direction | Horizontal discharge to alternate sides of the main diffuser pipe (the final port at the end of the diffuser discharging at an angle of 45º from horizontal in an offshore direction) |
| Number of diffuser sections | 3 sections |
| Tapers in main diffuser pipe (Inside Diameter) | 1st taper to 160 mm (PIPE CLASS 16) |
| | 2nd taper to 110 mm (PIPE CLASS 16) |
| Main pipe and port diameter per diffuser section | 1st section: Main pipe diameter = 200 mm ID; 1 ports; Port dia = 100 mm ID |
| | 2nd section: Main pipe diameter = 160 mm ID; 1 ports; Port dia = 110 mm ID |
| | 3rd section : Main pipe diameter = 110 mm ID; 1 ports; Port dia = 110 mm ID |
| Port spacing | 3.5 m |

No detailed assessment of the condition of the outfall and its diffuser was made available to the WSP team undertaking this study. It was reported in 2017 that from visits to site there had been no operational flaws/problems noted and from discussions with plant operators there had been no incidents on site regarding malfunction of the marine outfall pipeline (WSP, 2017b). The assumption for the present study therefore is that the existing marine outfall is fully functional as designed.

# 3 POLICY, LEGISLATION AND ENVIRONMENTAL QUALITY OBJECTIVES

## 3.1 GENERAL

A brief overview of statutory requirements and legislative frameworks, as well as the environmental authorising and permitting process follows, the purpose being to provide the necessary context for this specialist effluent dispersion modelling study.

### *3.1.1 STATUTORY REQUIREMENTS AND LEGISLATIVE FRAMEWORK*

Prior to the promulgation of the Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) (ICMA), the disposal of land-derived effluent into the coastal environment through pipelines was controlled and regulated by the Department of Water Affairs (DWA)[4], under the National Water Act, 1998 (Act No. 36 of 1998) (NWA). Guidance on regulation and management of such discharges was provided by a series of reports outlining the Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa (DWAF, 2004a-c).

Through the promulgation of the ICMA, this responsibility was transferred to the Department of Environmental Affairs (DEA). The Department of Environmental Affairs was renamed the Department of Forestry, Fisheries and the Environment (DFFE) in June 2019, incorporating the forestry and fisheries functions from the previous Department of Agriculture, Forestry and Fisheries (DAFF). Thus, the responsibility now lies with DFFE.

The ICMA is aimed at regulating the discharge of effluent into the coastal waters from any source on land (Section 69) by requiring that such discharges be authorised under a Coastal Waters Discharge permit (CWDP) or General Authorisation (GA). These authorisations are the Responsibility of DFFE Oceans and Coasts Division (DFFE:O&C) who have adopted the principles contained in the 2004 version of the Operational Policy referred to above and has developed two further key documents of relevance, namely:

- A *National Guideline for Coastal Effluent Discharges from Land-based Sources* (DEA, 2014) that takes cognisance of legislation and principles developed post-2004. This guideline includes a hierarchy of decision-making that contains elements of the Receiving Water Quality Objectives approach, as well as the Precautionary Principle of Environmental Protection that includes the key elements of source reduction, waste minimisation and responsible disposal.
- An *Assessment Framework for the Management of Effluent from Land-based Sources Discharged to the Marine Environment* (Anchor Environmental, 2015) that had as its key objective the development of an assessment framework that includes an effluent classification scheme as well as an approach that can be used to inform specific levels of assessment required for different types of effluent and also for determining discharge requirements/limits that should be applied in the different receiving environments. This document has been finalised, following a comprehensive public participation/consultation process.

4 presently the Department of Water and Sanitation (DW&S).

### 3.1.2 CLASSIFICATION OF THE PROPOSED EFFLUENT

The effluent comprises a standard wastewater effluent that does not include any waste water components of industrial origin. Furthermore, it is proposed that the effluent generated from the proposed new WWTW is consistent with the General Limit Values (GN 665 of 2013).

### 3.1.3 ENVIRONMENTAL AUTHORISATION AND COASTAL WATERS DISCHARGE PERMITTING PROCESS

In applying for Environmental Authorisation and a Coastal Waters Discharge Permit (CWDP) a holistic process needs to be followed whereby, beneficial uses in the receiving environment are identified and the potential impact of the discharge on the receiving environment, are assessed using recognised techniques for scientific assessment.

In applying for a CWDP evidence will be required that the discharge system has been designed, constructed and operated in accordance with recognised scientific, hydraulic and structural guidelines in order to ensure that relevant Environmental Quality Objectives are met. Potential impacts on the receiving environment will need to be assessed in both the near- and far-field and will need to take into account other anthropogenic activities and waste inputs when assessing possible synergistic or cumulative effects. Guidelines for such an assessment are outlined in detail in DWAF (2004b, c) and more recently summarised in Anchor Environmental (2015), with more specific detailed requirements outlined in the CWDP Regulations (DEA, 2019b) promulgated in 2019.

In terms of the CWDP Regulations the information necessary for a CWDP application is listed below. The information provided in this report is italicised in the list below. The remainder of the information is contained in the design report for the proposed project (Elemental, 2021), the Final Basic Assessment Report (WSP, 2021) and the specialist reports contained in its Appendices (mainly the marine ecology impact assessment report (Pisces, 2021)). Note that in terms of the receiving environment, this report provides only the detail of the coastal processes relevant to the modelling and assessment of the dispersion of the proposed WWTW discharge.

The CWDP necessarily needs to include the following information:

**General Information**

- a motivation explaining the reasons for the decision to discharge effluent into coastal waters as opposed to other alternative waste management measures;
- *detailed maps of the location of the infrastructure generating the effluent as well as the location of the infrastructure responsible for discharging the effluent and its Global Positioning Satellite (GPS) coordinate(s);*
- *provide a sufficiently detailed description of the receiving environment into which the effluent is, or will be discharged;*
- *provide details of any areas within a 1000 meter radius from the point of discharge which may be adversely affected as a result of the discharge, including marine protected areas, residential areas, recreational use areas, tourism areas, aquaculture use areas, seawater abstraction and industrial use areas;*
- provide details of any existing discharges within a 300 meter radius from the point of discharge being applied for;
- where applicable, provide the environmental authorisation and its reference number issued in respect of the discharge and its associated infrastructure or where one has not been issued, provide details of the status of the relevant environmental impact assessment process;
- *identify the activity, process or operation from which the discharge emanates*;

- provide details of the measures that are, or where applicable, will be undertaken, for the avoidance and prevention, minimisation and recycling of the effluent;
- demonstrate that discharging the effluent into coastal waters is the best practicable environmental, social and economic option;
- *provide all information about the characteristics of the effluent, its constituents and chemical composition, including:*
  - *its buoyancy;*
  - *the average concentration for all of the effluent's constituents per month;*
  - *the maximum discharge concentration for all the effluent's constituents; and*
  - *the quality variables applicable to the discharge and its unit of measurement;*
- *provide information about the maximum output volume, in cubic meters, anticipated for dry weather and wet weather, calculated for total volumes per day, per month and per year;*
- provide a proposed monitoring plan which illustrates how the applicant will, if the permit is granted, address the following:
  - system performance monitoring; and
  - the frequency, parameters and manner of sampling the effluent;
- where applicable, provide historic monitoring data for the discharge;
- provide details of any applicable estuarine management plan, in the case of a discharge into an estuary; and
- *the extent of a mixing zone, if required by the applicant.*

**Specialist Technical and Engineering Information**

- *the chemical, physical, geological, hydrological and biological processes and reactions that:*
  - *govern the composition of the receiving environment; and*
  - *which influences the dispersion of the effluent;*
- *a description of the process responsible for the generation of the effluent;*
- a report on the marine ecology of the proposed mixing zone and the natural receiving environment, including information on the marine habitats and its populations which may be affected by the discharge;
- *where applicable, the environmental factors that may assist in the die-off of any micro-organisms in the effluent;*
- *the optimum dispersion of the effluent for the discharge;*
- *the level of dilution of the effluent which can be achieved in the proposed mixing zone;*
- *the sedimentation or the re-suspension of solid-phase particles in the effluent;*
- *where applicable, details of the hydraulic design of the pipeline and the alternative proposals for the placement of the pipeline;*
- *where applicable, the structural integrity of the pipeline and its diffusers, as well as its structural design including details regarding the future decommissioning of the pipeline; and*
- *a detailed description of maintenance plans for the pipeline, associated infrastructure, recording and sampling devices.*

## 3.2 ENVIRONMENTAL QUALITY OBJECTIVES

The Environmental Quality objectives used for the dispersion modelling study are determined by both the sensitivity of the natural environment and beneficial uses in the area potentially impacted by proposed WWTW effluent discharge.

Robben Island is located within the West Coast Rock Lobster Sanctuary which extends from Melkbos Point to "Die Josie" near Chapmans Peak and extend 12 nautical miles seawards of the high water mark (Pisces, 2021). In addition, the marine environment around Robben Island within a one nautical mile buffer zone around the island, is legally protected as a National Heritage Site through the National Environmental Management Act (Act No 107 of 1998); National Environmental Management: Biodiversity Act (Act No 10 of 2004); and the National Environmental Management: Protected Areas Act (Act No 57 of 2003) (amongst others). Despite this one nautical mile exclusion zone around the island, and its inclusion in the West Coast Rock Lobster Sanctuary, the waters around the island have for many years been targeted by rock lobster and abalone poachers, and consequently these populations have been severely depleted. Nonetheless, an annual Total Allowable Catch (TAC) of 20 tonnes is currently still allocated to the commercial harvest of abalone in Zone F around Robben Island (Pisces. 2021).

## 3.3 RELEVANT WATER AND SEDIMENT QUALITY GUIDELINES

In terms of the existing water quality guidelines (DWAF, 1995a-d), the beneficial use areas for the marine environment are as summarised in Table 3-1 below. The DWAF (1995a-d) guidelines remain the official South African Water Quality guidelines documents, despite the process underway to update the South African Marine Water Quality Guidelines (DEA, 2019b). The only exception are the guidelines related to recreational waters (DWAF, 1995b) that have been replaced by interim guidelines for recreational waters (DEA, 2012).

**Table 3-1: Coastal areas: beneficial uses (DWAF, 1995a-d).**

| Beneficial Use Category | Description |
|---|---|
| Mariculture | Refers to the farming of marine and/or estuarine organisms in land-based (*i.e.* 'off-stream' tanks using pumped seawater) or water-based (*i.e.* 'in-stream') systems. |
| Industrial use | Wastewater discharges, cooling water, desalination, aquariums, ports and harbours. |
| Recreational Use | Full contact recreation: Activities such as swimming, diving (scuba and snorkelling), water skiing, surfing, paddle skiing, wind surfing, kite surfing, parasailing and wet biking.<br>Intermediate contact recreation: Activities such as boating, sailing, canoeing, wading, and angling, where users may come in contact with the water or swallow water.<br>Non-contact recreation: all recreational activities taking place in the vicinity of marine waters, but which do not involve direct contact, such as sightseeing, picnicking, walking, horse riding, hiking etc. |
| Filter feeders | Collection of filter feeders for food consumption. |
| Natural Environment | The entire area potentially impacted should be considered as natural environment. |

An assessment of the relevant beneficial use areas was undertaken in 1999 as part of the design of the existing outfall (Wamtech and Rossouw, 1999). According to that assessment, no recreational areas and areas where filter feeder were collected for food were identified which could be adversely affected by the ocean outfall. A similar observation was made for the 2014 dispersion modelling assessment (WSP|PB, 2014b), meaning that the only water quality guidelines of relevance are those related to the Natural Environment. This study makes no such assumption.

For completeness, all guidelines are listed in Table 3-2 below. The guidelines in light grey text represent the proposed new guidelines (DEA, 2019b) that presently are in draft form. For context, the recommended Western Indian Ocean (WIO) water quality guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009) are also provided in grey text (where deemed relevant). These also are in the process of being revised/updated.

**Table 3-2: Water Column: Recommended water quality guidelines or target values for the protection of marine ecosystems, as well as for filter feeder collection and recreational activities.**

| Basic Amenities – all marine and estuarine waters | |
|---|---|
| **Constituent** | **Guideline or Environmental Quality Target Value** |
| Aesthetics<br><br>(floating matter, including oil and grease) | Water should not contain floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance or in amounts sufficient to be unsightly or objectionable.<br>Water should not contain materials from non-natural land-based sources that will settle to form putrescence or objectionable deposits.<br>Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use. |
| | Coastal and marine waters should not contain -<br>• floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance;<br>• materials from non-natural land-based sources which will settle to form putrescence;<br>submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use |
| Turbidity / colour/ clarity | Turbidity or colour acting singly or in combination should not reduce the depth of the euphotic zone by more than 10 % of ambient levels measured at a comparable control site (turbidity).<br>With specific reference to colour, level should not increase by more than 35 *Hazen units* above ambient (background) levels in a particular area. Colour can also be measured in units of mg Pt/ℓ is equivalent to 1 Hazen unit. |
| | The guideline value should be determined as the 80%ile of the reference system(s) distribution. The median of the data for the monitoring period is not to exceed the guideline value. Additionally, the natural euphotic depth ($Z_{eu}$) should not be permitted to change by more than 10%. Test data: Median concentration for period |

| | |
|---|---|
| Suspended solids (SS) | SS should not be increased by more than 10 % of ambient concentrations[5], alternatively the SS should not exceed 1.67 times the ambient SS concentrations. |
| Turbidity & Suspended solids | The guideline value should be determined as the 80%ile of the reference system(s) distribution. The median of the data for the monitoring period is not to exceed the guideline value. Additionally, the natural euphotic depth ($Z_{eu}$) should not be permitted to change by more than 10%. Test data: Median concentration for period |

| **Maintenance of Ecosystems – physico-chemical parameters (all marine waters)** | |
|---|---|
| **Constituent** | **Guideline or Environmental Quality Target Value** |
| **Temperature** | The maximum acceptable variation in ambient temperature is ± 1 °C. |
| | The guideline value should be determined as the range defined by the 20%ile and 80%ile of the seasonal and/or event-driven distribution for the reference system. The median of the data for the monitoring period is not to exceed the guideline value. |
| **Salinity** | 33-36 ppt |
| | The guideline value should be determined as the range defined by the 20%ile and 80%ile of the seasonal and/or event-driven distribution for the reference system. The median of the data for the monitoring period is not to exceed the guideline value. |
| **pH** | 7.3 - 8.2 , however the upper limit of this guideline is too low as it is routinely exceeded in natural, unimpaired marine waters in both east and west coast systems of South Africa. |
| | The guideline value range should be determined as the range defined by the 20%ile and 80%ile of the seasonal and/or event-driven distribution for the reference system. The median of the data for the monitoring period is not lie outside the 20%ile and 80%ile guideline values.<br>pH changes of more than 0.5 pH units from the seasonal maximum or minimum defined by the reference systems should be fully investigated. |
| **Dissolved oxygen** | Dissolved oxygen should not fall below 5 mg/ℓ (99 % of the time) and below 6 mg/ℓ (95 % of the time). |
| | The median dissolved oxygen concentration (calculated using the lowest diurnal dissolved oxygen concentrations) must not be less that the 20%ile of the dissolved oxygen concentration measured in the reference system. Where possible, the 20%ile guideline value should be obtained during low flow and high temperature periods when the dissolved oxygen concentrations are likely to be at their lowest. Alternatively, where seasonal variations in dissolved oxygen concentrations are high, it may be appropriate, should sufficient data exist, to develop seasonal guideline values. |

[5] For the assumed ambient water quality of SS = 3 to 5 mg/ℓ, the target value will range from 3.3 to 5.5 mg/ℓ, depending on the assumed ambient (background) total suspended solids concentration assumed. This approach is deemed to be possibly overly conservative. An interim guideline for SS of a maximum of 1.67 times the mean ambient SS concentration has been suggested as an alternative guideline for proposed emergency desalination plants outfalls in the Western Cape. This would imply a TSS guidelines of between 5 mg/ℓ and 8.4 mg/ℓ, depending on the ambient (background) total suspended solids concentration assumed

## Maintenance of Ecosystems – Nutrients (all marine waters)

| Constituent | Guideline or Environmental Quality Target Value |
|---|---|
| ***Dissolved Nutrients (in µg/ℓ)***<br>**Ammonium, Nitrate, Nitrite, Phosphate, Silicate**<br>**Site-specific target values:**<br>**$NO_3$-N**<br>**$PO_4$-P**<br>**$NH_3$-N + $NH_4$-N** | 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)<br>330 µg/ℓ *1<br>53 µg/ℓ *2<br>500 µg/ℓ *3 |
| | Nutrient concentrations in the water column should not result in chlorophyll-a (see below), turbidity (see above) and/or dissolved oxygen (see above) concentrations that are outside the recommended guideline or environmental quality target concentrations above)<br>Where an appropriate reference system(s) is available and there are sufficient measured data for the reference system, the median nutrient concentration must not exceed the 80%ile of the nutrient concentration measured in the reference system.<br>Where insufficient or no reference data exists, single guideline values could be derived from available data based on professional judgement, as an interim measure |

| Interim EQT | Seagrasses | Mangroves | Corals |
|---|---|---|---|
| **Dissolved inorganic nitrogen ($NH_4$-N + $N0_3$-N + $NO_2$-N) *4** | 500 µg/ℓ | 1 000 µg/ℓ | 15 µg/ℓ |
| **Dissolved organic phosphate-P*4** | 50 µg/ℓ | 100 µg/ℓ | 5 µg/ℓ |

## Maintenance of Ecosystems – Toxic substances (all marine waters)

| Constituent | Guideline or Environmental Quality Target Value |
|---|---|
| **Ammonia (as $NH_3$)** | 20 µg N/ℓ |
| | No guideline |
| **Total Ammonia Nitrogen (TAN) (as $NH_3$-N + plus $NH_4^+$-N)** | 600 µg N/ℓ |
| | 600 µg N/ℓ or median TAN should not exceed the 80th percentile of the ambient concentration |
| **Cyanide ($CN^-$)** | 12 µg/ℓ |
| | 1 µg/ℓ (WIO: 4 µg/ℓ (95% protection)) |
| **Total Residual Chlorine-Cl** | 3 µg/ℓ |
| | 3 µg/ℓ |
| **Fluoride ($F^-$)** | 5 000 µg/ℓ |
| | 1 500 µg/ℓ (marine); 1 500 µg/ℓ (estuarine) |
| **Sulphides (S-)** | No guideline specified |
| | 2 µg/ℓ (chronic) |
| **Trace Metals (as Total Metal)** | |
| **Arsenic (As)** | 12 µg/ℓ |
| | 8 µg/ℓ (WIO: As(III) 2.3 µg/ℓ and As (VI) 4.5 µg/ℓ) |
| **Cadmium (Cd)** | 4 µg/ℓ |
| | 0.12 µg/ℓ (WIO: 0.7 µg/ℓ (99% protection) 5.5 µg/ℓ (95% protection)) |

| | |
|---|---|
| **Chromium (Cr)** | 8 µg/ℓ |
| | 4 µg/ℓ (chronic) (WIO: r (III) – 10 µg/ℓ ; Cr (VI) – 4.4 µg/ℓ |
| **Copper (Cu)** | 5 µg/ℓ |
| | 3 µg/ℓ (chronic) (WIO: 1.3 µg/ℓ for seagrasses and coral reefs in WIO region) |
| **Lead (Pb)** | 12 µg/ℓ |
| | 3 µg/ℓ (chronic) (WIO: 4.4µg/ℓ (95% protection)) |
| **Mercury (Hg)** | 0.3 µg/ℓ |
| | 0.016 µg/ℓ (chronic) (WIO: 0.4µg/ℓ (95% protection)) |
| **Nickel (Ni)** | 25 µg/ℓ |
| | 5 µg/ℓ (chronic) (WIO: 70 µg /ℓ (95% protection)) |
| **Silver (Ag)** | 5 µg/ℓ |
| | 0.7 µg /ℓ (chronic) (WIO: 1.4 µg /ℓ (95% protection)) |
| **Sn (as Tributyltin)** | No guideline |
| | 0.002 µg/ℓ (chronic) (WIO: 0.006 µg /ℓ (95% protection)) |
| **Vanadium** | No guideline |
| | No guideline (WIO: 100 µg /ℓ (95% protection)) |
| **Zinc (Zn)** | 25 µg/ℓ |
| | 20 µg /ℓ (chronic) (WIO: 1.4 µg /ℓ (95% protection)) |
| **Guidelines for Direct Contact Recreation** | |
| **Constituent** | **Guideline or Environmental Quality Target Value** |
| **South African Water Quality Guidelines (DWAF, 1995b)** | |
| **Faecal coliform (incl. E. coli)** | Maximum acceptable count per 100 mℓ:<br>100 in 80 % of the samples<br>2000 in 95 % of the samples |
| **Proposed Interim guidelines for Recreational Waters (DEA, 2012)** | |
| ***Escherichia coliform* (E. coli)*[5]** | Category: Excellent Water Quality – 2.9% gastrointestinal (GI) illness risk<br>Minimum acceptable count of ≤ 250 counts / 100 mℓ in 95% of the samples<br>Category: Good Water Quality (5% GI illness risk)<br>Minimum acceptable count of ≤ 500 counts / 100 mℓ in 95% of the samples<br>Category: Sufficient or Fair Water Quality (8.5% GI illness risk)<br>Minimum acceptable count of ≤ 500 counts / 100 mℓ in 90% of the samples which is the minimum requirement for South African recreational waters |
| **Intestinal *Enterococci*** | (not utilised in this study (refer to DEA (2012) for more detail on these guidelines |
| ***C. perfringens*** | Mean ≤ 5 counts / 100 mℓ. |

| Guidelines for Collection of Filter Feeders | |
|---|---|
| **Constituent** | **Guideline or Environmental Quality Target Value** |
| **Faecal coliform (incl. *E. coli*)** | Maximum acceptable count per 100 mℓ:<br>20 in 80 % of the samples<br>60 in 95 % of the samples |

*1 Values assumed is based on the observation that $NO_3$-N concentrations for upwelling systems on the West coast typically are 280 ± 56 µg/ℓ (DWAF, 1995a). Assuming that the value of 56 µg/ℓ represents the standard deviation of the measurements, a $NO_3$-N concentration of 280+56 = 336 µg/ℓ would represent approximately the 84th percentile value of the ambient $NO_3$-N concentrations that is close to the recommended 80th percentile concentration guideline value. Accordingly, a slightly lower $NO_3$-N concentration of 330 µg/ℓ has been assumed as the guideline value. Other studies in the region (PRDW, 2017 and Lwandle, 2017) have assumed significantly higher $NO_3$-N guideline values of 1 280 µg/ℓ; however, these seem unrealistically high,

*2 This guideline value for phosphate is the reported site-specific guideline derived for the ESKOM nuclear power plant located approximately 15 km NNE of the Robben Island marine outfall (Lwandle, 2017) and is reportedly based on both data from the South African Data Centre for Oceanography (SADCO) and DFFE.

*3 No site-specific guidelines exists for ammonia as a nutrient in Table Bay. Consequently, the rather conservative (and possibly over-conservative) guideline for seagrasses 500 µg/ℓ (UNEP/Nairobi Convention Secretariat and CSIR, 2009) has been utilised. This also is the value for ammonia as a toxicant deemed to be protective of 99% (of all species) protection in the ANZECC (2000) guidelines.

*4 These are guidelines for the WIO region (UNEP/Nairobi Convention Secretariat and CSIR, 2009)

*5 Guidelines are expressed as the maximum acceptable counts of *F.coli* per 100 mℓ. The counts typically are expressed CFU (colony forming units) or more typically as MPN (most probable number). (see http://files.differencebetween.com/wp-content/uploads/2017/06/Difference-Between-CFU-and-MPN.pdf.)

## 3.4 REQUIRED DILUTIONS

Typically, it is possible to design a marine outfall and test its compliance with site-specific environmental objectives using only target values for the water column. This approach is taken as the assessment methodology in the most modelling studies is founded primarily on the concept of required dilutions of pollutants in the water column, based on the transport and fate of a conservative tracer in the model.

However, such modelling cannot assess the potential for accumulation of pollutants in the sediments. Specifically, the potential impacts related to the transport and fate of toxic contaminants adsorbed onto cohesive sediment particles cannot be assessed using the near-field modelling approach utilised in this study. For this, a significantly more complex and costly far-field modelling approach would be necessary. However, a baseline survey conducted in January 2001 prior to the commencement of the discharge and a subsequent further three monitoring surveys being conducted in May 2002, October 2002 and February 2003 (Pisces, 2021), indicated that:

— the proportion of sand in the sediments around the diffuser (<30 m radius) increased significantly (possibly due to scour effects related to the outfall infrastructure;

— there was no marked increase in the organic content around the diffuser, and;

— that heavy metal concentrations in the sediments were below the maximum allowable effects range low (ERL) levels stipulated by the South African Sediment Quality Guidelines of that time (see also Toefy, 2010).

These results were for the discharge of the combined preliminary treated and brine discharge effluent of significantly poorer water quality and an order of magnitude higher suspended sediment content (SS = 250 mg/ℓ) compared to the wastewater effluent (SS = 25 mg/ℓ ) from the proposed new WWTW. For this reason, the detailed modelling of the transport and fate using a far-field numerical model is not warranted in the present study. This assessment therefore follows the “required dilution” approach, that is based on determining whether the total Achievable Dilution ($S_t$) of dissolved constituent(s) in the effluent being discharged into the marine environment exceeds the Required Dilution (*RD*) that will ensure compliance with the relevant marine water quality guidelines for the effluent constituent(s) under consideration.

The total achievable dilution ($S_t$) at a distance from the effluent discharge location is the product of the initial dilution ($S_i$), secondary or eddy dilution ($S_e$) and, to the extent that it exists, dilution due to the die-off of non-conservative parameters such as microbiological organisms ($S_d$). The formula for the total achievable dilution of an effluent in the marine environment is given in Section 3.5 below.

The area within which the total achievable dilution ($S_t$) does not exceed the Required Dilutions necessary to comply with the relevant water quality guidelines often is referred to as the "sacrificial zone", a zone where water quality impacts are expected to occur.

The Required Dilution (*RD*) of the effluent required to ensure compliance with marine water quality guidelines is calculated as follows

$$Required\ Dilution\ (RD) = \frac{(C_E - C_A)}{(C_G - C_A)}$$

where

$C_E$ is the constituent concentration in the effluent;

$C_G$ is the target or guideline constituent concentration that is not be exceeded, according to the relevant water quality guideline;

$C_A$ is the ambient (or background) constituent concentration in the marine environment.

From the above formula it is clear that as $C_A \longrightarrow C_G$, then $(C_A - C_G) \longrightarrow 0$. As a consequence the Required Dilution $\longrightarrow \infty$, *i.e.* it can be inferred that, as the ambient constituent concentration tends towards the water quality guideline constituent concentration, no amount of dilution of the discharged effluent will be sufficient to ensure that the effluent constituent concentrations in the receiving environment will meet the relevant water quality guidelines.

The required dilutions for the effluents associated with the proposed new WWTW are summarised in Table 3-3 below. Both the required dilutions calculated for the original 2014 BAR outfall dispersion modelling specialist study (WSP|PB, 2014a) and those calculated for the present study, are included in the table.

**Table 3-3: Required Dilutions of the various constituents within the effluents associated with the discharge scenarios assessed in this study.**

| | Constituent | Constituent concentrations | | | Required dilutions | |
|---|---|---|---|---|---|---|
| | | Background (reference) concentration | Recommended water quality target concentration | Concentration in the WWTW Effluent | This Study | WSP\|PB. 2014) |
| Protection of Marine Ecosystem (Natural Environment) | Oil, soap and grease (mg/ℓ) | negligible | 2[*1] | 2.5 | 2 | - |
| | Temperature (°C) | - | Less than ± 1 °C change to ambient | - | < 5[*2] | < 5[*2] |
| | Salinity (psu) | ~ 35 | 33 -36 | ~ 1[*3] | 17 | 7 - 10 |
| | pH | 7.9 – 8.2 | 7.3 – 8.2 | 5.5 - 9.5[*4] | -[*4] | -[*4] |
| | Suspended Solids (mg/ℓ) | 3.5 – 5.0[*5] | < 10% above ambient | 25 | 40 - 62 | 40 |
| | | | < 1.67 x ambient | | 6 - 11 | - |
| | $BOD_5$ (mg/ℓ) | 7[*6] | above 5 mg/ℓ for 99% of all samples | 25[*7] | 3[*8] | - |
| | | | above 6 mg/ℓ for 95% of all samples | | 5[*8] | |
| | COD (mg/ℓ) | 7[*6] | above 5 mg/ℓ for 99% of all samples | 75 | 8[*9] | 3.2 |
| | | | above 6 mg/ℓ for 95% of all samples | | 15[*9] | |

| | Constituent | Constituent concentrations | | | Required dilutions | |
|---|---|---|---|---|---|---|
| | | Background (reference) concentration | Recommended water quality target concentration | Concentration in the WWTW Effluent | This Study | WSP\|PB. 2014) |
| | **Nitrate, Nitrite, Ammonia and Phosphate as nutrients** | | | | | |
| | Ammonium (mg/ℓ) ($NH_4^+$-N) | 0.033[*10] | 0.500 [*11] | 5.7[*12] | 13 | - |
| | Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) | 0.016 4<br>(0.080)<br>(0.100) | 0.330 | 15 | 48<br>(60)[*13]<br>(65)[*13] | - |
| | Dissolved inorganic nitrogen ($NH_4$-N + $N0_3$-N + $NO_2$-N) | 0.052<br>(0.080)<br>(0.100) | 0.500 [*11] | 20.7 | 46<br>(49) [*14]<br>(52) [*14] | - |
| | $PO_4$-P (mg/ℓ P) | 0.015 to 0.037[*15] | 0.053 | 10<br>(6)[*16]<br>(4)[*16] | 262 - 622[*17]<br>(158 – 373)[*17]<br>(105 – 250)[*17] | - |
| | **Ammonia, Fluoride, chlorine and metals as toxicants** | | | | | |
| | Total Ammonia (mg/ℓ) ($NH_3$-N + $NH_4^+$-N) | 0.035<br>(0.015)[*18] | 0.600[*19] | 6 | 11<br>(11)[*17] | 10 |
| | Cyanide (mg/ℓ) | negligible | 0.012 | 0.02 | 2 | 2 |
| | Fluoride (mg/ℓ) | 1.292 | 5.0 | 1 | 0 | - |
| | Chlorine as Free Chlorine | 0 | 0.003[*20]<br>0.01[*21] | 0.25[*22]<br>(0.1) | 25 – 83[*23]<br>(10 – 33) | - |
| | Arsenic (mg/ℓ) | 0.002 6[*23] | 0.012 | 0.02 | 2 | 2 |
| | Boron (mg/ℓ) | - | - | 1 | - | - |
| | Cadmium (mg/ℓ) | 0.000 079[*24] | 0.004 | 0.005 | 2 | 1 |
| | Chromium (VI) (mg/ℓ) | 0.000 071[*24] | 0.008 | 0.05 | 7 | 6 |
| | Copper (mg/ℓ) | 0.000 899[*24] | 0.005 | 0.01 | 3 | 2 |
| | Iron (mg/ℓ) | | - | 0.3 | - | - |
| | Lead (mg/ℓ)[8] | 0.000 150[*24] | 0.012 | 0.01 | 1 | 1 |
| | Manganese (mg/ℓ) | | | 0.1 | 9 | |
| | Mercury (mg/ℓ) | 0.000 055[*24] | 0.000 3 | 0.005 | 21 | 20 |
| | Nickel (mg/ℓ) | 0.000 563[*24] | 0.025 | 0.088 | 4 | - |
| | Selenium (mg/ℓ) | | | 0.02 | - | - |
| | Silver (mg/ℓ) | 0.000 1[*25] | 0.005 | 0.000 45[*26] | 0 | = |
| | Zinc (mg/ℓ) | 0.006 591[*24] | 0.025 | 0.1 | 6 | 5 |
| **Contact Recreation** | F. Coli (MPN/100 m ℓ) | Negligible | 2000 (95% of time) | 1 000 | 1 | |
| | | | 100 (80% of time) | | 10 | |
| | | | 500 (90% of time) | | 2 | |
| **Collection of Filter Feeders** | F. Coli (MPN/100 m ℓ) | negligible | 60 (95% of time) | 1 000 | 17 | |
| | | | 20 (80% of time) | | 50 | |

*1 Water quality guideline used for the proposed East London WWTW outfall (van Ballegooyen *et al*., 2016).

*2 Based on the fact that the WWTW effluent from the WWTW is unlikely to differ in temperature by more than 5ºC from the ambient temperature of the marine waters of the receiving environment.

*3 An effluent salinity of < 1 psu (ppt) is consistent with the General Limit Values for conductivity (for the range of expected ambient temperatures of the effluent). The effluent is expected to have a low salinity (< 1 psu), provided that the practise of flushing the outfall with desalination (reject) brine effluent is discontinued as proposed for the new WWTW.

*4 In reality the pH of the effluent is unlikely to lie outside the range specified by the water quality guidelines. Furthermore, seawater has a strong buffering capacity meaning that it is highly unlikely that there will be any direct adverse effects on the receiving environment due to the pH of the effluent.

*5 The original dispersion modelling study (WSP|PB, 2014b) study for the 2104 BAR (WSP|PB, 2014a), assumed an ambient (reference) SS concentration of 5 mg/ℓ, based on the values reported in Wamtech and Rossouw (1999). More recent studies in the open waters of Table Bay (van Ballegooyen *et al*, 2006) and the more sheltered nature of waters surrounding the Robben Island Marine outfall, both suggest that the use of lower ambient SS concentrations to determine required dilutions of the effluent may be more appropriate. :PRDW (2017) and Lwandle (2017) used an ambient (reference) SS concentration of 4 mg/ℓ in an assessment of possible discharges from the ESKOM Nuclear site located approximately 15 km NNE of Robben Island.

*6 The saturated dissolved oxygen values for seawater temperatures ranging between 14ºC and 21ºC (representative of Robben Island), range from 7.3 to 8.3 mg/ℓ. We have therefore conservatively estimated the ambient dissolved oxygen concentration of the shallow waters of Robben Island to be approximately 7 mg/ℓ.

*7 Only the COD of the proposed effluent has been specified via reference to the General Limit Values. We have estimated the BOD based on the relationship between BOD and COD reported in the literature. Fadini *et al*. (2004) provided a relation of BOD = 0.46 COD for raw sewage and much lower (~0.3) for treated sewage, even as low as ~0.1 in final effluent from a WWTW (https://cgi.tu-harburg.de/~awwweb/wbt/emwater/lessons/lesson_a1/lm_pg_1068.html).

*8 The approach used is one whereby the required dilution can be estimated from natural DO levels, the BOD concentrations in an effluent and the water quality target values (Lusher, 1984). In this approach, it is assumed that 20% of the BOD will be demanded within one hour after discharge. For example, 20% of a $BOD_5$ of 25 mg/ℓ is 5 mg/ℓ. For average background values of 7.0 mg/ℓ, a total of 2.0 mg/ℓ and 1.0 mg/ℓ will be available in the water column before the target values of 5 mg/ℓ (99%) and 6 mg/ℓ (95%) are exceeded. Therefore, to meet these target values, dilutions of 5 and 2.5 are required, respectively.

*9 Indicative required dilutions calculated based on the same argument as for $BOD_5$ (which is likely not to be entirely valid), does however provide indicative required dilutions required to avoid unacceptable "sags" in dissolved oxygen.

*10 Assumed background (reference) concentration for ammonium (as used in van Ballegooyen *et al*., 2016).

*11 Water quality guideline for ammonium ($NH_4^+$-N), *i.e.* as a readily available nutrient that could lead to "nuisance" growth in marine environments (see van Ballegooyen *et al*., 2016). No site-specific guidelines exists for ammonia as a nutrient in Table Bay. Consequently, the rather conservative (and possibly over-conservative) guideline for seagrasses in the WIO region of 0.5 mg/ℓ (UNEP/Nairobi Convention Secretariat and CSIR, 2009) has been utilised. A previous WWTW study for East London used a guideline value of 0.1 mg/ℓ (van Ballegooyen *et al*., 2016). The same guideline value of 0.5 mg/ℓ has been used for the total dissolved inorganic nitrogen ($NH_4$-N + $N0_3$-N + $NO_2$-N).

*12 Estimated ammonium concentration based on the expected percentage of unionised ammonia concentrations compared to the total ammonia nitrogen (TAN) expected for the prevailing temperature and pH of the waters surrounding the Robben Island outfall is assumed as the background (reference) concentration for ammonium (as used in van Ballegooyen *et al*., 2016). The unionised ammonia in seawater can be as little of 20% of that in freshwater, thus this estimate is conservative in that it is most probably significantly higher than that expected for the effluents from the WWTW.

*13 Based on an ambient (background) ($NO_3$-N + $NO_2^-$-N) concentration of 0.016 4 mg/ℓ as reported in DWAF (1995a), a required dilution of 46 will be necessary to meet the assumed water quality guideline. However, this ambient concentration is very low compared to the average values expected in a bay in an upwelling region (*e.g.* De Villiers, 2014). Consequently, a higher value seems appropriate. It should be noted that the Required Dilution of the effluent will remain below 60 for an ambient (background) $NO_3$-N + $NO_2$-N concentration of < 0.080 mg/ℓ and below 65 for an ambient (background) ($NO_3$-N + $NO_2$-N) concentration of< 0.100 mg/ℓ.

*14 Based on an ambient (background) ($NO_3$-N + $NO_2^-$-N + $NH_4$¯N) concentration of 0.052 mg/ℓ (comprising 0.0164 mg/ℓ for ambient ($NO_3$-N + $NO_2^-$-N) concentrations as reported in DWAF (1995a) plus 0.033 mg/ℓ for (NH4+-N) concentrations), a required dilution of 46 will be necessary to meet the assumed water quality guideline. The Required Dilution of the effluent will remain below 60 for ambient (background) ($NO_3$-N + $NO_2$-N + $NH_4$¯N) concentrations of < 0.155 mg/ℓ and below 65 for ambient (background) ($NO_3$-N + $NO_2^-$-N + $NH_4$¯N) concentrations of < 0.185 mg/ℓ.

*15 The ambient (background) concentrations for $PO_4$-P are uncertain. The higher value of 0.037 mg/ℓ is the reported site-specific ambient $PO_4$-P concentration derived for the ESKOM nuclear power plant located approximately 15 km NNE of the Robben Island marine outfall (PRDW, 2017; Lwandle, 2017) and is reportedly based on both data from the South African Data Centre for Oceanography (SADCO) and DFFE. This value is consistent with other observations expected in a bay in a West Coast an upwelling region (*e.g.* De Villiers, 2014).

*16 Although the wastewater effluent is specified to comply with the General Limit Value for $PO_4$-P concentration of 10 mg/ℓ, it is likely that the $PO_4$-P concentration in the WWTW effluent will range between 4 and 6 mg/ℓ (see Section 2.2.2 for more detailed information in this regard).

*17 The range of required dilutions reported for the assumed effluent concentrations of $PO_4$-P for the range of assumed ambient (background) concentrations assumed. The higher required dilution values are the most likely to be correct as they are for a higher ambient $PO_4$-P concentration (0.037 mg/ℓ) which is the most likely to be correct.

*18 The ambient (background) concentration of ($NH_3$-N + $NH_4^+$-N) is uncertain. Values reported include 0.028 mg/ℓ (DWAF, 1995a), 0.035 mg/ℓ (van Ballegooyen *et al*., 2016) and 0.015 mg/ℓ (Lwandle, 2017), however the resulting required dilutions calculated are not sensitive to these assumed background concentrations of ($NH_3$-N + $NH_4^+$-N).

*19 This water quality guidelines for total ammonia ($NH_3$-N + $NH_4^+$-N) includes ammonia both as a toxicant ($NH_3$-N) and as a nutrient ($NH_4^+$-N) (see DWAF, 1995a).

*20 The general guideline of 0.003 mg/ℓ is that reported in DWAF (1995a). ANZECC (2000) classifies this value as a low-reliability trigger value due to the lack of sufficiently robust toxicity test data for marine organisms (*i.e.* the guideline concentration of 0.003 mg/ℓ incorporates a precautionary factor of 10 below the NOEC level assessed).

*[21] To evaluate actual risks to local biota from desalination and other wastewater discharges from the location of the ESKOM nuclear power plant located approximately 15 km NNE of the Robben Island marine outfall, an environmental water quality guideline of 0.01 mg/ℓ was used as a site-specific guideline that would be protective of Kelp and some associated sub-canopy phaeophyte algae (PRDW, 2017; Lwandle, 2017). The guideline was based on the United Kingdom environmental quality standard 0.01 mg/l (CEFAS, 2011).

*[22] Compliance with the General Value Limits require that the wastewater effluent from the WWTW contain a free chlorine residual of < 0.25 mg/ℓ. For the more restrictive South African water quality guideline of 0.003 mg/ℓ, however a required dilution of 65 will be exceeded should the free chloride residual in the WWTW effluent exceed 0.19 mg/ℓ. Should the less restrictive 0.01 mg/ℓ water quality target value be used, there will be compliance with the water quality guidelines as the maximum required dilution required will be 33 (*i.e.* less than the minimum achievable dilution of the WWTW effluent in the near-field.)

*[23] The expected ambient arsenic concentration in seawater (salinity ~ 35 ppt) is expected to be 0.002 3 mg/ℓ (Riley and Chester, 1976) while arsenic concentration of between 0.002 6 mg/ℓ and 0.000 3 mg/ℓ have been reported for South African marine waters (Lusher, 1984). Accordingly, an ambient arsenic concentration of 0.002 6 mg/ℓ has been assumed for the Robben Island marine waters.

*[24] Ambient (background) concentration (Lusher (1984) as reported in DWAF (1995a).

*[25] Ambient (background) concentrations DWAF (1995a).as reported in van Ballegooyen *et al.* (2015).

*[26] The dissolved silver concentration expected for a secondary treated effluent (Le Roux and Botes, 2007 as reported in van Ballegooyen *et al*., 2015), is 0.16 mg/ℓ. However more recent studies (Johnson *et al*. 2014) suggest mean concentrations of colloidal silver (2 – 450 nm) of only 0.012 µg/ℓ and particulate silver (> 450 nm) of only 3.314 µg/ℓ in influents to WWTW and colloidal silver concentrations of 0.00 6 5µg/ℓ and particulate silver concentrations of 0.078 µg/ℓ in effluents from WWTW. The maximum combined colloidal and particulate silver concentration for a WWTW effluent of 0.454 µg/ℓ as observed by Johnson *et al*. (2014), has been conservatively assumed for this study. It should be noted that even the highest combined colloidal and particulate silver concentration of 14.99 µg/ℓ observed as an influent to WWTW by Johnson *et al.* (2014), requires only a 3 times dilution to comply with the existing South African water quality guideline for dissolved silver.

## 3.5 ACHIEVABLE DILUTIONS

The effluent plume behaviour and resultant dilution of the discharged effluent is determined both by the design of the outfall and the environmental condition prevailing in the environment into which the effluent is being discharged. Typically, for surf-zone discharges the influence of the outfall design is minimal, the dilution largely determined by wave-driven flows and turbulent mixing by wave processes in the surf-zone (Figure 3-1). For an offshore outfall, the outfall and diffuser design play an important role in the initial plume behaviour and mixing processes. In the immediate vicinity of the outfall and diffuser, the plume behaviour and a resultant dilution of the effluent is determined largely by the momentum of the effluent discharge and associated entrainment processes. Further afield, the plume behaviour and dilution of the effluent is determined by the prevailing environmental conditions and secondary dilution processes (Figure 3-2).

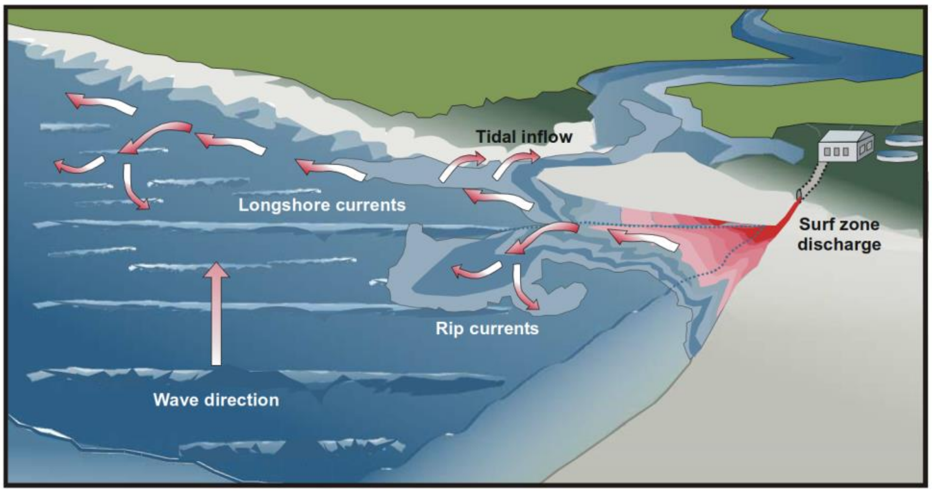



**Figure 3-1: Dilution processes for a surf-zone discharge (DWAF, 2004b).**

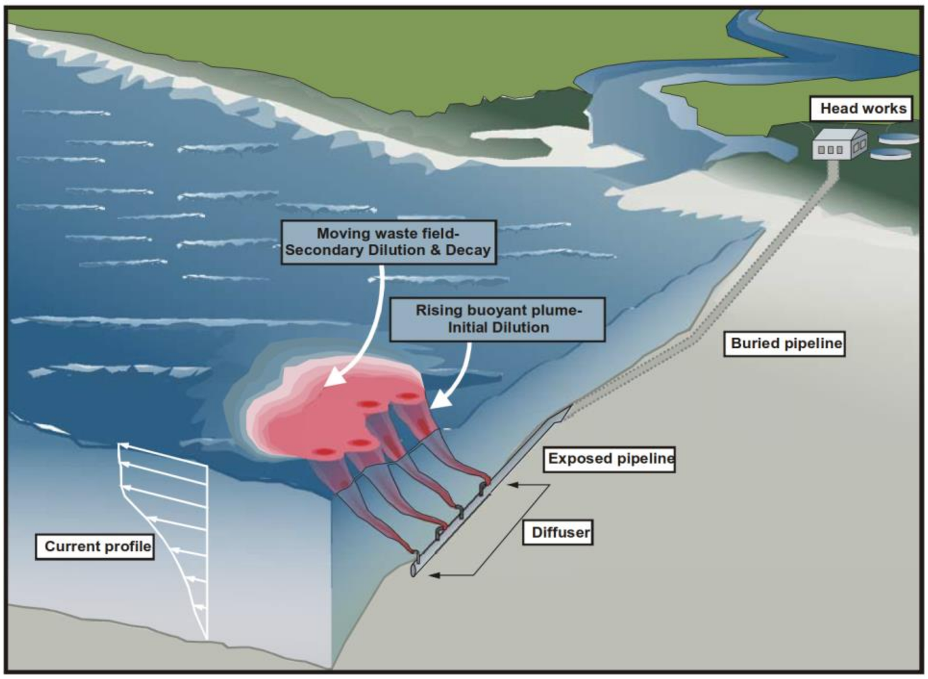



**Figure 3-2: Dilution processes for an offshore (deep-water) outfall (DWAF, 2004b).**

The total achievable dilution ($S_t$) which can be expected at a distant location is the product of the initial dilution ($S_i$), secondary or eddy dilution ($S_e$) and, to the extent that it exists, dilution due to the die-off of non-conservative parameters such as microbiological organisms ($S_d$). The total achievable dilution, $S_t$, at a distance location therefore is given by:

$S_t = S_i \times S_e$ for conservative substances

$S_t = S_i \times S_e \times S_d$ for microbiological indicators where there is die-off

where,

$S_i$ = initial dilution

$S_e$ = secondary dilution

$S_d$ = "dilution" due to decay

A schematic of the different dilution process is provided in Figure 3-3 below.

*Initial dilution* is the process ($S_i$) in which a buoyant plume rises from the diffuser or an open-ended pipeline towards the surface of the sea. As the plume rises through the water column, there is entrainment of seawater at the periphery of the rising plume. The parameters influencing the near-field behaviour of a buoyant WWTW effluent are the buoyant and momentum flux of the jet, the ambient currents and the density structure of the receiving water column. A range of plume behaviours is possible (see section 3.5.1). Where the buoyant and momentum flux of the effluent plume have been largely dissipated, is considered the outer edge of the near-field. The physical extent (*i.e.* height above the diffuser and distance from the diffuser) of the initial dilution process (*i.e.* the near field) is often described as the *Initial Mixing Zone.*

The *secondary dilution* ($S_e$) (after dissipation of the discharge energy / momentum during the initial dilution phase) is considered to occur when turbulence, eddies and velocity shears result in further entrainment/mixing of the plume with surrounding waters resulting in the further dilution of the effluent plume. In contrast to the initial dilution process, secondary dilution is not directly influenced by the design of the outfall and is primarily dependent on the ambient oceanographic conditions.

The concentration of non-conservative substances will be further reduced by *"decay"* (*e.g.* biogeochemical transformation processes or the die-off of the microbial organisms). A predominant factor determining the rate of die-off of microbial organisms is the UV component of solar radiation. Other factors such as osmotic shock (caused by rapid changes in salinity in the near-field). The die off rate of the coliforms is generally expressed as the “$T_{90}$ rate”, *i.e.* the time taken for 90% of the coliforms present in the effluent to die off. As the main accelerator for the die-off rate is exposure to sunlight, a faster die-off rate is observed during the daytime while a slower die-off rate occurs during the night.

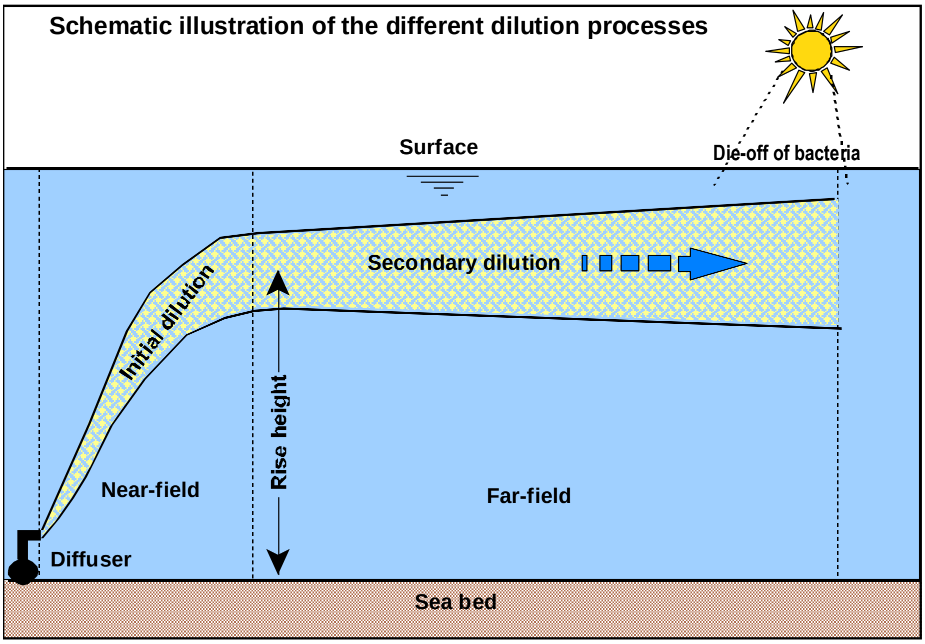



**Figure 3-3: Schematic illustration of the different dilution processes in the offshore region (DWAF, 2004b).**

## 3.5.1 NEAR-FIELD DILUTIONS

While a wide range of near-field effluent plume behaviours is possible (see Figure 3-4), the behaviours can broadly be characterised according to the prevailing ambient (receiving water) conditions as follows:

- *Stagnant, non-stratified conditions* (no current and limited or no water column stratification) under which the effluent plume will rise vertically to the sea surface and then spread laterally as a surface plume;
- *Stagnant stratified conditions* (no current and a significant density gradient between the surface and deeper waters) under which the rising of the buoyant plume can be inhibited resulting in the trapping of the plume and the development of a submerged waste field;
- *Flowing, non-stratified conditions* (significant currents but limited or no stratification) under which the time and path of the rising plume will lengthen, resulting in increased entrainment of surrounding seawater and increased initial dilutions;
- *Flowing, stratified conditions* (significant currents as well as a significant density gradient between the surface and deeper waters) under which the time and path of the rising plume will lengthen but also under which the rising of the buoyant plume can be inhibited resulting in the trapping of the plume and the development of a submerged waste field. Typically the greater the flow velocity the greater the trapping of the effluent plume within the water column and the less the rise height of the effluent plume.

The occurrence with which the effluent plume reaches the surface may be of concern should the dilution on the effluent be insufficient to meet all water quality guidelines upon reaching the sea surface. The greatest risks occur should there be recreational activities (*e.g.* kayaking) in the immediate vicinity of the proposed discharge. In general, it is expected all water quality criteria, other than microbial water quality guidelines, will be met before reaching the sea surface or shortly thereafter, due to the entrainment and dilution processes occurring during the surfacing of the plume.

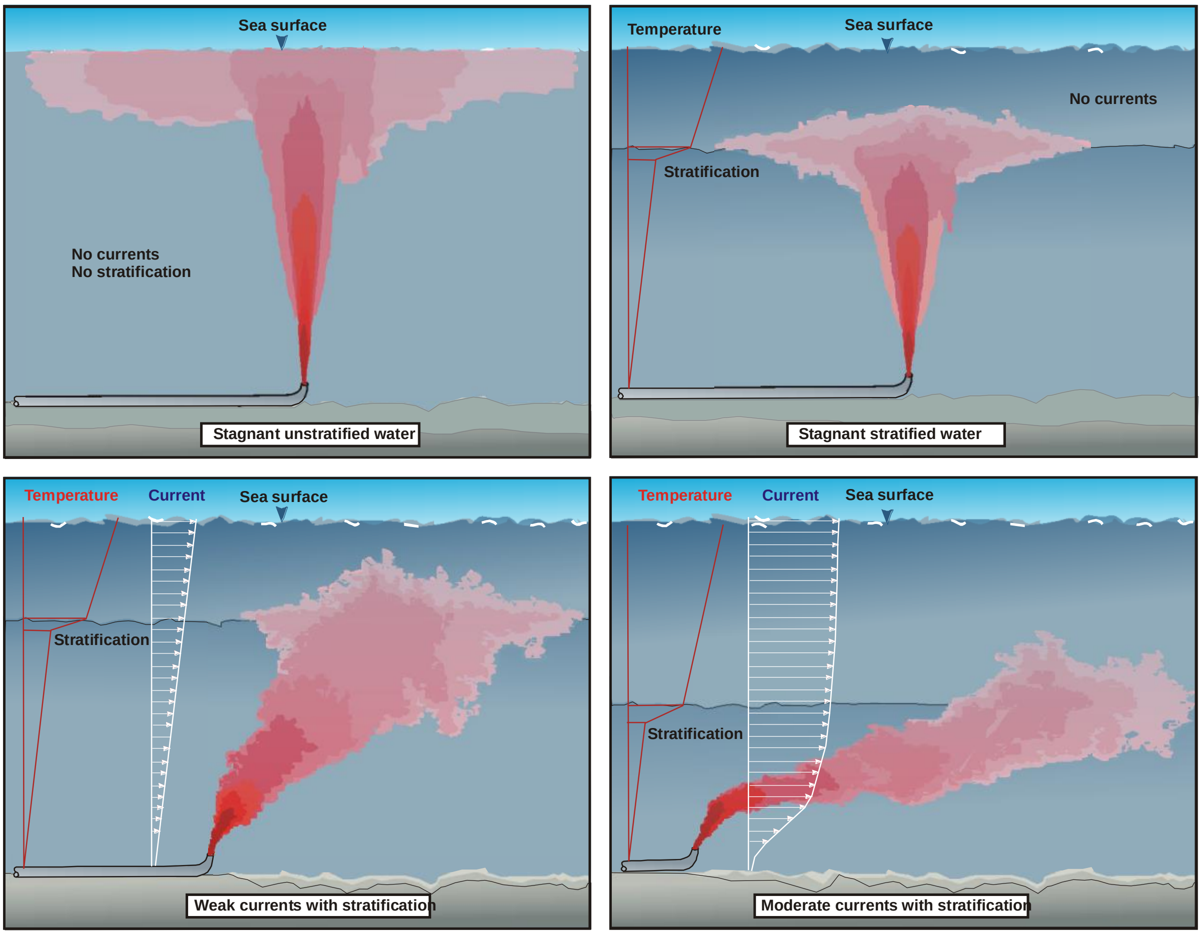



**Figure 3-4: Buoyant plume in (a) stagnant, unstratified water, (b) stagnant, stratified water, (c) moving (weak currents) stratified water and (d) in moving (moderate currents), stratified water (after DWAF, 2004b).**

### 3.5.2 FAR-FIELD DILUTIONS

The secondary dilution ($S_e$) or far-field dilution (after dissipation of the energy during the initial dilution phase) occurs when the plume (waste field) is transported to distant locations by ocean currents. During the transport of the waste field, mixing occurs as a result of eddies and larger scale turbulence that arise from various physical processes, also referred to as eddy diffusion. In contrast to the initial dilution process, secondary dilution is not directly influenced by the design of the outfall and is primarily dependent on the near-shore oceanographic conditions.

# 4 ENVIRONMENTAL DESCRIPTION

## 4.1 PHYSICAL FEATURES

Robben Island is a roughly oval in shaped island (approximately 3.3 km long in the north-south axis and 1.9 km wide, with an land surface area of 5.07 km²) located in Table Bay, South Africa. The island has a flat profile with its highest point (Minto Hill) lying only 24 m above sea level. Robben Island has a total shoreline of 9 km of which 91% is rocky (CMS, 1995 as reported in Van Ballegooyen *et al*., 2006). The rocky shores of the island are characterised by wave-cut platforms in the low-shore and steep storm beaches composed of large cobbles on the high-shore (Pisces, 2021). A small pocket of fine sand occurs on the eastern shore of the island in Murray's Bay, just south of the Harbour.

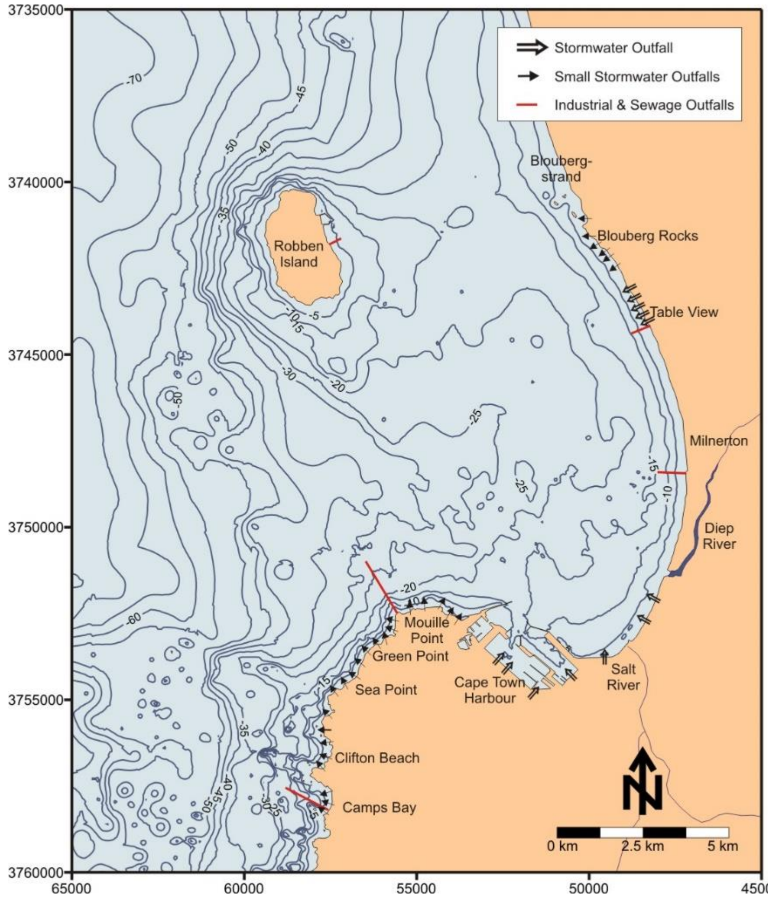



**Figure 4-1: The bathymetry of Table Bay showing also the location of marine outfall pipelines and storm water discharges are also shown (Source: Pisces (2021) ).**

Table Bay is a relatively shallow bay with a maximum depth of approximately -35 m Chart Datum (CD). A shallow underwater saddle connects Robben Island to the adjacent coastline at Blouberg (Figure 4-1). The seabed is mainly covered by thin layers of sand but has fairly extensive areas of exposed bed rock (Woodborne, 1983). The eastern nearshore region between Blouberg and the harbour is generally comprised of fine sand with a tongue of fine sediments extending from the nearshore zone seaward to a depth of approximately 25 m between Table View and Rietvlei (Figure 4-2). Smaller pockets of fine sand are found at the bay entrance and on the eastern shore of Robben Island. The remaining areas of Table Bay are covered by medium sand (Woodborne, 1983; Monteiro, 1997). The major sources of the sand in Table Bay are seasonal (mainly winter) inputs from the Diep and Salt rivers and local erosion of Malmesbury shales (Quick and Roberts, 1993) with little appreciable sediment supply to the bay from longshore transport from the south. Sediment is transported out of Table Bay by local wave and storm driven transport with an estimated overall residence time for surficial sediments of estimated at 2-3 years (Monteiro, 1997).

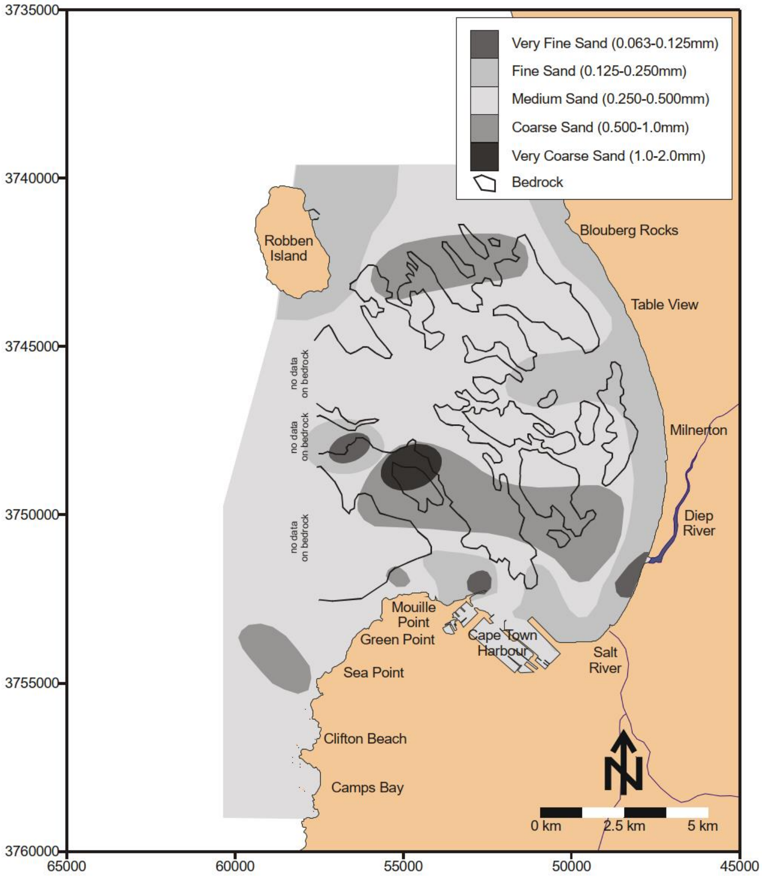



**Figure 4-2: Sediment and bedrock distribution in Table Bay (as adapted from Woodborne, 1983 and reported by Lwandle, 2006 in van Ballegooyen *et al*., 2006).**

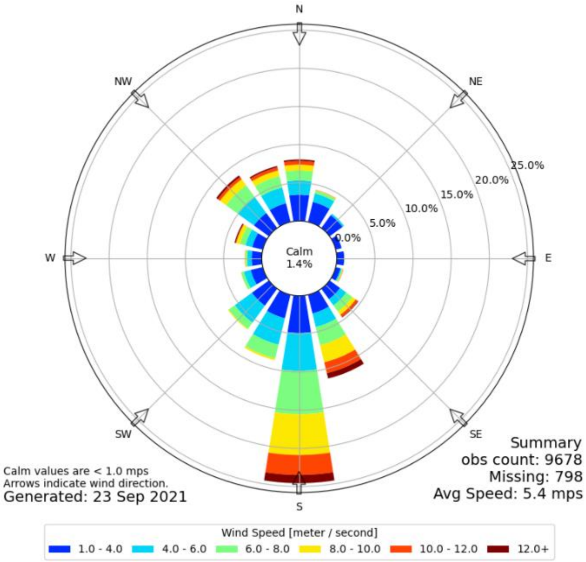
## 4.2 PHYSICAL OCEANOGRAPHY / COASTAL PROCESSES

### *4.2.1 WINDS*

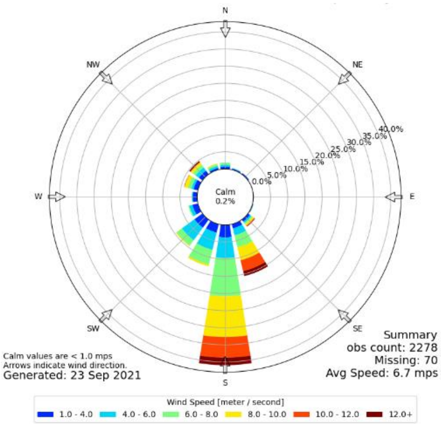
As evidenced in wind measurements at a number of sites in Table Bay (i.e. SAWB weather stations at the Cape Town airport, at Table Bay harbour and on Robben Island, Eskom wind stations at Koeberg and on Robben Island, and Transnet wind stations in the Port of Cape Town), the wind fields over Table Bay are quite complex due to the presence of the Table Mountain range.

The most reliable and long-term wind measurements with which to characterise the winds over Table Bay, are those measured at Cape Town International Airport (Figure 4-3). These measurements indicate that the predominant wind directions are S to SE winds in summer and N to NW winds in winter. The maximum wind speeds are of the order 20 m/s with wind speeds of 15 m/s being exceeded approximately 1% of the time (Wamtech and Rossouw, 1999). Strong S to SE winds also occur in spring with a number of weaker NW wind events occurring in early spring. Autumn is the period of the weakest winds, particularly the period from March to April. Onshore wind conditions occur at Robben Island, however wind-driven currents typically are alongshore (thus limiting the chance of the effluent reaching the shoreline).

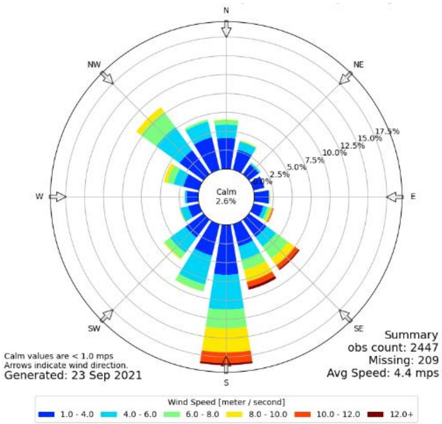
## ANNUAL



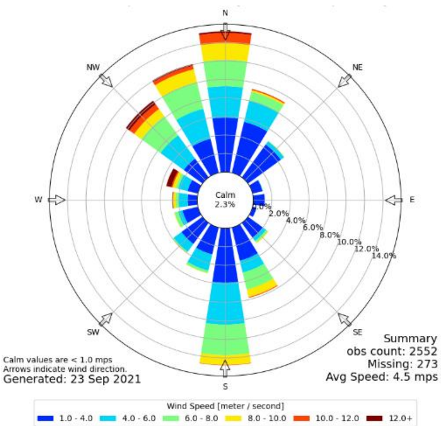

## SUMMER




## AUTUMN




## WINTER




## SPRING

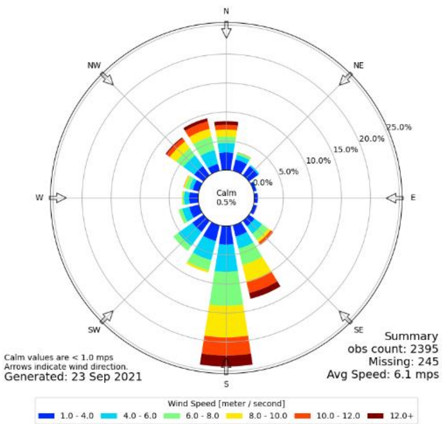



**Figure 4-3: Wind roses for Cape Town Airport for the period Dec 2016 to Nov 2017, a period broadly representative of the annual wind conditions. (Source: IEM :: IOWA State University).**

### 4.2.2 WAVES

Wamtech and Rossouw (1999) provided detail of the wave conditions for both the design and construction of the original outfall, however of relevance to this study is only the possible wave-driven currents and wave-generated bed shear stresses that determine the transport and fate of mainly the particulate material (SS loads) contained in the effluent of the proposed new WWTW.

The marine environment surrounding the outfall is sheltered from the predominant WSW to SW swell conditions (Figure 4-4), however it is exposed to locally generated seas both from the south and the north (Figure 4-7 and Figure 4-8). For this reason there is an expectation of limited locally wave-driven currents in the area into which the effluent is being discharged, however significant wave-driven currents occur on the southern shoreline of Robben Island under moderate to high wave conditions. Also expected is limited wave-generated elevations in bottom shear stress in the vicinity of the effluent discharge, suggesting limited re-suspension of all but the finest sediments. The SS in the existing effluent comprises fine material that would not require significant bottom shear stresses to prevent sedimentation of SS or re-suspension of fine particulate material that may have already settled on the seabed under calm conditions.

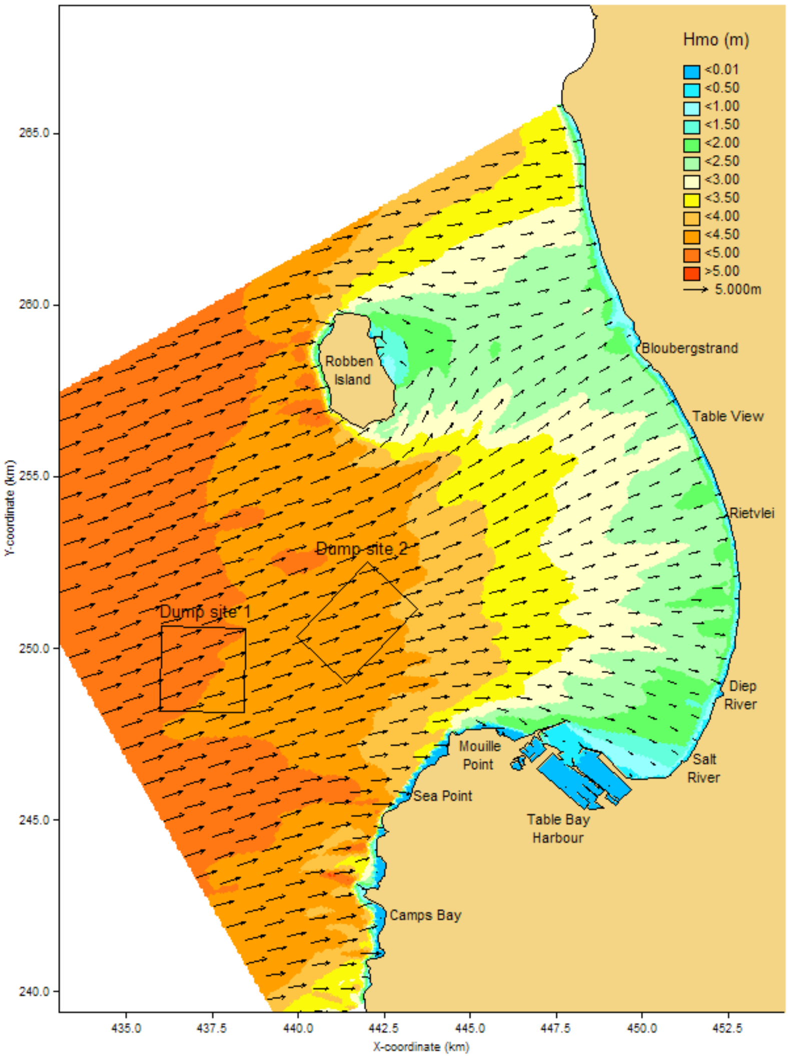



**Figure 4-4: Modelled wave conditions showing the sheltering effect of Robben Island on wave conditions in the vicinity of the existing Robben Island marine outfall ( for offshore wave condition: $H_{mo}$ = 5.0 m, $T_p$ = 12.8 s and Direction = 250° N) (after van Ballegooyen et al. (2006) ).**

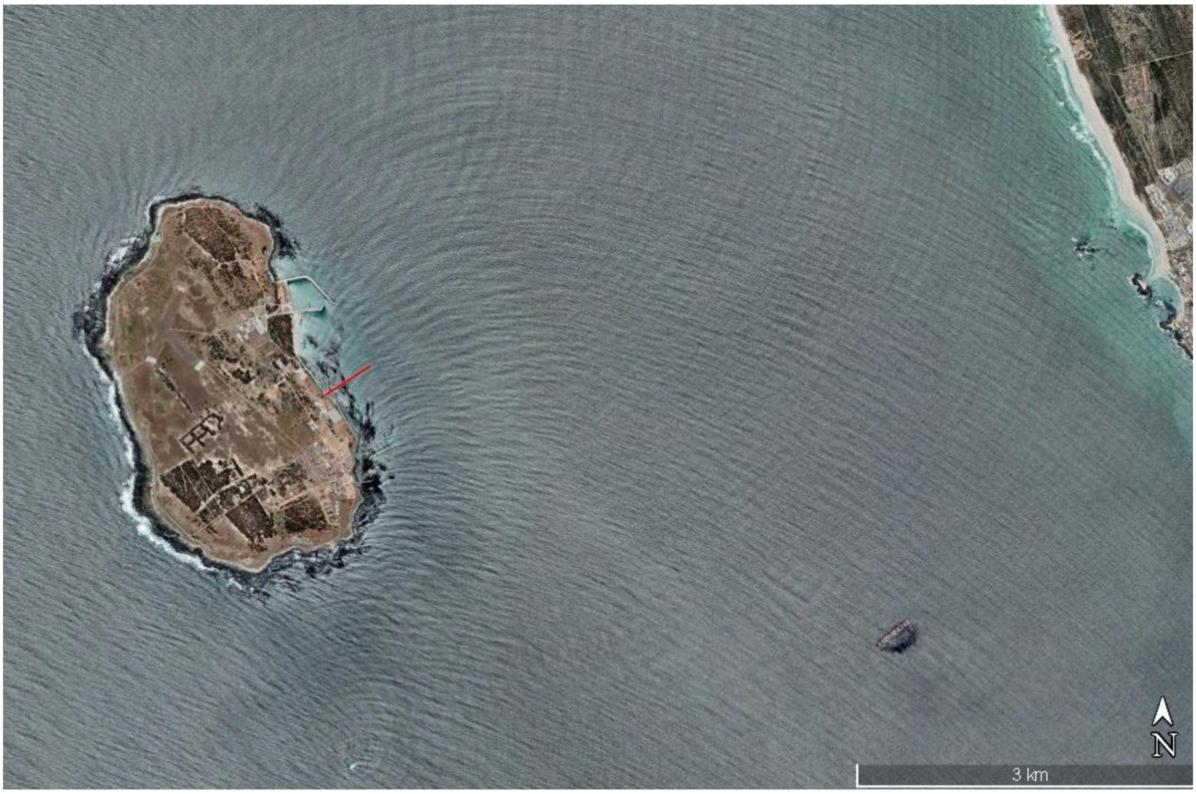



**Figure 4-5: Wave conditions surrounding Robben Island under weak S to SE wind conditions in summer (GoogleEarth : Dec 2020).**

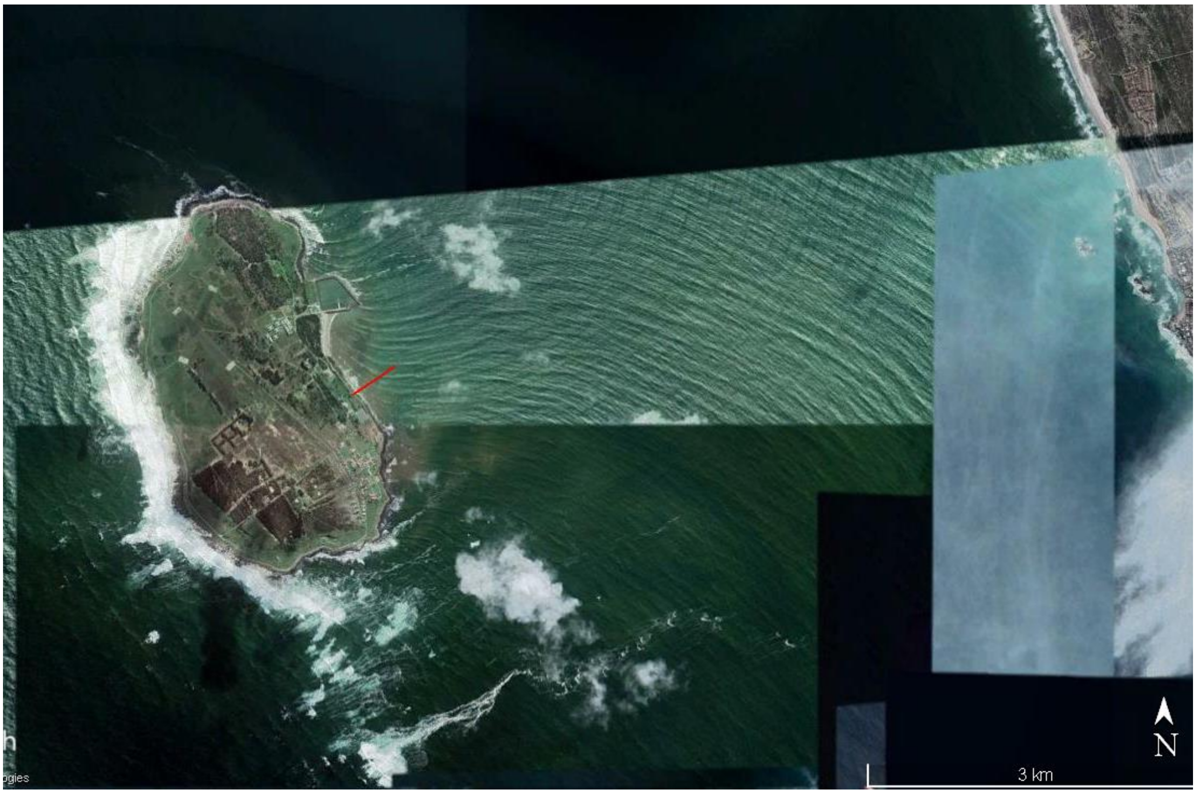



**Figure 4-6: Wave conditions surrounding Robben Island under strong N to NW wind conditions in winter (GoogleEarth : June 2018).**

## 4.2.3 CURRENTS

Table Bay is located within the southern Benguela upwelling system and its circulation and water properties are characteristic of this region. Water movement within the bay is primarily wind-driven, experiencing minor effects from shelf currents further offshore and with waves and swell playing an influential role in driving currents in the nearshore. Water movement is further influenced by tides, although the forcing of this nature is considered minor.

Accordingly, the two main systems of water movement have been described by Quick and Roberts (1993), namely wind-driven flows in the greater bay and wave-driven flows in the nearshore. The wind-driven currents, described in detail by van Ieperen (1971), differ from summer to winter according to the predominant wind directions. Wind from a south-easterly direction result in currents that tend to flow northwards resulting in an anti-clockwise motion in the bay. Conversely, winds from a north/north-westerly sector drive water towards the south producing a slight clockwise motion in the bay.

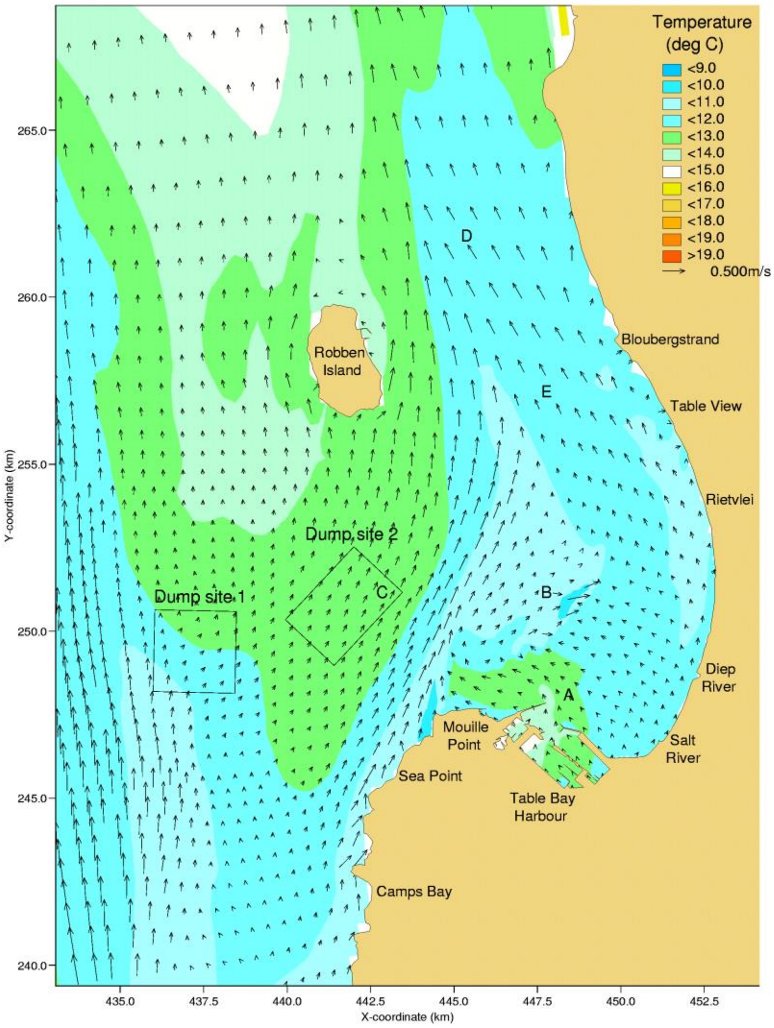



**Figure 4-7: Example of simulated surface currents and temperature on the 8 January 1995 during a 15 m/s south easterly wind (after van Ballegooyen *et al*., 2006).**

Summer is dominated by strong south-easterly winds, therefore northerly, anti-clockwise flows occur during the summer months (Figure 4-7). During summer upwelling, cold water (9° - 13°C) invades Table Bay from the Oudekraal upwelling centre, south of Table Bay, resulting in generally shoreward bottom flows under S to SE winds. However, seawater temperatures can increase rapidly to >20°C during relaxation phases of the upwelling cycle as water flows into Table Bay from the north and north-west (Monteiro, 1997). Upwelling and solar heating leads to a highly stratified water column during summer.

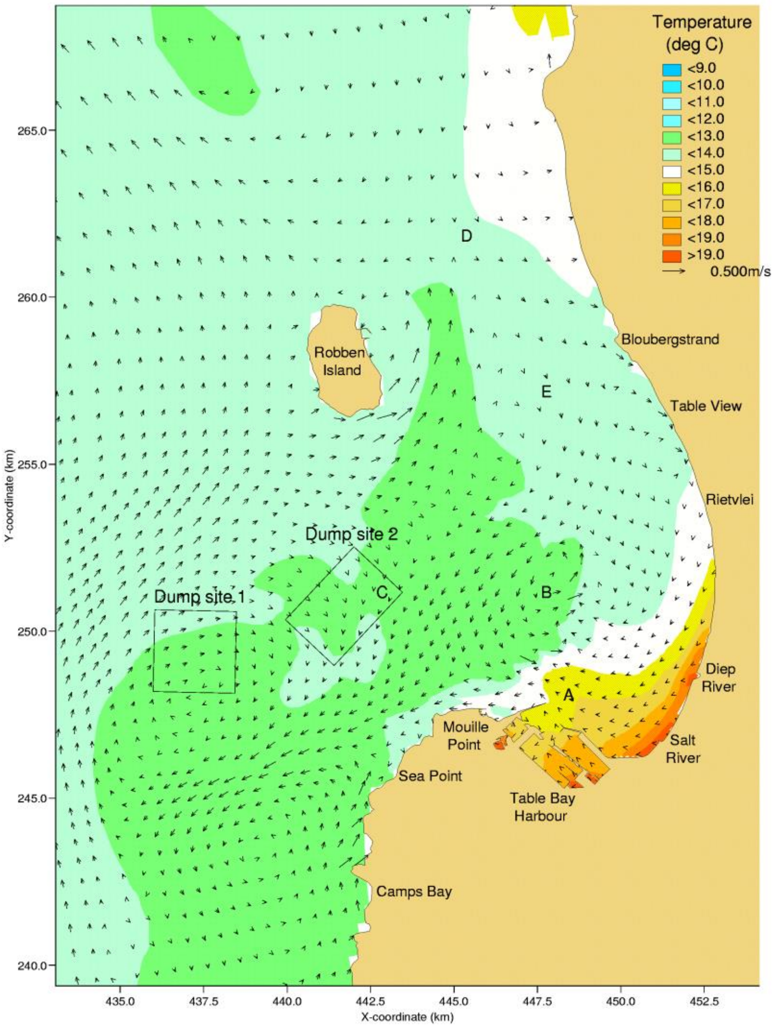



**Figure 4-8: Example of simulated surface currents and temperature on the 2 January 1995 during a 12 m/s north westerly wind (after van Ballegooyen *et al*., 2006).**

Storms during the winter months bring frequent strong north-westerly wind events to the area causing clockwise flow within the central part of the bay although wave-driven currents can complicate the circulation around Robben Island (Figure 4-8). Winter seawater temperatures are more uniform than those of summer and fall in the narrow range of 14 - 16°C. This is a result of no upwelling and strong mixing driven by storms.

Typical wind-driven surface current velocities are between 20 and 30 cm/s (Quick and Roberts, 1993) with bottom velocities much reduced to less than 5 cm/s. Such velocities would indicate long residence times of water within the bay with average flushing periods of 4 days being reported by Quick and Roberts (1993). This particularly applies to the bottom waters where van Ieperen (1971) (cited in Quick and Roberts, 1993) noted that currents were undetectable in 80% of the measurements made over an annual cycle. This contrasts with recent estimates of comparatively short residence times for surficial sediments in Table Bay, suggesting that the main drivers for sediment turnover are episodic winter storms (cf Hill *et al*., 1994), which probably also completely flush the waters of the bay. Nearshore currents are wave driven; waves approach the coast obliquely (predominantly 200° - 260°) generating a generally northerly longshore current along the eastern shore of Table Bay.

The current data used in the design of the Robben Island outfall was two sets of measurements(summer and winter) by the Institute of Maritime Technology (IMT). Approximately 6 weeks of data in summer and 6 weeks of data in winter are available at 5 locations in the bay (Figure 4-9). Current statistics for the near- field modelling undertaken in Wamtech and Rossouw (1999) and WSP|PB (2014a) are based on the currents measured at one of these sites, namely measurements at a location point between Murray's Bay harbour and the shore (Site E in Figure 4-9). These currents were measured at a depth of -9 m MSL in a total water depth of -17 m MSL

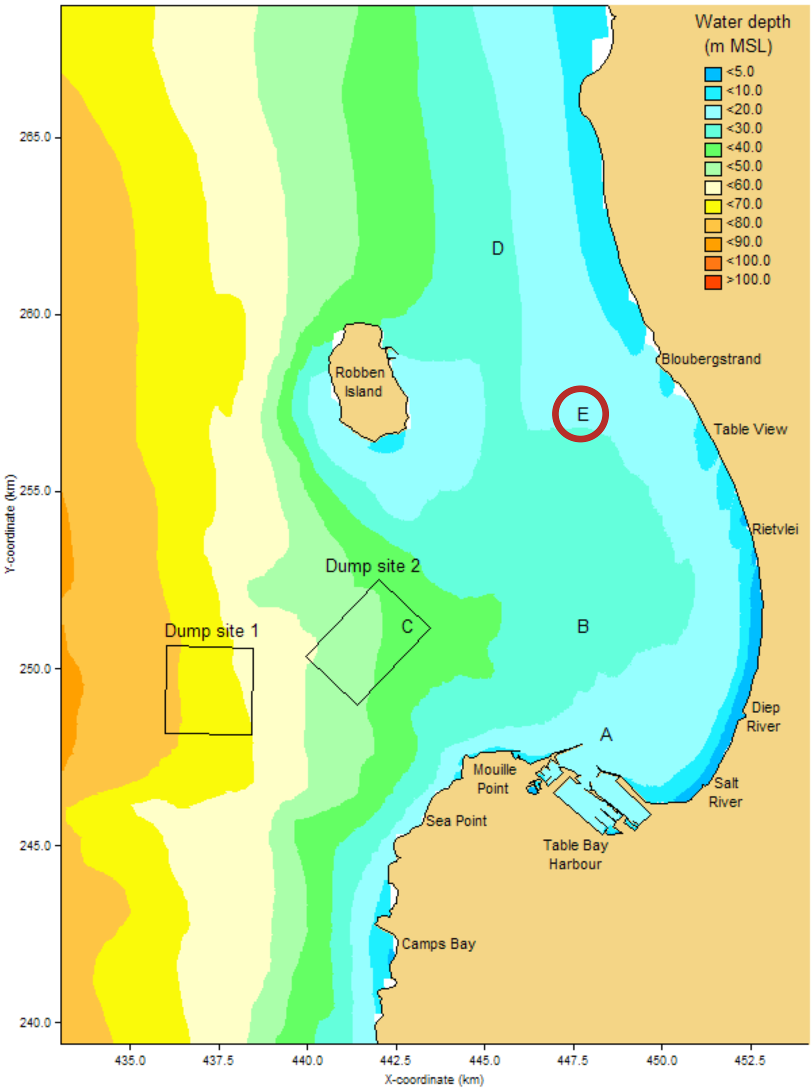



**Figure 4-9: Measurement locations of available current meter data in Table Bay as measured by the Institute of Maritime Technology (IMT. The data from Site E was used to generate the current speed statistics used in this study (after van Ballegooyen *et al*., 2006.**

The percentage occurrences of the various current speed ranges at this location (Site E) are given in Table 4-1 while the current speed at various exceedances are listed in Table 4-2. These data show the currents to be slightly weaker in summer. The current direction at Site E is predominantly northwards in summer and more evenly spread between northwards and southward currents in winter (Wamtech and Rossouw, 1999).

**Table 4-1: Percentage occurrence of current speed recorded at Site E in Table Bay at a -9 m MSL depth in an overall -17 m MSL water depth.**

| Current speed (cm/s) | Occurrence | |
|---|---|---|
| | Summer | Winter |
| 0 to 4 | 18 % | 24 % |
| 4 to 6 | 22 % | 26 % |
| 6 to 10 | 31% | 32 % |
| > 10 | 29 % | 17 % |

**Table 4-2: Current speed for various exceedances as recorded at Site E in Table Bay in a -9 m MSL depth in an overall 17 m MSL water depth.**

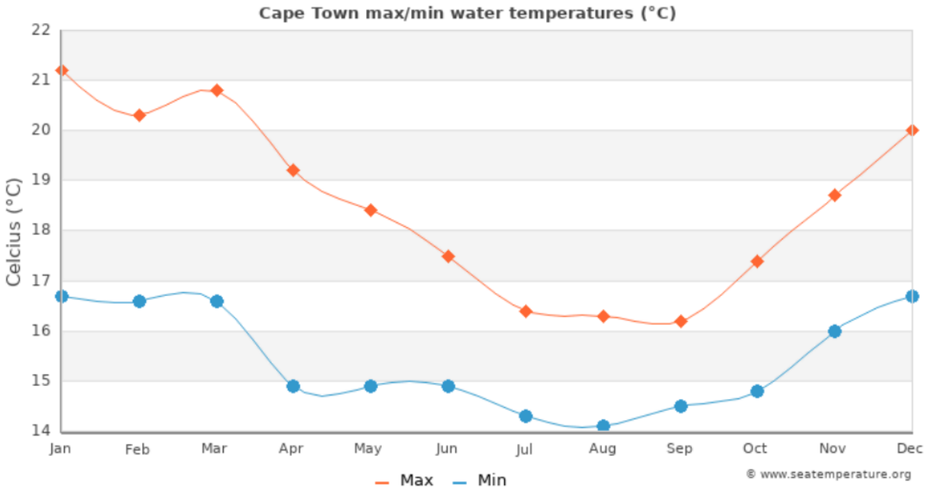
| Exceedance | Current speed (cm/s) | |
|---|---|---|
| | Summer | Winter |
| 50 % | 7 | 6 |
| 20 % | 11 | 10 |
| 10 % | 15 | 14 |
| 5 % | 18 | 16 |
| 1 % | 24 | 19 |

It was noted by Wamtech and Rossouw (1999) that the currents at the outfall location would in all likelihood be less that those recorded at site E that lies in a more exposed location. In particular, it is expected that the kelp beds will increase the resistance to flow and also dampen the onshore flows when they occur.

Relatively strong wave-driven currents are expected along the southern coastline of Robben Island due to the relatively acute angle between the shoreline and the deep ocean swell. Conversely, in the lee of the island where the marine outfall is located, it is expected that the wave heights will be low and that the waves will break inside the area of the kelp beds. Accordingly, the wave wave-driven currents are expected to be weak, although locally generated sea under high winds could result in wave-generated flows.

### 4.2.4 SEAWATER TEMPERATURE, SALINITY AND DENSITY

The temperature and salinity of the waters of Table Bay was investigated by van Ieperen (1971), however more representative temperature data in the immediate area of interest are available from satellite imagery. van Ieperen (1971) reported that salinity ranged between 34.7 and 35.3 ppt with very little difference in values between stations across the bay. Two rivers, the Diep and Salt River, flow into Table Bay, which would result in lowering of salinity in the direct vicinity of these discharge into the bay. When either of the rivers experience increased flow, the area of decreased salinity is expected to increase. Remotely sensed temperature data indicate a high temperature variability in summer related to successive upwelling and relaxation events (Figure 4-10). In winter, conditions are more well-mixed and the seawater temperature significantly less variable.




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Min °C** | 16.7 | 16.6 | 16.6 | 14.9 | 14.9 | 14.9 | 14.3 | 14.1 | 14.5 | 14.8 | 16 | 16.7 |
| **Max °C** | 21.2 | 20.3 | 20.8 | 19.2 | 18.4 | 17.5 | 16.4 | 16.3 | 16.2 | 17.4 | 18.7 | 20 |

**Figure 4-10: Minimum and maximum seasonal sea surface temperatures for Cape Town (Source: https://www.seatemperature.org/africa/south-africa/cape-town.htms)**

Excluding periods of major freshwater inflows, the range of temperature and salinity in Table Bay, (14ºC;34.85 psu) to (21ºC;35.25 psu), suggest and ambient density that ranges between 1 025 to 1 026 kg/m³ (Figure 4-11). While significant stratification exists in Table Bay, especially under upwelling conditions, the relative shallow location of the marine outfall diffuser, suggests that the stratification at this location will be limited.

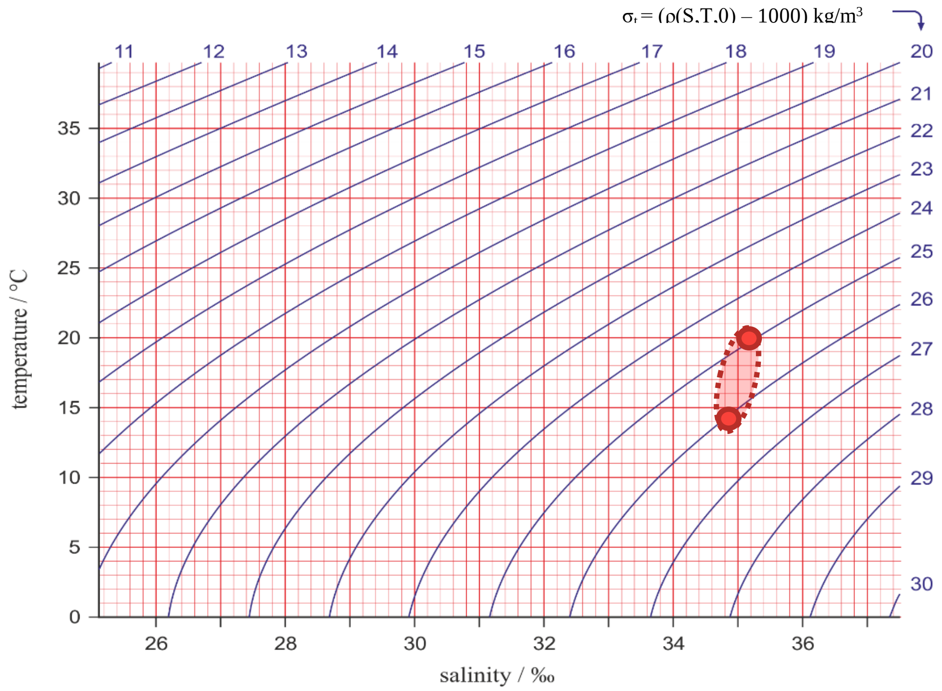



**Figure 4-11: Seawater density for the range of typically observed water temperatures and salinities in Table Bay**

# 5 MODELLING APPROACH

The hydraulic analysis and the prediction of achievable initial dilutions for the outfall system reported here are those reported in WSP|PB (2014b).

## 5.1 SOFTWARE UTILISED

### 5.1.1 NEAR-FIELD MODELLING AND INITIAL DILUTIONS

The near-field dilution in that study was undertaken using a near-field plume dispersion numerical model developed by WAMTechnology cc (DWAF, 2004b) that applies the basic principles of hydraulics as described in WRc (1990).

The Wamtech near-field model uses the methods for estimating effluent dilution for various ambient and diffuser conditions, as developed by the United States Environmental Protection Agency (US-EPA, 1985). In this method, a "plume element" is followed (for each modelling time step) as it gains mass due to entrainment of the ambient water the density. The density of the "plume element" at each time step is the average of the previous value and the entrained values, weighted by their relative masses. Horizontal momentum is conserved. The difference between the evolving density of the plume and the surrounding environment creates a vertical acceleration (buoyancy) on the plume element. The plume dimensions are determined based on the conservation of mass and momentum. The model output comprises the plume trajectory, rise height and dimensions (radius). The model output includes interactive visual trajectories of the plumes for all the ports of the diffuser and standard graphical outputs of the entire range of diffuser characteristics. The dilutions calculated comprise the near-field dilution of the plume. The model is similar to the Cormix (Doneker and Jirka, 2007) and Visjet (Chueng *et al.*, 2000) near-field models and provides similar output predictions of plume behaviour and effluent dilutions.

### 5.1.2 FAR-FIELD MODELLING AND SECONDARY DILUTIONS

A far-field dilution prediction technique (a straight-line analytical prediction method developed by Brooks (1960) for conservative and non-conservative substances (bacteriological parameters), was utilised to predict the secondary dilution occurring in the far-field based on the initial dilutions predicted at the end of the near-field. This far-field modelling approach is described in greater detail in Botes and Taljaard (1996). The far-field model was used to predict the zone of non-compliance of those dissolved parameters that did not achieve compliance with the relevant water quality guidelines within the near-field. Given that the SS (=25 mg/ℓ) in the presently proposed WWTW effluent is an order of magnitude less than that (SS ~ 250 mg/ℓ) of the combined preliminary treated and brine discharge effluent assessed when designing the marine outfall Wamtech and Rossouw (1999), the use of a more complex far-field modelling approach to simulate the transport and fate of such limited particulate matter is deemed superfluous.

## 5.2 MODEL PARAMETERS

The hydraulic parameters (Table 5-1 and Table 5-2), effluent volumes and quality and environmental conditions (Table 5-3) used in the modelling are summarised below.

**Table 5-1: Main characteristics of the Robben Island marine outfall.**

| Pipeline diameter | Pipeline Length | Dissuer Length | No.diffuser sections | No of ports | Port Spacing | Port Height |
|---|---|---|---|---|---|---|
| 0.2 m | 465 m | 10 m | 3 | 3 | 3.5 m | 780 mm above main pieline |

**Table 5-2: Characteristics of the marine outfall diffuser for an effluent flow of 0.025 ℓ/s.**

| Diffuser ID | Pipeline diameter (m) | Pipe velocity (m/s) | Port diameter (m) | Port flow rate (ℓ/s) | Port exit velocity (m/s) | Depth of discharge (m MSL) | Froude number |
|---|---|---|---|---|---|---|---|
| Diffuser Section 1 | 0.2 m | 0.80 m/s | 0.10 | 8.5 | 1.08 | -7.3 | 6.9 |
| Diffuser Section 2 | 0.16 m | 0.83 | 0.11 | 9.2 | 0.97 | 7.3 | 5.9 |
| Diffuser Section 3 | 0.11 m | 0.78 | 0.11 | 7.4 | 0.78 | 7.3 | 4.7 |
| Average | - | **0.83** | - | **8.37** | **0.934** | - | **5.81** |

The total headloss is 2.03 m, comprising a headloss of 1.91 m in the main pipeline and 0.11 m in the diffuser.

**Table 5-3: Effluent characteristics and the characteristics of the receiving environment.**

| Effluent Flow | Effluent flow duration | Effluent Density | Ambient seawater density | Water column stratification |
|---|---|---|---|---|
| 0.025 ℓ/s | Estimated an approximate cumulative duration of 3 hours and 20 minutes each day | ~ 1 000 kg/m$^3$ *1 | ~ 1 026 kg/m$^3$ *2 | Water column stratification was assumed to be negligible at the discharge location |

*1 This assumes that the practise of flushing the sewer pipelines with desalination (reject) brine will cease and an alternative found for flushing the sewer pipelines.

*1 This is the likely upper range of the expected density of the ambient seawater of the receiving environment.

Using the near-field model, achievable dilution were predicted for the same range of environmental conditions used by Wamtech and Rossouw (1999) to design the outfall and also as utilised in WSP|PB (2014a). These conditions are summarised in Table 5-4 below.

**Table 5-4: Environmental conditions used in the near-field model achievable dilution predictions. .**

| Ambient Condition | Current speed (m/s) | |
|---|---|---|
| | Surface | Bottom |
| Stagnant | 0.01 | 0.01 |
| Average | 0.07 | 0.04 |
| 20% exceedance* | 0.11 | 0.07 |
| 5 % exceedance* | 0.17 | 0.11 |

* These currents speeds will be exceeded for 20% and 5% of the time, respectively.

# 6 MODEL RESULTS

The predicted achievable dilutions of the model are reported as:

— initial dilutions for the effluent constituents having a required dilution not exceeding the predicted minimum achievable dilutions (~ 65) of the wastewater effluent from the proposed WWTW, and;

— total dilutions (*i.e.* the combined result of both initial and secondary dilutions) for those constituents with a required dilution that will possibly exceed the predicted minimum achievable dilutions (~65) of the wastewater effluent from the proposed WWTW.

## 6.1 ACHIEVABLE DILUTIONS IN THE NEAR-FIELD.

The predicted achievable dilution in the near-field are summarised in Table 6-1. The achievable dilutions reported in the table are those attained at the end of the near-field. The plume is predicted to reach the sea surface under all environmental conditions modelled. Thus, for all environmental conditions modelled, the end of the near-field is the location where the effluent reached the sea surface.

It should be noted that the predicted achievable dilutions are not necessarily conservative. Should for some reason the effluent accumulate around the outfall, the effluent plume will entrain waters containing previously discharged effluent, albeit in a dilute form. Under these circumstances, the "effective" initial dilutions could be lower than those predicted by the near-field model. However, given the relatively good effluent quality, the generally low effluent volumes and the fact that it is an intermittent discharge, means that it is highly unlikely that there will be accumulation of effluent around the marine outfall to the extent that the near-field model predictions will not remain accurate, (*i.e.* sufficiently conservative).

**Table 6-1: Near-field model predicted minimum achievable dilutions for a representative range of environmental conditions.**

| Ambient Condition | Current speed (m/s) | |
|---|---|---|
| | Minimum initial dilutions | Horizontal distance from the diffuser |
| Stagnant | 66 | 3 |
| Average | 79 | 5 |
| 20% exceedance | 250 | 8 |
| 5 % exceedance | 756 | 18 |

## 6.2 ACHIEVABLE DILUTIONS IN THE FAR-FIELD.

Estimations of the total dilution comprising both initial and secondary dilutions have been determined for specified distances from the diffuser for all of the environmental conditions assessed. These are summarised in Table 6-2 below. However, where necessary, actual concentrations of effluent constituents have been calculated, *i.e.* where there is not compliance with the relevant water quality guidelines within the near-field (see Section 6.3 below).

**Table 6-2: Predicted near and far-field dilutions for a representative range of environmental conditions.**

| PREDICTED ACHIEVABLE DILUTIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model Type** | **Near-field** | **Far-field** | | | | | | |
| **Distance from Diffuser** | **< 10 m** | **20 m** | **30 m** | **50 m** | **100 m** | **200 m** | **300 m** | **400 m** |
| Stagnant conditions | 66 | 335 | 530 | 1 000 | 2 575 | 6 900 | 12 450 | 19 000 |
| Average conditions | 79 | 95 | 115 | 155 | 280 | 600 | 990 | 1 440 |
| 20% exceedance | 250 | 270 | 30 | 370 | 595 | 1 140 | 1 800 | 2 540 |
| 5% exceedance | 756 | 770 | 810 | 925 | 1 310 | 2 245 | 3 245 | 4 580 |

## 6.3 COMPLIANCE WITH WATER QUALITY GUIDELINES

Assuming a minimum achievable dilution of 65, reference to Table 3-3 indicates that almost all effluent constituents have required dilutions less than the predicted minimum dilution. The only exceptions are possible residual concentrations of free chlorine, SS concentrations, nutrient concentrations (specifically Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) and Phosphate ($PO_4$-P)) Each of these potential exceptions are discussed below.

Should the residual chlorine concentrations in the effluents be as high as the upper limit specified in the General Value Limits (residual chlorine < 0.25 mg/ℓ), there will not be compliance with more restrictive existing South African Water Quality guideline (residual chlorine < 0.00 3 mg/ℓ) within the near-field under stagnant flow conditions. There will however be compliance for all of the other environmental conditions assessed. Despite an effluent with a chlorine residual concentration of 0.25 mg/ℓ not complying in the near-field, predicted secondary dilutions nevertheless indicate compliance within a 10 m radius of the outfall deemed to be an acceptable zone of non-compliance.

The above assessment has been made without assuming any decay of the residual chlorine concentrations whether by reactive with organic matter or due to decay by exposure to sunlight. This constitutes a very conservative approach to assessing potential impacts of residual chlorine concentrations in the effluent.

This study assumes a lower ambient SS concentration (~ 3.5 mg/ℓ, see Table 3-3) than the original 2014 BAR specialist effluent dispersion modelling study (WSP|PB, 2014b). This necessarily increases the number of required dilution of SS to ensure compliance with the existing South African Water Quality guidelines. The required dilution for SS reported in WSP|PB (2014a) is 40, while in this study the required dilution for SS to ensure compliance with the existing South African Water Quality guidelines has increased to 62. However, even this higher required dilution remains below the minimum predicted achievable dilution (~65) in the near-field for all environmental conditions assessed.

A potential additional concern related to SS concentrations in the effluents, is that contaminated particulate matter may settle on the seabed. Such predictions are not part of the near-field model utilised in this study (see Section 3.4). However as reported in Pisces (2021), monitoring of the existing wastewater effluent being discharged (that contains an order of magnitude higher SS concentration), indicated that approximately 10 months after the commissioning of the outfall:

- the proportion of sand in the sediments around the diffuser (<30 m radius) increased significantly;
- there was no marked increase in the organic content of the sediment around the diffuser;
- heavy metal concentrations in the sediments were below the maximum allowable effects range low (ERL) levels stipulated by the South African Sediment Quality Guidelines (see also Toefy, 2010);

While the situation may have changed since then, it is highly unlikely that the proposed new effluent that contains an order of magnitude less suspended sediments load than the existing sewage effluent being discharged, is likely to lead to the accumulation of fine contaminated sediments in the vicinity of the marine outfall. Short-term deposition of such fine material may occur, however it is likely to be re-suspended and dispersed by wind- and wave-forcing during subsequent "weather events".

Possibly of greatest potential concern, are elevated level of nutrients that could possibly lead to causing excessive or nuisance growth. The two effluent constituents of concern in this regard are Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) and Phosphate ($PO_4$-P).

The potential impacts of high Nitrate/Nitrite concentrations is exacerbated by high ambient concentrations of Nitrate and Nitrite in the marine receiving environment. Should the ambient concentrations of Nitrate and Nitrite remain below 0.1 mg/ℓ then there will be compliance with the site-specific guidelines for Nitrate and Nitrite as a nutrient within a 10 m radius of the outfall diffuser. However, given that high ambient Nitrate and Nitrite concentrations are unlikely to occur for stagnant conditions (*i.e.* no upwelling or advection of upwelled waters into the area of interest), it is likely that the greatest risks of nuisance growth would be for non-stagnant conditions (i.e. average flow conditions). The implication therefore is that it is likely that ambient Nitrate and Nitrite concentrations of up to 0.14 mg/ℓ will not result in the achievable dilutions of the Nitrate and Nitrite concentrations in the effluent exceeding the required minimum dilution (~79) for average flow conditions (*i.e.* ambient Nitrate and Nitrite concentrations of up to 0.14 mg/ℓ are highly unlikely to lead to excessive or nuisance growth in the receiving environment). The most vulnerable period for such nuisance growth would be the relaxation phase after a period of strong upwelling when nutrient concentrations in the receiving environment are likely to be high and the environmental conditions relatively quiescent.

High phosphate concentrations in the discharged effluent is possibly the greatest source of potential concern. Compliance with the relevant guidelines will not be achieved in the near-field. The upper range of required dilutions reported in Table 3-3 (*i.e.* required dilutions of 250 to 620) are significantly higher than the predicted minimum achievable dilution of 65. The upper Phosphate concentration limit of 10 mg/ℓ specified in the General Limit Values is likely to be significantly greater than the Phosphate concentrations in 4 to 6 mg/ℓ expected in the effluents from the proposed new WWTW (see comment below Table 2-2 in Section 2.2.2). For Phosphate concentrations of 4 to 6 mg/ℓ in the wastewater from the proposed new WWTW, required dilutions of 250 to 375 will be necessary to comply with relevant water quality guidelines. For such concentrations, there will be compliance with the relevant water quality guidelines within a radius of 30 m of the outfall. Should the Phosphate concentrations in the effluent from the WWTW be as high as 10 mg/ℓ, under some environmental conditions there will only be compliance with the relevant water quality guidelines within a 100 m radius of the outfall. However, it should be noted that Phosphate is generally not a limiting nutrient in the environment under consideration (Lwandle, 2017).

The compliance of the various constituents of the wastewater effluent from the proposed new Robben Island WWTW are summarised in Table 6-3 below.

It should be noted that a single outfall performance assessment was undertaken in 2002 upon full commissioning of the outfall (Robert, 2002). This assessment comprising dye dilution studies reported an initial dilution of > 30 between the diffuser ports and the sea surface and a minimum dilution of 50 within a 50m radius of the diffuser. The effluent flow rate and quality (density) during this dye dilution study were not reported but presumably comprised a combination of WWWT and desalination brine for which the outfall was originally designed, Such an effluent, being less buoyant effluent that the WWTW only effluent considered in this study, would have resulted in lower dilution of the effluent, particularly in the near-field, thus at least partially (if not fully) explaining the discrepancies between the these earlier results and the results of the present modellingstudy.

**Table 6-3: Compliance summary for the wastewater effluent from the proposed new Robben Island WWTW.**

| | Constituent | Compliance Distance | Comment |
|---|---|---|---|
| **Protection of Marine Ecosystem (Natural Environment)** | Oil, soap and grease (mg/ℓ) | < 10 m | - |
| | Temperature (ºC) | < 10 m | - |
| | Salinity (psu) | < 10 m | - |
| | pH | < 10 m | - |
| | Suspended Solids (mg/ℓ) | < 10 m | - |
| | $BOD_5$ (mg/ℓ) | < 10 m | - |
| | COD (mg/ℓ) | < 10 m | - |
| | **Nitrate, Nitrite, Ammonia and Phosphate as nutrients-** | | |
| | Ammonium ($NH_4^+$-N) | < 10 m | - |
| | Nitrate/Nitrite as Nitrogen ($NO_3$-N + $NO_2^-$-N) | < 10 m | Provided the ambient Nitrate/Nitrite as Nitrogen concentrations remain below 0.14 mg/ℓ |
| | Dissolved inorganic nitrogen ($NH_4$-N + $N0_3$-N + $NO_2$-N) | < 10 m | - |
| | $PO_4$-P (mg/ℓ P) | < 30 m<br>< 100m | assuming an effluent concentration of 4 to 6 mg/ℓ<br>assuming an effluent concentration of 10 mg/ℓ |
| | **Ammonia, Fluoride, chlorine and metals as toxicants** | | |
| | Total Ammonia (mg/ℓ) ($NH_3$-N + $NH_4^+$-N) | < 10 m | - |
| | Cyanide (mg/ℓ) | < 10 m | - |
| | Fluoride (mg/ℓ) | compliant at point of discharge | - |
| | Chlorine as Free Chlorine | < 10 m | Does not comply in the near-field but does comply within 10 m of the outfall diffuser |
| | Arsenic (mg/ℓ) | < 10 m | - |
| | Boron (mg/ℓ) | < 10 m | - |
| | Cadmium (mg/ℓ) | < 10 m | - |
| | Chromium (VI) (mg/ℓ) | < 10 m | - |
| | Copper (mg/ℓ) | < 10 m | - |
| | Iron (mg/ℓ) | - | - |
| | Lead (mg/ℓ)[8] | < 10 m | - |
| | Manganese (mg/ℓ) | < 10 m | - |
| | Mercury (mg/ℓ) | < 10 m | - |
| | Nickel (mg/ℓ) | < 10 m | - |
| | Selenium (mg/ℓ) | < 10 m | - |
| | Silver (mg/ℓ) | Compliant at point of discharge | |
| | Zinc (mg/ℓ) | < 10 m | - |
| **Contact Recreation** | F. Coli (MPN/100 m ℓ) | < 10 m | Complies with all of the relevant guidelines for contact recreation |
| **Collection of Filter Feeders** | F. Coli (MPN/100 m ℓ) | < 10 m | Complies with all of the relevant guidelines for collection of filter feeder |

# 7 CONCLUSIONS AND RECOMMENDATIONS.

## 7.1 CONCLUSIONS

There is compliance with the existing water quality guidelines within a predicted 10 m of the outfall diffuser for all effluents constituents other than Phosphate. Phosphate is predicted to comply within between 30 m and 100 m of the outfall diffuser, depending on the assumed phosphate concentration in the wastewater effluent from the proposed new WWTW. However this non-compliance beyond a 10 m radius of the outfall may be considered non-substantive, as phosphate is generally not a limiting nutrient in the environment under consideration (Lwandle, 2017).

It should be noted that the largest predicted mixing zones are generally for quiescent (stagnant conditions) that are unlikely to be a common occurrence for the marine outfall location. Furthermore, the discharge of effluents from the WWTW will be intermittent (*i.e.* a cumulative 3 hours and 20 minutes per day for the sewage flow volumes envisaged). The “no-flow” periods between the intermittent discharges will give the effluent time to disperse, suggested a very low likelihood of the accumulation of effluent around the outfall diffuser.

## 7.2 RECOMMENDATIONS

It is recommended that the actual phosphate concentration of the WWTW effluent be monitored. Should they be higher than anticipated there may be a need to introduce mitigation measures. However, as phosphate is generally not a limiting nutrient in the environment under consideration, such mitigation measures may not be strictly necessary especially if the phosphate concentration is restricted to 4 to 6 mg/ℓ (as is expected for the new WWTW). While the capital costs of such measures are modest, the operational costs are unlikely to be so.

It is further recommended that the condition of the outfall be assessed either directly (*e.g.* diver surveys) or indirectly (performance assessment via monitoring activities), to confirm that it is indeed operating as specified (and as simulated in this modelling study).

# 8 REFERENCES


Anchor Environmental (2015). Assessment framework for the management of effluent from land-based sources discharged to the marine environment, *Anchor Environmental Consultants Report No. 1618/1*, 87pp.

ANZECC (2000). Aquatic Ecosystems — Rationale and Background Information. In Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Volume 2). pp. 8.1–1 – 8.1–32. Available at: NATIONAL WATER QUALITY MANAGEMENT STRATEGY - Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) - Volume 2 - Aquatic ecosystems [Accessed 22 Sept 2021]. Updated guidelines 9ANZECC (2018) are available at Water Quality Guidelines Home [Accessed 22 Sept 2021]

Brooks, N.H. (1960). Diffusion of sewage effluent in an ocean current. *Proceedings of the First International Conference on Waste Disposal in the Marine Environment*. Edited by E.A. Pearson. Pergamon Press, New York. pp. 246–267.

Botes, W.A.M. and S. Taljaard (1996). Comparison of predicted secondary dilutions to measured field data and the determination of prototype diffusion coefficients. *WRC Report No 675/1/96*. Pretoria.

CEFAS (2011). Influence of cooling water temperature upon oxygen saturation and relevance to regulations, *Scientific position paper* (SPP064).

Chueng, S.K.B., D.Y.L.Leung, W. Wang, J.H.W. Lee and V. Chueng (2000). Visjet – a computer outfall modelling system, *Computer Graphics International Proceedings*, Geneva, Switzerland, 19-24 June 2000, 75-80.

CMS (1995). Water quality assessment of Table Bay Harbour. Summer survey, prepared by the Centre for Marine Studies, University of Cape Town, for Watermeyer Prestedge Retief, 33 pp.

Department of Environmental Affairs (DEA) (2012). South African Water Quality Guidelines for Coastal Marine Waters. Volume 2: Interim guidelines for recreational waters. Department of Environmental Affairs Report, Cape Town, RSA, 25pp + 66pp App

Department of Environmental Affairs (DEA) (2012). South African Water Quality Guidelines for Coastal Marine Waters. Volume 2: Interim guidelines for recreational waters. Department of Environmental Affairs Report, Cape Town, RSA, 25pp + 66pp App

Department of Environmental Affairs (DEA) (2014). National guideline for the discharge of effluent from land-based sources into the Coastal Environment, Pretoria, South Africa, *RP101/2014*, 54 pp.

Department of Environmental Affairs (DEA) (2015). Environmental Authorisation for the proposed construction on a Sewage Package Plant at Robben Island, Western Cape, Department of Environmental Affairs (DEA authorisation no. 14/12/16/3/3/3/83: NEAS Reference: DEA/EIA/0002777/2015), 19pp.

Department of Environmental Affairs (2019a). Draft South African Water Quality guidelines for Coastal Marine Waters – Volume 1: Natural Environment and Mariculture Use Department of Environmental Affairs report, 164pp.

Department of Environmental Affairs (2019b). National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) - Coastal Waters Discharge Permit Regulations, *Notice No 382 in Government Gazette No 42304 (15 March 2019)*, pp25 – 39.

Department of Public Works (DPW) (2012). Small wastewater treatment works DPW design guidelines, *DPW Report no 2011/1*, 100pp.

Department of Water Affairs and Forestry (DWAF) (1995a). South African water quality guidelines for coastal marine waters. Volume 1. Natural Environment. Pretoria.

Department of Water Affairs and Forestry (DWAF) (1995b). South African water quality guidelines for coastal marine waters. Volume 2. Recreation. Pretoria.

Department of Water Affairs and Forestry (DWAF) (1995c). South African water quality guidelines for coastal marine waters. Volume 3. Industrial use. Pretoria.

Department of Water Affairs and Forestry (DWAF) (1995d). South African water quality guidelines for coastal marine waters. Volume 4. Mariculture.

Department of Water Affairs and Forestry (DWAF) (2004a). Water Quality Management Series Sub-Series No. MS 13.2. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa. Edition 1. Pretoria, 77pp.

Department of Water Affairs and Forestry (DWAF) (2004b). Water Quality Management Series Sub-Series No. MS 13.3. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation. Edition 1. Pretoria, 251 pp.

Department of Water Affairs and Forestry (DWAF) (2004c). Water Quality Management Series Sub-Series No. MS 13.4. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices. Edition 1. Pretoria.

Department of Water Affairs (DWA) (2013). Revision of the General Authorisations in terms of Section 38 of the National Water Act, 1988 (Act No. 36 of 1988) (The ACT), government Notice No 663 in Government Gazette No 26820, pp 3 – 31.

Department of Water and Environmental Affairs (DWEA) (2013). Rievision of th eGeneral Authorisations in terms of Section 39 of the NaTIONAL Water ASct of 1998 (Act 36 of 1998, 42pp.

De Villiers, S. (2014). Chapter 9: Nutrients off South Africa's West Coast, In: *State of the Oceans and Coasts around South Africa 2013*, ed. (H. Verheye and R. Crawford), Department of Environmental Affairs (DEA) Branch: Oceans and Coasts, 126pp.

Doneker, R.L. and G.H. Jirka (2007). "CORMIX User Manual: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters", *EPA-823-K-07-001*, Dec. 2007. Available for download at http://www.mixzon.com/downloads/

Elemental (2021). Robben Island Wastewater Treatment Works: Design Report. *Elemental Consulting Engineers Report No PO0011044*, 17 pp + App.

Fadini, P.S., W.F. Jardim and n F, J.R. Guimarães (2004). Evaluation of organic load measurement techniques in a sewage and waste stabilisation pond. *Journal of the Brazilian Chemical Society*, **15(1)**, 131-135.

Hill P.S., Sherwood, C.R., Sternberg, R.W. & A.R.M. Nowell (1994). In situ measurements of particle settling velocity on the northern California continental shelf. *Continental Shelf Research*, **14(10/11)**, 1123-1138.

Johnson, A.C., M.D. Jürgens, A.J. Lawlor, I. Cisowska and R.J. Williams (2014) Particulate and colloidal silver in sewage effluent and sludge discharged from British wastewater treatment plants, *Chemosphere*, **112,** 49-55.

Le Roux, M and W. Botes (2007a). Feasibility study: Ocean outfall for the Mdloti and Tongati Catchments, WAMTECH Report PM/66/Durban North, 81pp.

Lusher, J.A.(ed.) (1984). Water quality criteria for the South African coastal zone. *South African National Scientific Programmes Report No 94*, 25 pp.

Lwandle (2006). Ben Schoeman Dock berth deepening: Specialist Study on Sediment toxicology and Marine Ecology, *Lwandle Report (Job No 06-35)*, Draft Report.

Lwandle (2017). Koeberg nuclear power station marine discharge assessment in support of the CWDP application: Marine ecology specialist study, Lwandle Report LT-267 Rev-08, 97pp. http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/KoebergNuclearPowerStation/2017%20Amendment/CWDP%20Assessment%20Report_Appendix%20B1.pdf.

Monteiro P.M.S. (1997). Table Bay sediment study Phase III (1997). A quantitative assessment of the impact of land based discharges of organic matter and trace metals on the sediment characteristics of Table Bay. *CSIR Report ENV-S-C 97085*. Stellenbosch, 56pp + Appendices.

Noziac, D.J and S.D. Freese (2010). Process design for small wastewater works, *WRC Report No TT 389/09*, 200pp.

Pisces (2021). Basic Assessment for a Marine Outfall at Robben Island, South Africa, *Pisces Environmental Services (Pty) Ltd report*, 81pp.

PRDW (2017). Koeberg Nuclear Power Station: Coastal Processes Information in Support of the Coastal Waters Discharge Permit Application: Dispersion modelling of thermal, chemical, sediment and radionuclide discharges. *Specialist Study S2015-RP-CE-001-R4*.docx. 90pp + Appendices.

Quick A.J.R. and M.J. Roberts (1993). Table Bay, Cape Town, South Africa: synthesis of available information and management implications. *S. Afr. J. Sci.*, **89**. 276-287.

Riley, J.P. and Chester, R.C. (1976). Chemical Oceanography. 2nd edition. Volume 6. Academic Press, London.

Roberts, M., (2002). Dye dispersion study of the Robben Island Marine Sewer outfall: Worst case conditions. *Report to Ove Arup Consulting Engineers*, pp73.

Toefy, R., (2010). Extant benthic foraminifera from two bays along the SW coast of South Africa, with a comment about their use as indicators of pollution. Unpublished PhD Thesis, University of the Western Cape, South Africa, pp308.

UNEP/Nairobi Convention Secretariat and CSIR (2009). Guidelines for the Establishment of Environmental Quality Objectives and Targets in the Coastal Zone of the Western Indian Ocean (WIO) Region, UNEP, Nairobi, Kenya, 169p.

US-EPA (1985). Initial mixing characteristics of municipal ocean discharges. *Report EPA/SW/MT-86/012a*.

van Ballegooyen, R.C., W.A.M. Botes and S. Taljaard (2003). Durban North Marine Outfall Study: Part 1 - Preliminary Assessment of a Proposed Marine Outfall. CSIR Report *ENV-S-C 2003-013*, 121pp.

Van Ballegooyen, R.C., G. Diedericks, N. Weitz, S. Bergman and G. Smith (2006). Ben Schoeman Dock Berth Deepening Project: Dredging and Disposal of Dredge Spoil Modelling Specialist Study, *CSIR Report No CSIR/NRE/ECO/ER/2006/0228/C*, 130 pp + 163 pp App.

Van Ballegooyen, N. Steffani and A. Pulfrich (2007). Environmental Impact Assessment: Proposed Reverse Osmosis Plant, Iron –ore Handling Facility, Port of Saldanha - Marine Impact Assessment Specialist Study, Joint CSIR/Pisces Report, CSIR/NRE/ECO/ER/2007/0149/C, 190pp + 198pp App.

Van Ballegooyen, R.C., van Eerden, F., M. Retief, S. Weerts and B. Newman (2015). Strategic assessment of WWTW discharge options: Environmental screening of a proposed nearshore marine outfall for the Durban South region, *WSP | Parsons Brinckerhoff Report No. 20179.P-002F*, 131 pp. + 10 pp. Appendices

van Ballegooyen, R.C., G. Jacobs, F. van Eeden and G. Smith (2016). East London Hood Point Outfall EIA: Hydrodynamic and Water Quality Modelling Specialist Study, *WSP Report No. 14672.R-108*, 178pp + 34pp App., Stellenbosch, South Africa.

Van Ieperen, MP (1971). Hydrology of Table Bay. Final Report. Institute of Oceanography, University of Cape Town, South Africa.

WAMTechnology and J. ROSSOUW (1999). Robben Island: Marine Outfall. Environmental conditions, Outfall hydraulics and dilutions. August 1999. *Report No: PW34/ZLH/98/R1*. Stellenbosch, 30pp.

Woodborne M.W. (1983). Bathymetry, solid geology and Quaternary sedimentology of Table Bay. *Joint GSO/UCT Mar. Geol. Prof. Tech. Rep., 14*, 266-277. Geology Department, University of Cape Town.

WRc (1990). Design guide for marine treatment schemes. Water Research Centre, Swindon, *United Kingdom. Report No. UM1009*, Volumes I and II.

WSP|PB (2014a). Robben Island Sewage Package Plant Department of Public Works: Final Basic Assessment Report, 306pp.

WSP|PB (2014b). Robben Island Marine Outfall: Specialist study for Basic Assessment Diffuser performance, Final Basic Assessment Report, *WSP|PB Report 17127-R01*, 22pp + 3pp Appendices.

WSP|PB (2014c). Robben Island Sewage Package Plant Department of Public Works: Application for a Coastal Waters Discharge Permit, 31pp + 135 pp Appendices.

WSP (2016). Robben Island WWTW Inception Report, *WSP Report No. 22214-01*, 12pp + 4pp Appendices.

WSP (2017a). Robben Island WWTW Preliminary Design Report, *WSP Report No. 22214-02*, 23pp + 6 pp Appendices.

WSP (2017b). Robben Island WWTW Preliminary Design Report, *WSP Report NO. 22214-03*, 17pp + 7pp Appendices.

# APPENDIX

# A

## “AS-BUILT” DRAWINGS FOR THE ROBBEN ISLAND WWTW MARINE OUTFALL

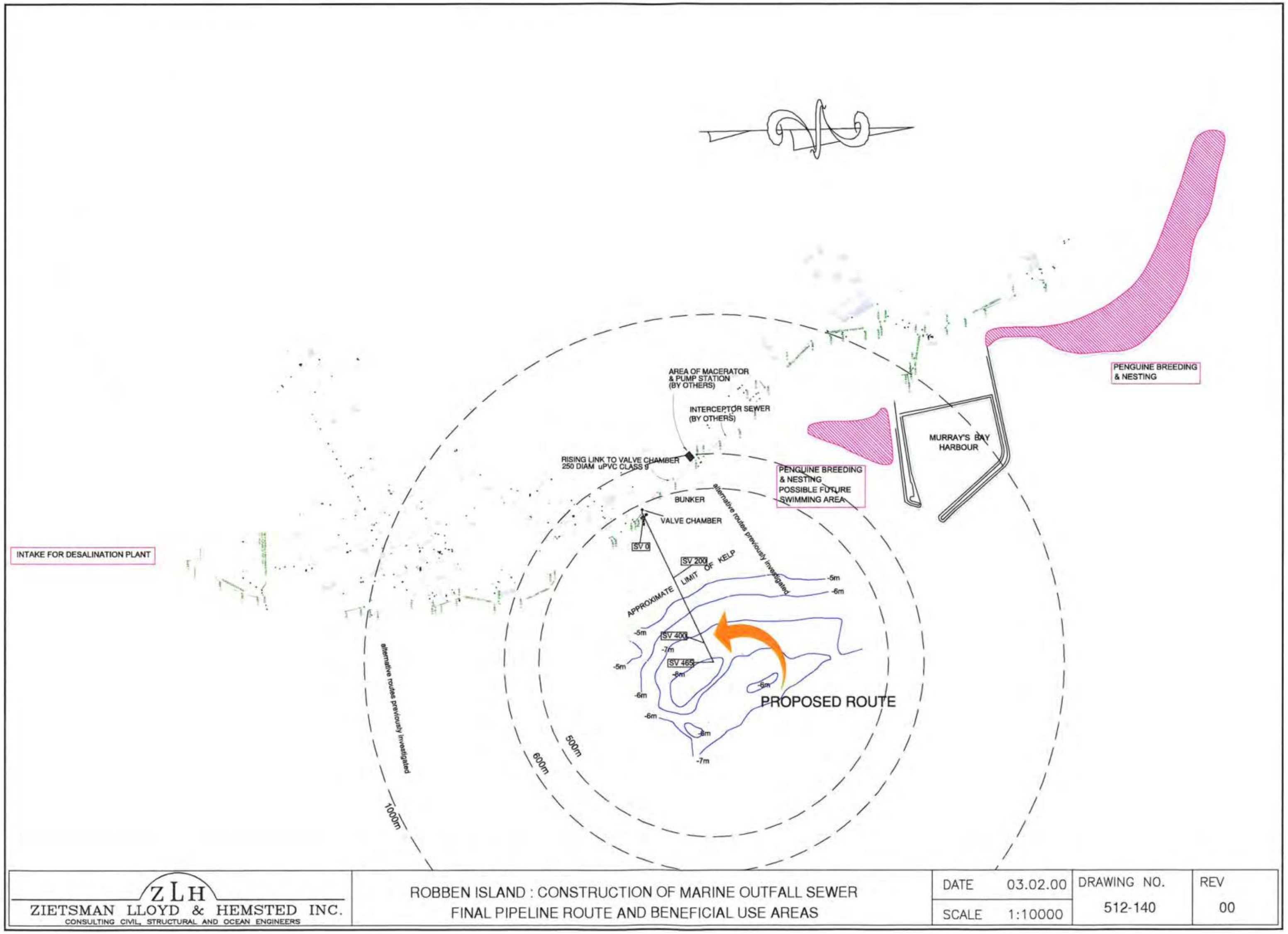



**Figure A-1:** **Robben Island marine outfall final pipeline route and beneficial use areas (Drawing No: 512-140).**

# APPENDIX A

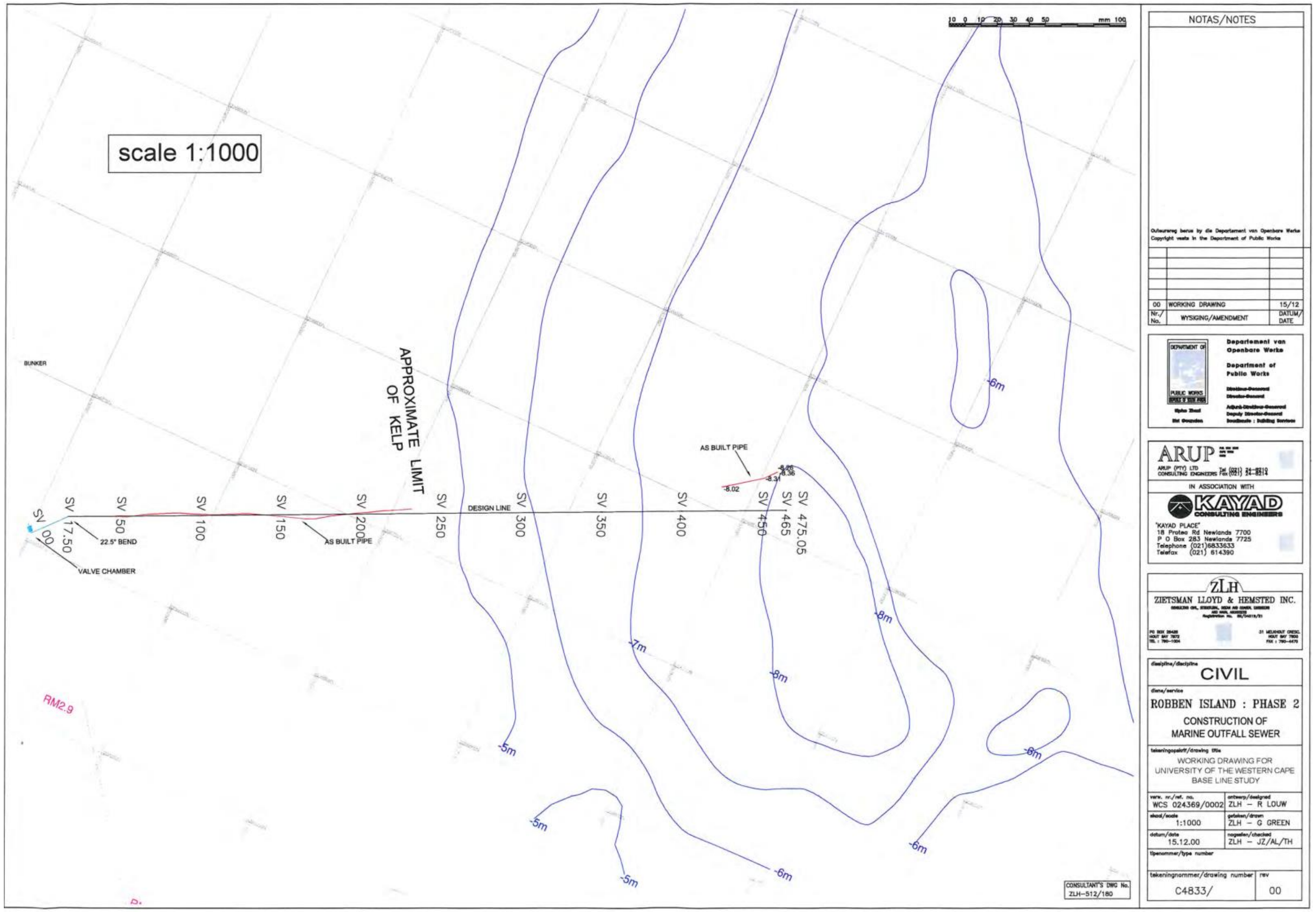



Figure A-2: “As-built” drawing for the Robenn Island marine outfall (Drawing No: C4833/00).

# APPENDIX

# B MODELLED PLUME TRAJECTORIES, ACHIEVABLE DILUTIONS AND NEAR-FIELD DIMENSIONS (EXTENTS)

# APPENDIX B

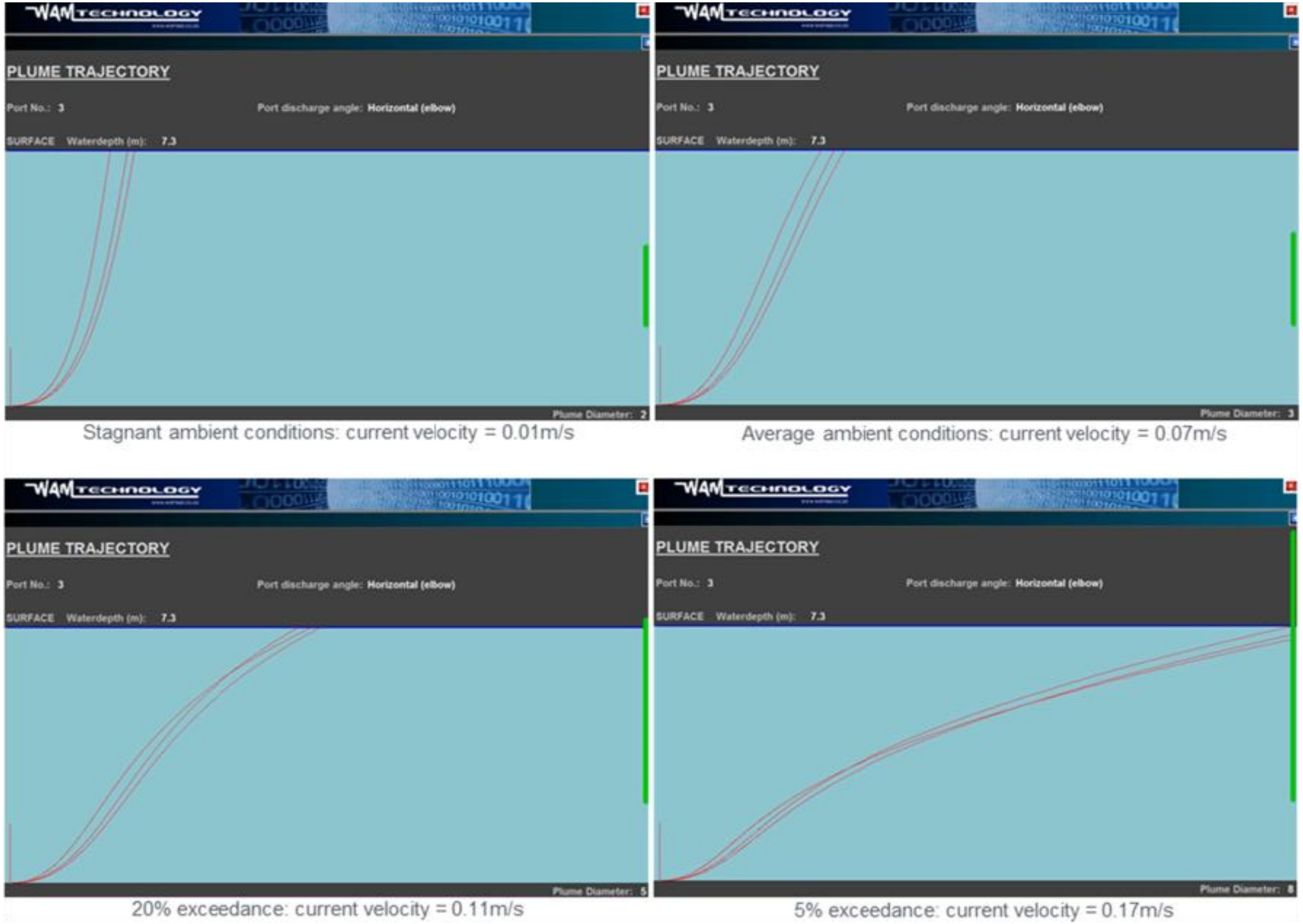



**Figure B-3: Modelled plume trajectories for a representative range of environmental (flow) conditions.**

# APPENDIX B

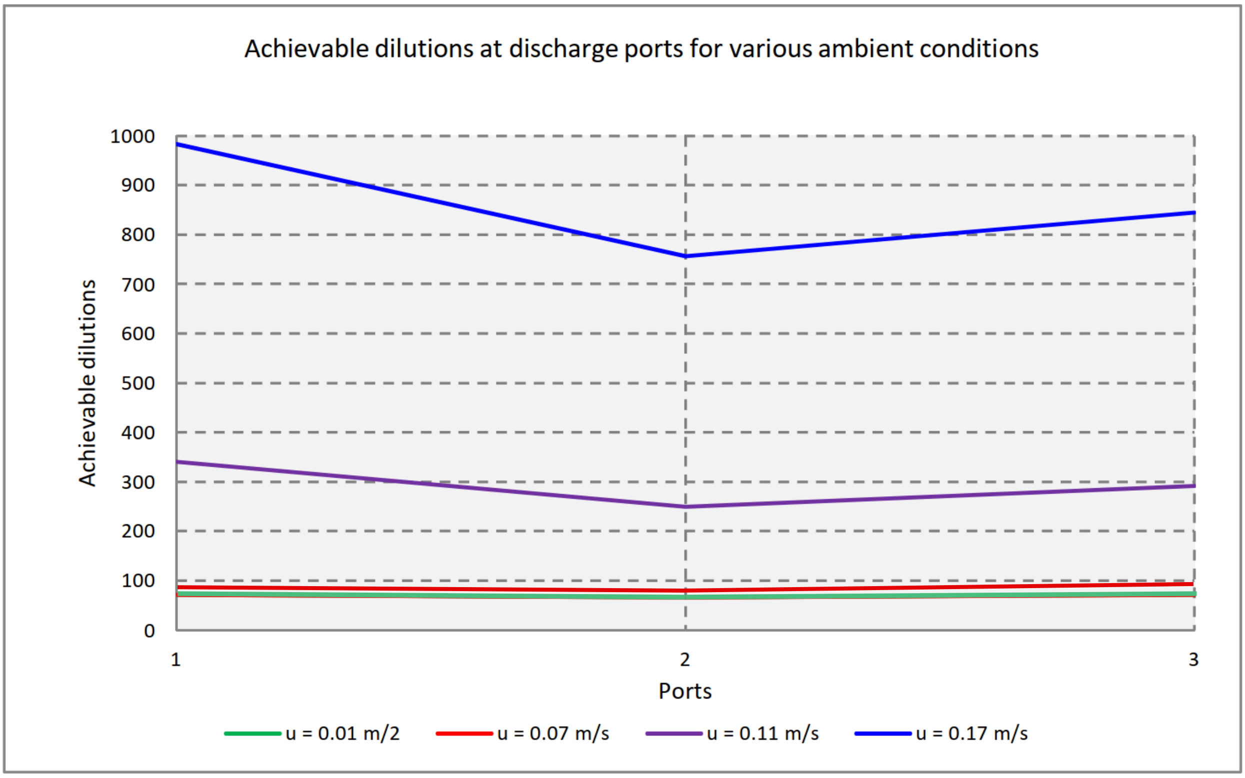



**Figure B-4: Predicted achievable dilutions at the discharge ports for a representative range of environmental (flow) conditions.**

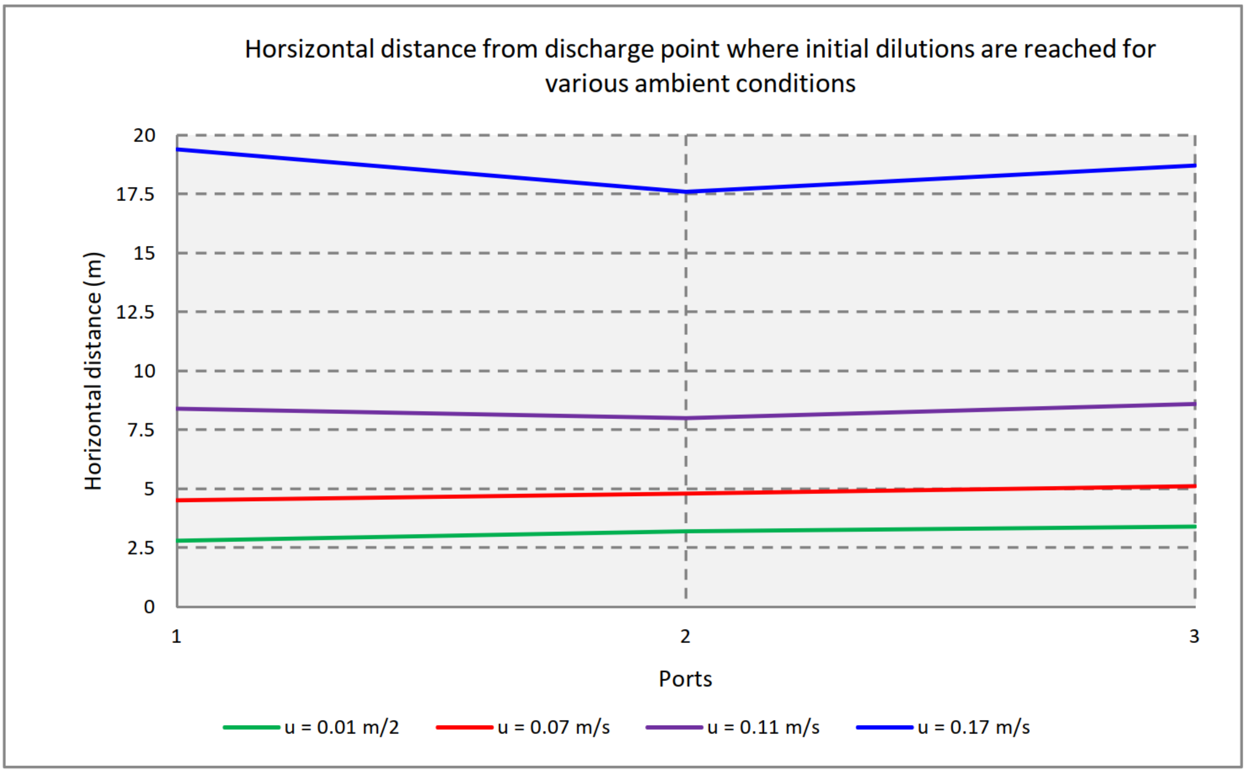



**Figure B-5: Model-predicted horizontal distances from the diffuser ports where the initial dilution is achieved (i.e. the distance from the ports to the end of the near-field) for various environmental (flow) conditions.**