Desalination Project

Hout Bay Outfall - Specialist Report

29 September 2017

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South Africa

C00686-0X-CS-REP-0001

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1 Introduction

1.1 Background

The City of Cape Town, South Africa, is currently experiencing the worst drought since 1904 and the Premier of the Western Cape has declared the City and other areas in the Western Cape as a disaster area.

Because of the drought, the city's dam levels have dropped substantially and the City of Cape Town wants to augment the city's potable water supply by using reverse osmosis (RO) and desalination plants at several sites along the coastline.

WorleyParsons has been appointed to develop the design of the marine desalination pipelines and structures, prepare technical tender documents for the appointment of a contractor to construct the works and administer and monitor the construction works.

There are 9 potential desalination sites being investigated. The current document focuses on Hout Bay, one of the potential sites where the brine can be discharged through existing marine outfalls using its spare capacity (see Figure 1-1).

The current scope of work includes providing the Contactors with sufficient information and detail to undertake a detailed design of a seawater desalination intake and outfall systems to be erected at each site. The Contractor's scope includes the Design, Supply, Establish, Commission, Operate and later Decommission of a Sea Water Reverse Osmosis (SWRO) Plant at a Site, or Sites, to Supply SANS 241:2015 Compliant Potable Water to the City of Cape Town. For Hout Bay, a rate of **4 Ml** of potable water per day is required

Figure 1-1: Hout Bay desalination plant option.

1.2 Scope of Work

To assist with describing the environmental impacts associated with discharging of liquid effluents associated with the Project both near- and far-field dispersion modelling have been undertaken. The near-field modelling assesses the initial mixing and configuration of the discharge jet as it exits the discharge pipe/outfall and enters the receiving water body, or as defined by Donenker & Jirka (2007) it considers the "region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge". Effluent mixing in the far-field is dominated by dispersion processes where the ambient current velocity and density differences between the mixed flow and the ambient receiving water control the plume characteristics (Doneker & Jirka, 2007).

The scope of work for this project included the following tasks:

- Near-field modelling of effluent discharges to assess the maximum allowable brine volume combined with the existing wastewater discharge to comply with the current license conditions/requirements, the Marine Water Quality Guidelines (MWQG) and the Department of Environmental Affairs (DEA) framework policy for a range of varying metocean current speeds;

- Far-field simulation of the combined effluent discharges (wastewater and brine combinations) to examine the extent and duration of the excess concentration of the effluent for the representative metocean conditions occurring at the study sites.

1.3 Project Datum and Projections

Unless otherwise specified, the horizontal projection used in this study is UTM34S, spheroid WGS84, and the vertical datum is Chart Datum (CD).

1.4 Abbreviations

The abbreviations that are summarised in Table 1-1 are used throughout this report.

Table 1-1: Abbreviations.

Abbreviation	Definition
CD	Chart Datum
CoCT	City of Cape Town
CORMIX	Cornell Mixing Zone Expert System
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
ML	Mean Level
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MWQG	Marine Water Quality Guideline
NFR	Near-Field Region
NOAA	National Oceanic and Atmospheric Administration

Abbreviation	Definition
PPT	Part Per Thousand
PSU	Practical Salinity Units
RMZ	Regulatory Mixing Zone
SANHO	South African Navy Hydrographic Office
SI	International System of Units
WWTW	Wastewater Treatment Works

1.5 Units

The project shall use the International System of Units (SI) for all project documentation. Table 1-2 provides a list of the units used by the Project.

Table 1-2: Units.

Parameter	Unit
Rainfall	mm
Humidity	%
Temperature	°C
Water Depth	m
Current & Wind Speed	m/s
Current & Wind Direction	°N
Discharge	m^3/s
Salinity	PSU

2 Site description and available data sources

2.1 Site description

A summary of the relevant available environmental characteristics for the Hout Bay site is outlined in the sub-sections that follow. For further details refer to the Basis of Design for the Batch 1 locations (Adivisian, 2017).

2.2 Bathymetry

Offshore bathymetric data was provided by digitised South African Navy Hydrographic Office (SANHO) Admiralty nautical charts. Additionally, local bathymetric data for Hout Bay was provided by the Council of Geoscience, which was also digitised and added to the SANHO charts.

The local bathymetric data for Hout Bay are presented in Figure 2-1; the vertical datum is referenced to Mean Sea Level. The surveyed seabed levels vary from approximately 5 m to 50 m below MSL; with water depths of approximately 37 m at the existing marine outfall.

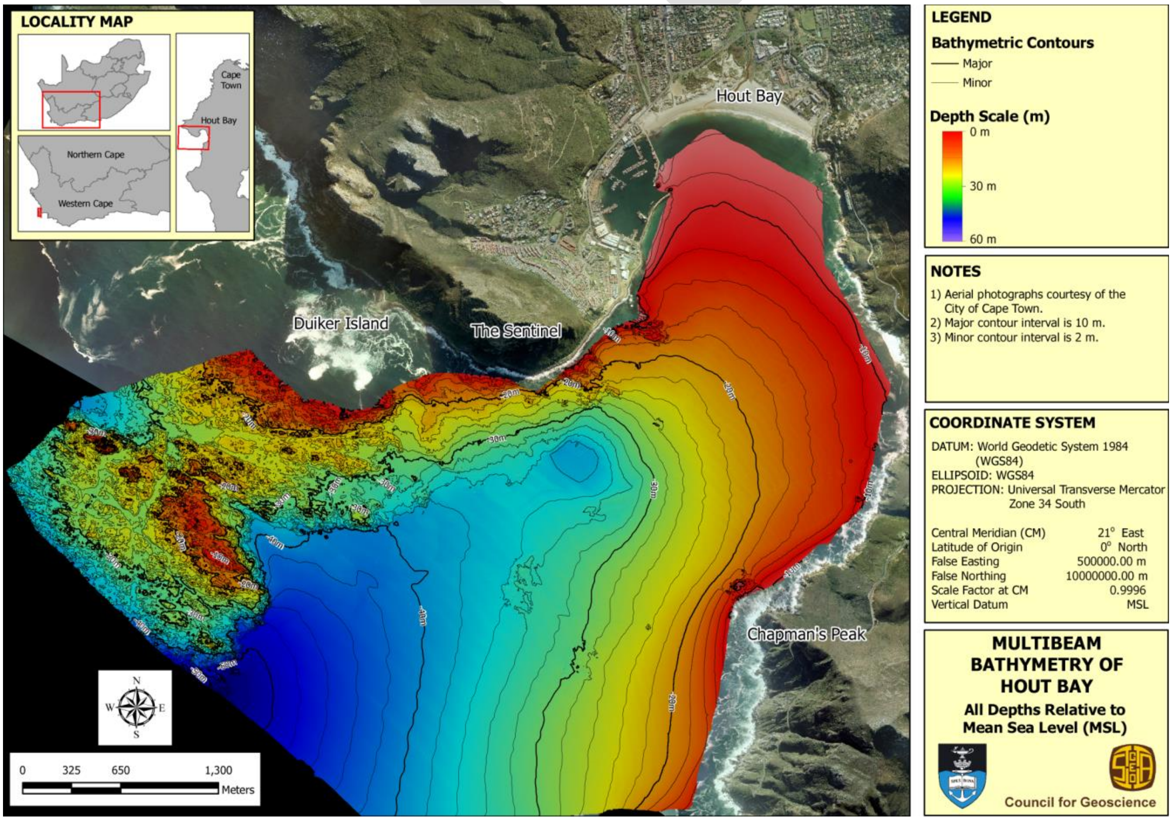

Figure 2-1: Extents of the bathymetric data for Hout Bay. Source: Council for Geoscience

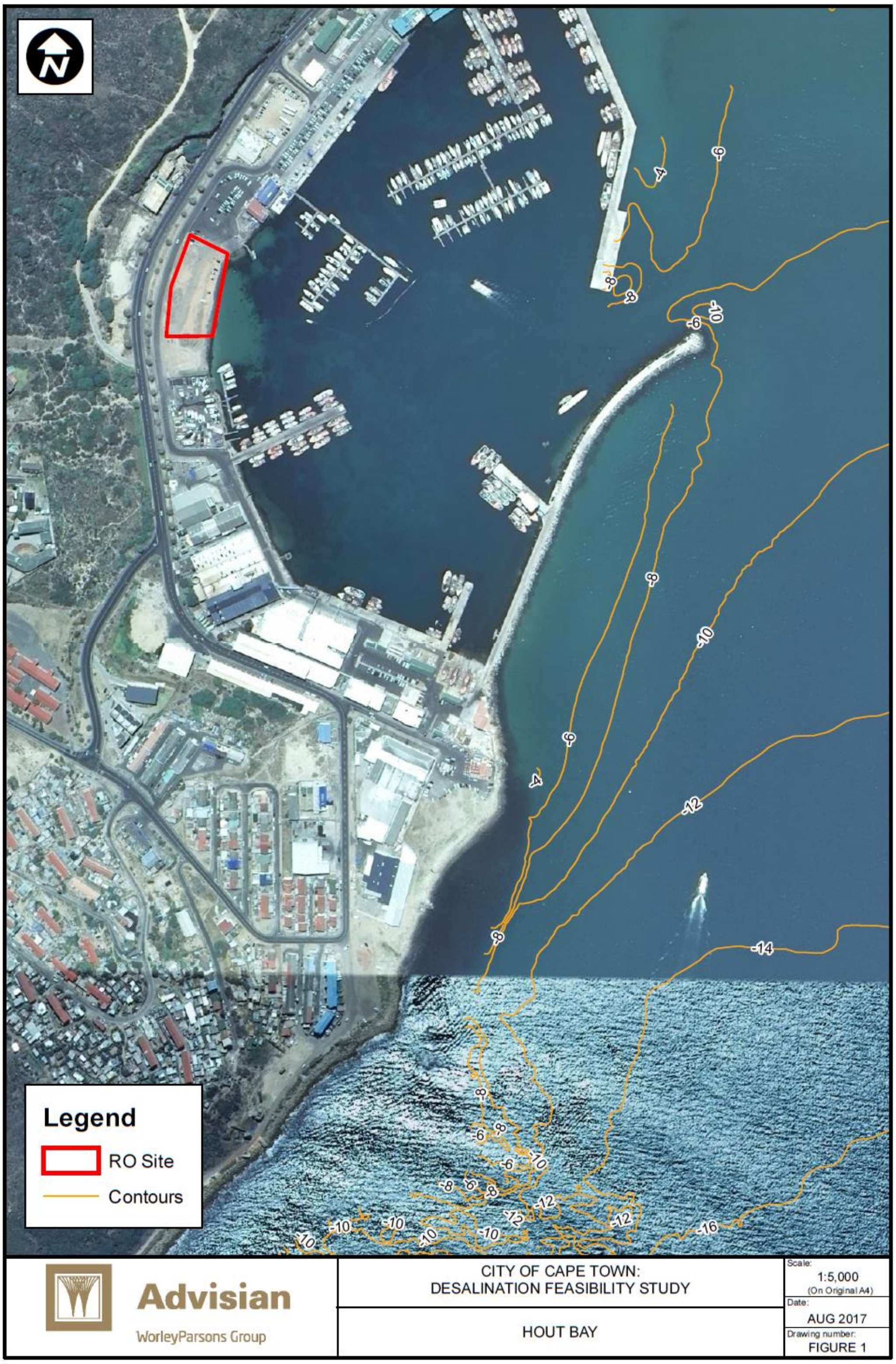

Figure 2-2: Bathymetric data at the Hout Bay Project Site (m MSL). Source: Council for Geoscience

2.3 Wind

A wind rose for Hout Bay was obtained from (Meteoblue, 2017). Figure 2-3 depicts the wind rose for the site with the strongest winds coming predominantly from the north-west and south-east.

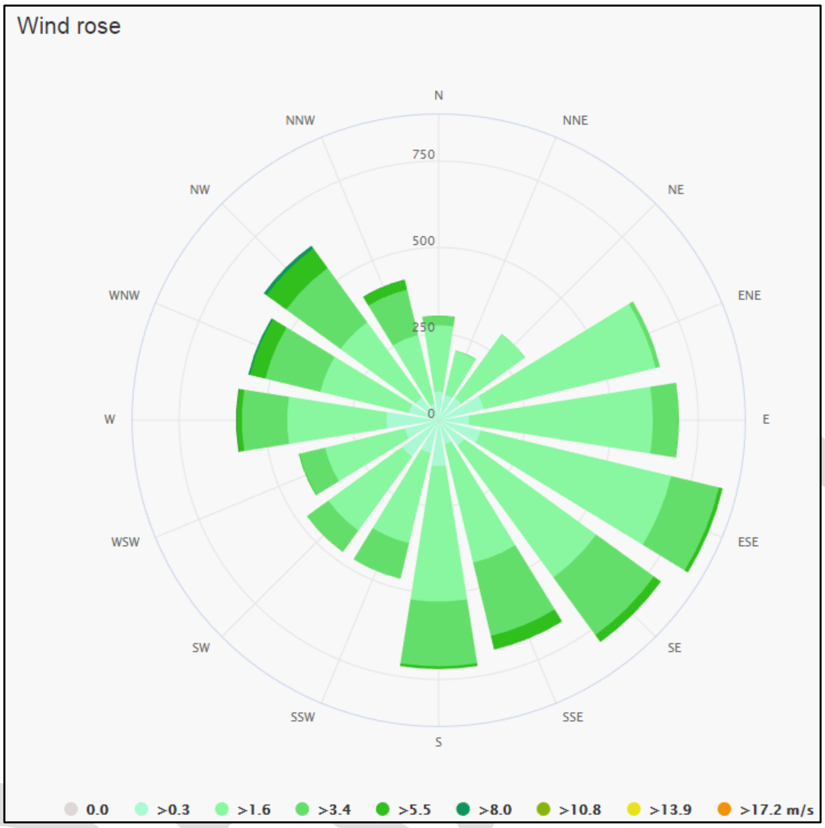

Figure 2-3: Annual Wind Rose for Hout Bay. Source: (Meteoblue, 2017).

No further wind measurements are available at present.

2.4 Waves

In the absence of local wave measurements at the locations of interest, wave modelling is the preferred approach to estimate the nearshore wave conditions.

Due to the short project duration and computational effort required, it was not feasible to model the entire offshore wave time series (extracted from NOAA Wave Watch III hindcast model at 35 ^{o}S, 17.5 ^{o}E). To transform the offshore wave climate into the nearshore a linear approach was followed, where a number of wave and wind condition bins, representative of the offshore wind and wave climate, were modelled. Transformation matrices for the wave conditions at the specified nearshore locations were established and the entire offshore wave time series was then transformed to these nearshore locations for further analysis.

The Delft3D modelling suite was used to set up the model domain and simulate the wave climate in the vicinity of the project sites. For these simulations Delft3D-WAVE modelling module was used. The Delft3D-WAVE module uses SWAN (Simulating Waves Nearshore) numerical model to simulate the generation and propagation of wind-generated waves. For this study, the flow effect on waves is defined by a spatially uniform water level.

Indicative wave conditions at the project site were estimated at Position 1 and Position 2 shown in Figure 2-4 through numerical modelling.

Figure 2-4: Wave extraction locations.

It should be noted that the annual conditions and derived extreme estimated have not been validated and are provided as an indication only.

Indicative annual wave roses for the extraction points are presented in Figure 2-5 and Figure 2-6; whilst Table 2-1 provides a summary of the wave parameters.

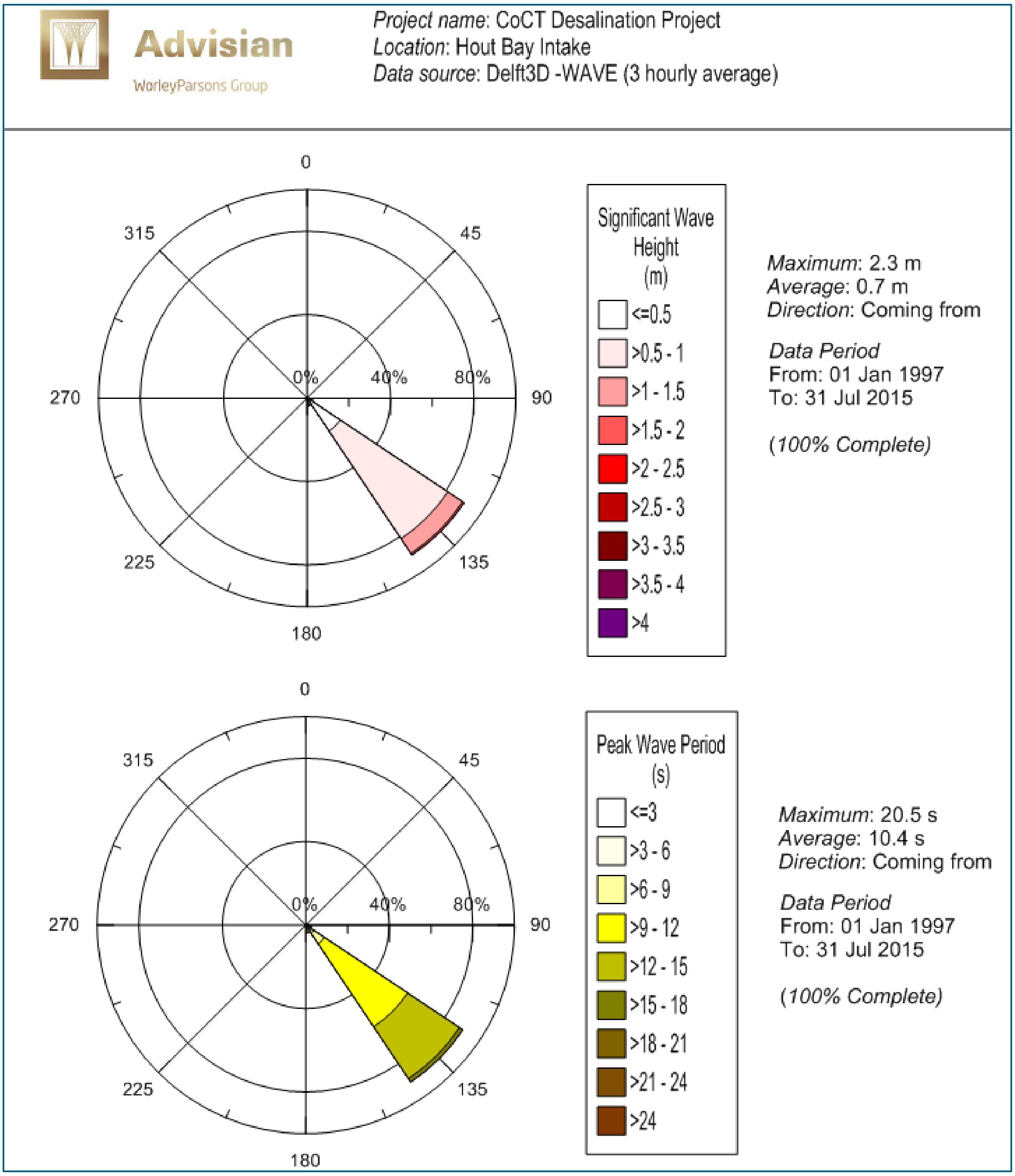

Figure 2-5: Indicative annual wave rose for Position 1, Hout Bay

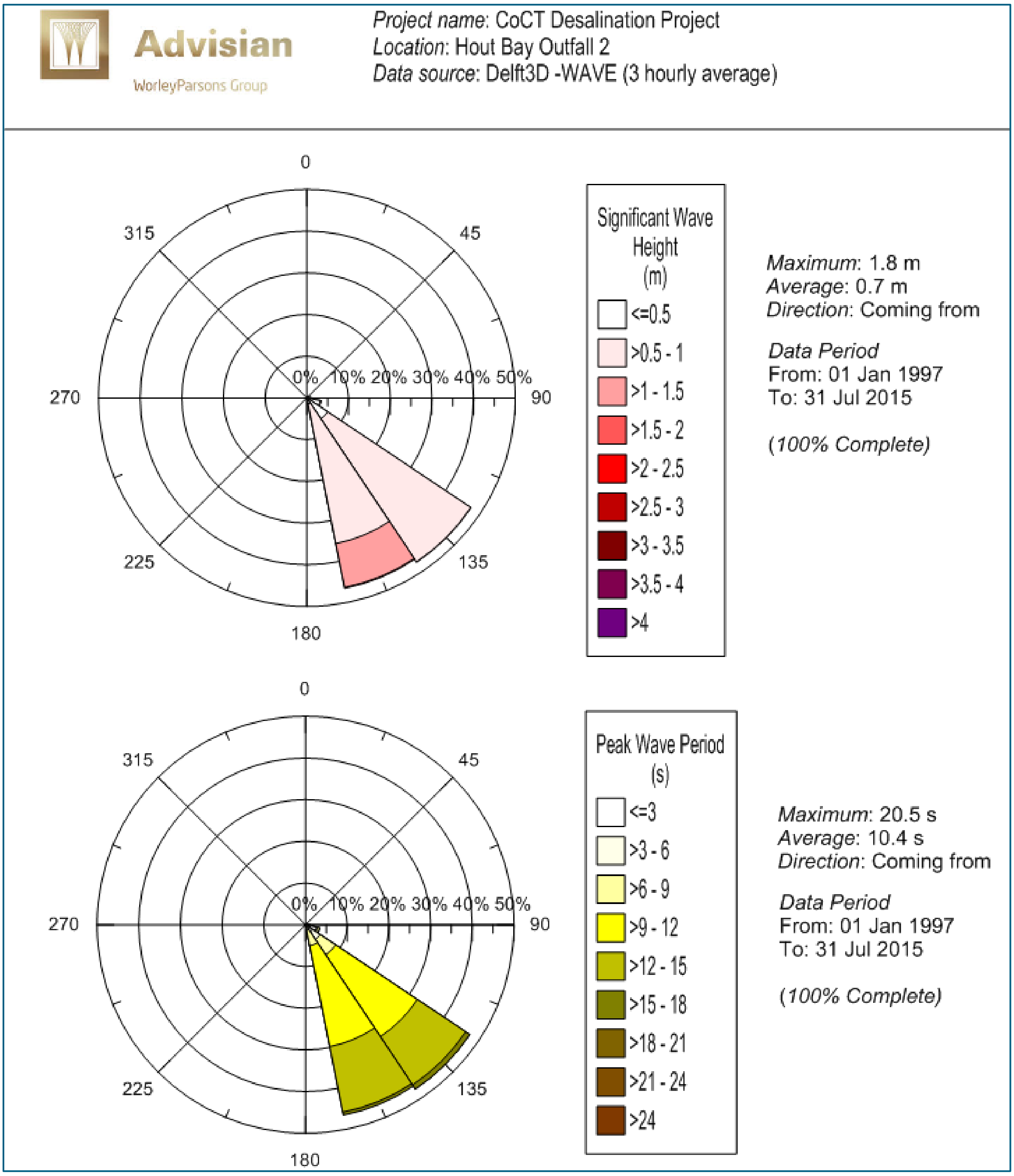

Figure 2-6: Indicative annual wave rose for Position 2, Hout Bay.

Table 2-1: Indicative wave climate for Hout Bay.

Parameter	Position 1	Position 2
Sea bed level	-4.5 m CD	-0.5 m CD
Spectral wave height (H_{mo})		
Annual Maximum	2.3 m	1.8 m
Annual Average	0.7 m	0.7 m
Peak Wave Period (T_p)		
Annual Maximum	20.5 s	20.5 s
Annual Average	10.4 s	10.4 s

The estimated extreme wave conditions for various average return intervals (ARI's) are presented in Table 2-2 for Position 1 and in Table 2-3 for Position 2.

Table 2-2: Estimated extreme wave conditions with associated ARI's (Position 1)

ARI (yr)	Directioin: SE			
	Wave characteristics		95% Confidence Interval	
	H_s	T_P	Lower Limit	Upper Limit
1	1.8	13.9	1.7	1.9
5	2.1	14.4	2.0	2.2
10	2.2	14.5	2.1	2.3
25	2.4	14.8	2.3	2.5
50	2.5	14.9	2.4	2.6
100	2.6	15.1	2.5	2.7

Table 2-3: Estimated extreme wave conditions with associated ARI's (Position 2)

ARI (yr)	Direction: SE			
	Wave characteristics		95% Confidence Interval	
	H_s	T_P	Lower Limit	Upper Limit
1	1.5	13.7	1.5	1.6
5	1.7	14.2	1.7	1.8
10	1.8	14.4	1.7	1.9
25	1.9	14.6	1.8	2.0
50	2.0	14.8	1.9	2.1
100	2.1	14.9	2.0	2.1

2.5 Currents

Currents in Hout Bay are governed by the dominant meteorological conditions for a particular period. In summer, with predominant southeast winds, a northerly flow dominates, with the opposite true in winter when north-westerly winds dominate (CSIRc, 2017).

Limited current data at the project site is available. A measurement campaign was undertaken by CSIR in 1982 where currents were measured in the vicinity of the existing Hout Bay Outfall, approximately 600 m from the shoreline (CSIRb, 1986). The average speed for surface currents is approximately 0.16 m/s and decreases to between 0.08 m/s and 0.1 m/s. The dominant current directions are northwest toward Badtamboer for 40% of the time, south for 30% of the time, southwest (offshore) for 10% of the time, and northeast (into the bay) for 20% of the time (CSIRc, 2017).

2.6 Water levels

Tides in Hout Bay are semi-diurnal. The tidal level range for Hout Bay is expected to be similar to that of Cape Town even though Hout Bay is located 15 km south-southwest of Table Bay.

Table 2-4 provides the tidal levels related to Chart Datum for Cape Town.

Table 2-4: Tidal Levels of Cape Town (The Hydrographer, 2017)

Location	LAT	MLWS	MLWN	ML	MHWN	MHWS	HAT
Cape Town	0	0.25	0.7	0.98	1.26	1.74	2.02

It should be noted that meteorological conditions such as wind and atmospheric pressure can cause considerable differences between predicted and actual tides.

2.7 Air Temperature and rainfall

The climate-data org website provides information about the temperatures and rainfall in the area. These data is based on a climate model that uses weather data from thousands of weather stations from all over the world collected between 1982 and 2012 with a resolution of 30 arc seconds. This model uses weather data from (Climate-Data Org, 2017).

Figure 2-7 presents the monthly distribution of temperature and rainfall extracted from the climate-data org website. The average air temperature exceeds 25°C in summer and drops to around 12°C during the winter months; with a mean annual air temperature of approximately 16.5°C.

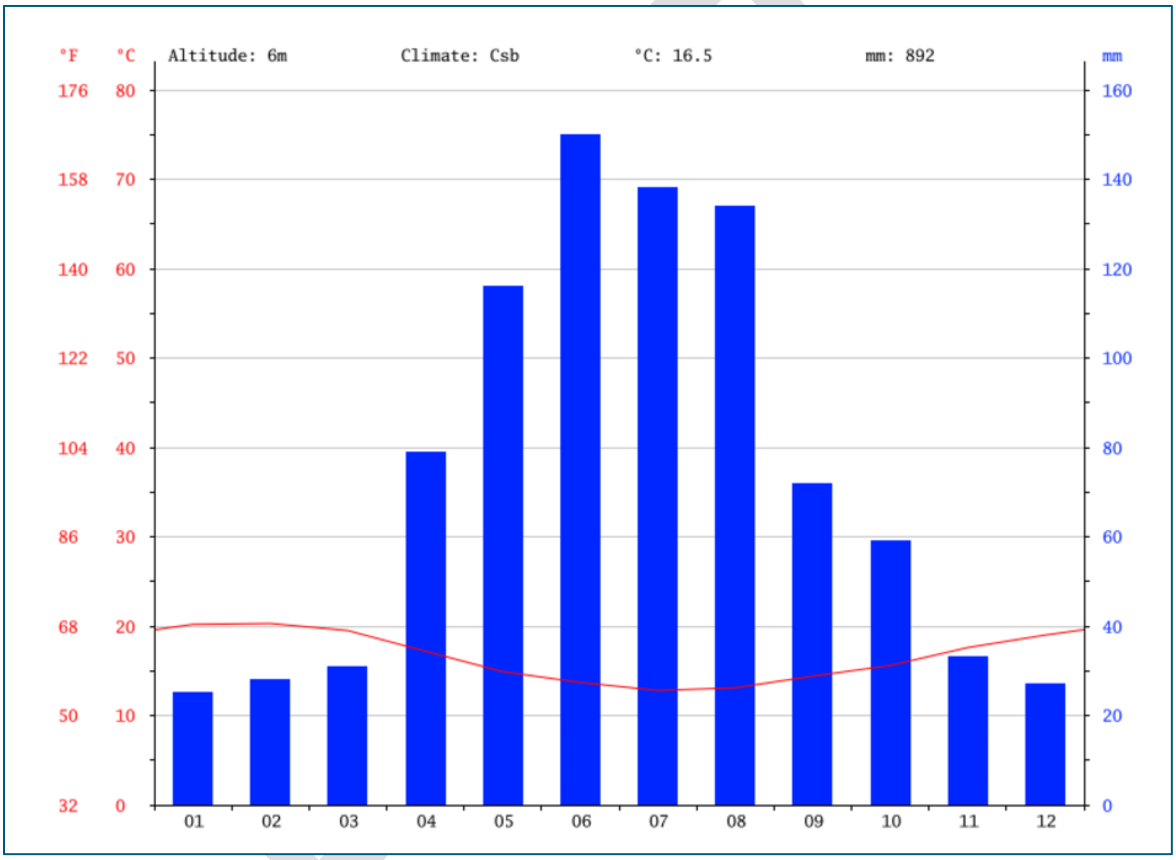

Figure 2-7: Hout Bay mean monthly rainfall and temperature distribution. Source: (Climate-Data Org, 2017)

3 Water Quality Objectives

3.1 Water quality Guidelines

The South African Water Quality Guidelines for Coastal Marine Waters provides recommended target values for a range of water quality constituents to prevent negative impacts on the marine ecosystem (DWAF, 1995).

These guidelines are applicable to the entire marine environment. Specific water quality exists for other beneficial use areas as described in Table below (DWAF, 1995) provides target values for constituents which may have impact on the marine ecosystem or on other beneficial use areas. These target values are listed in Table xx

Recreational use of the coastal marine waters	
Full contact recreation	Activities such as swimming, diving (scuba and snorkeling), water skiing, surfing, paddle skiing, wind surfing, kite surfing, parasailing and wet biking
Intermediate contact recreation	Activities such as boating, sailing, canoeing, wading, and angling, where users may come in contact with the water or swallow water
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.
Basic amenities	Aesthetically acceptable environment.
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 uses	Waste water discharges, cooling water, desalination, and aquariums.

Table 3-1: Target values: South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995)

BASIC AMENITIES - all marine & estuarine water	
Constituents	**Guideline (Target Value)**
Aesthetics	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. Water should not contain materials from non-natural land-based sources which will settle to form putrescent or objectionable deposits. Water should not contain materials from non-natural land-based sources which will produce color, odors, turbidity or taints or other conditions to such a degree as to be unsightly or objectionable. Water should not contain submerged objects and other sub-surface hazards which arise from non-natural origins and which would be a danger or cause nuisance or interfere with any designated/recognized use.
Color (turbidity)	Turbidity and color acting singly or in combination should not reduce the depth of the euphotic zone by more than 10 per cent of background levels measured at a comparable control site. With specific reference to color, levels should not increase by more than 35 Hazen units above background levels in a particular area. Color can also be measured in units of mg Pt/l, where 1 mg Pt/l is equivalent to 1 Hazen unit.

BASIC AMENITIES - all marine & estuarine water	
Constituents	**Guideline (Target Value)**
Suspended Solids	The concentration of suspended solids (SS) should not increase above 10% of the background concentrations.
MAINTENANCE OF THE ECOSYSTEM - all marine waters	
Temperature	Should not exceed the ambient temperature by more than 1^{0}C.
PH	The pH should lie within the range of 7.3-8.6.
Dissolved Oxygen	Should not fall below 5 mg/l (Dissolved oxygen should not fall below 5 mg/l (99 per cent of the time) and below 6 mg/l (95 per cent of the time))
Salinity	Salinity should lie within the range 32 to 36.
Dissolved Nutrients in mg/l Phosphates: $P0_4$-P Nitrogen ($N0_2$ and NO_3 and NH_3	Should not cause excessive algae growth and the loads should not exceed the levels which are introduced by natural processes such as upwelling.
Ammonia (mg/l)	0.02 mg N /liter as NH_3 0.60 mg N /liter as NH_3 + NH_4^+
Toxic Inorganics in mg/l Arsenic (As)	 0.012

BASIC AMENITIES - all marine & estuarine water	
Constituents	**Guideline (Target Value)**
Cadmium (Cd)	0.004
Chromium (Cr)	0.008
Copper (Cu)	0.005
Lead (Pb)	0.012
Mercury (Hg)	0.0003
Nickel (Ni)	0.025
Silver (Ag)	0.005
Zinc (Zn)	0.025
ADDITIONAL GUIDELINES FOR DIRECT CONTACT RECREATION - (Specific Areas)	
Faecal coliforms (if limits are exceeded, test for E.coli using same target values)	Maximum acceptable count per 100 ml 100 in 80 percent of the samples 2000 in 95 percent of the samples
ADDITIONAL GUIDELINES FOR FILTER FEEDER COLLECTION - (Specific Areas)	
Faecal coliforms (if limits are exceeded, test for E.coli using same target values)	Maximum acceptable count per 100 ml 20 in 80 percent of the samples 60 in 95 percent of the samples

3.2 Background water quality

3.2.1 Seawater temperature and salinity

The average water temperature close to the existing Hout Bay marine outfall measured 2 m above the seabed ranges between 10 °C and 16 °C with an average of 11.5 °C (CSIRb, 1986); whilst the average surface temperature is 14 °C.

The average water salinity close to the existing Hout Bay marine outfall measured 2 m above the seabed ranges between 33.6 ppt and 35.8 ppt with an average of 35.1 ppt (CSIRb, 1986); whilst the surface salinity ranges between 33.8 ppt and 35.5 ppt with an average salinity of 35.1 ppt.

The values applied for the receiving water (ambient temperature and salinity) were derived from the metocean conditions outlined in Section 2. Water temperatures of 10 °C and 15 °C were adopted for the effluent discharge and receiving surface water temperature respectively. The ambient density applied in the far-field modelling was 1026.18 kg/m^3, derived from a salinity of 35.5 ppt (all densities were calculated using El-Dessouky, Ettouny (2002).

Water samples close to the location where the intake is foreseen, were measured on the 11th of August and again on the 22nd of August 2017 (Lwandle, 2017). Details of the water sampling locations are provided in Table 3-2 and Table 3-3 and locations are mapped in Figure 3-1.

Table 3-2: Sampling locations and summary of activities carried out at Hout Bay on 11 August 2017 (Lwandle, 2017)

Date	Site	Waypt	Co-ordinates		Depth (m)	CTD		Water samples
			Lat (°S)	Lon (°E)		Start time	End time	
11th Aug 2017	HtB1	80	-34.054846	18.34946	8	11:00:00 AM	11:04:00 AM	1L glass; 500ml; 1L big; 1L slim
11th Aug 2017	HtB2	81	-34.054646	18.351708	13	11:21:00 AM	11:23:00 AM	1L glass; 500ml; 1L big; 1L slim

Table 3-3: Sampling locations and summary of activities carried out at Hout Bay on 22 August 2017 (Lwandle, 2017)

Date	Site	Co-ordinates		Depth (m)	CTD		Water samples
		Lat (°S)	Lon (°E)		Start time	End time	
22nd Aug 2017	HB1	-34.05517	18.34962	10	9:02:00 AM	9:05:00 AM	1L glass; 500ml; 1L big; 1L slim
22nd Aug 2017	HB2	-34.05577	18.33548	13	9:12:00 AM	9:15:00 AM	1L glass; 500ml; 1L big; 1L slim

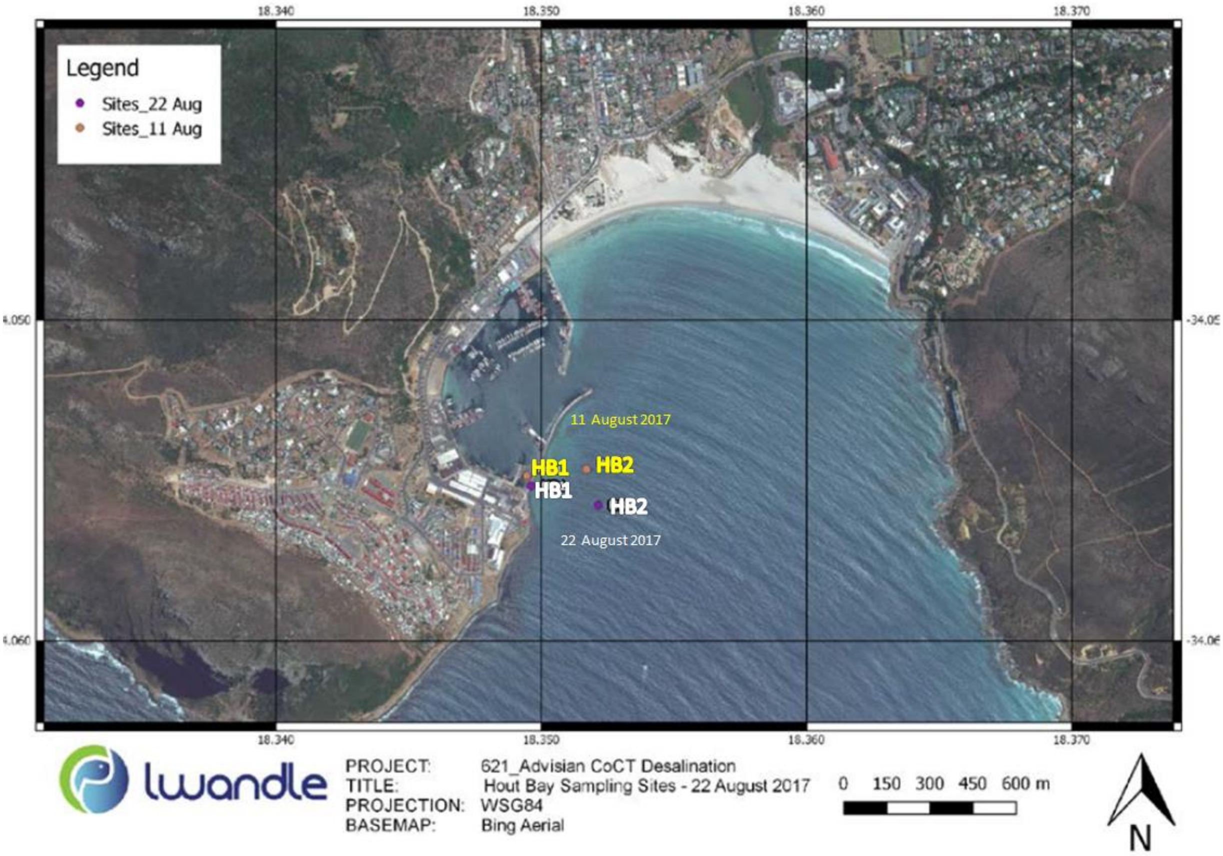

Figure 3-1: Site map of the Hout Bay sampling locations, sampled on the 11th and 22nd Aug 2017 (Lwandle, 2017)

The collected Conductivity, Temperature and Depth (CDT) data is presented in Table 3-4 and Table 3-5 for the 11th and the 22nd of August respectively.

Table 3-4: CTD Results from Hout Bay on the 11th Aug 2017

Station	Depth (m)	Temp (C)	Salin (PSU)	Turb (NTU)	Dissolved O2 (%)	Dissolved O2 (mg/l)
Station 1_HB1	4.131905254	12.25683642	34.98499102	4.469051053	103.5495507	6.232642564
Station 2_HB2	5.635940363	12.24875677	35.01722656	2.626397988	102.60995	6.175617313

Table 3-5: CTD Results from Hout Bay on the 22nd Aug 2017

Station	Depth (m)	Temp (C)	Salin (PSU)	Turb (NTU)	Diss.O2 (%)	Diss. O2 (mg/l)
Station 1_HB1	4.10	12.29	35.00	1.41	100.55	8.63
Station 2_HB2	5.78	12.30	34.98	1.34	101.20	8.69

The laboratory results for the samples taken on the 11th of August is presented Appendix C.

3.2.2 Suspended solids

Typically rage of suspended sediment concentrations close to the Hout Bay outfall is between 5 and 9 mg/l ((CSIRc, 2017).

For the purpose of determining required dilutions of the brine stream, the background suspended solid concentrations are taken as 5 mg/l, which is considered as conservative approach for the initial deep water dilutions.

4 Effluent Characteristics

4.1 Effluent volumes

The Hout Bay outfall was designed to discharge 9.8 Ml effluent per day. Presently, the current average discharge volume is 5 Ml/day with a spare capacity of 4.8 Ml/day. A summary of the effluent volumes for the combined effluent (WWTW effluent and brine stream) is listed in the Table 4-1.

Table 4-1: Effluent volumes discharge over 2 year period (Nov 2017 – Dec 2019)

	Ml/day	m^3/s
WWTW effluent	5	0.058
Brine stream from desal plant	4.8	0.056
Total combined effluent (WWTW & Brine)	9.8	0.113

4.2 Effluent quality

The composition of the existing waste water effluent discharge and the typical composition of a brine stream from a reverse osmosis plant are listed in Table 4-2 and Table 4-3 respectively.

Table 4-2: Composition of the existing waste water treatment works effluent

Quality Variable and unit of measurement	Average Discharge Concentration per month	Maximum Anticipated Discharge Concentration per month
Coliforms (Colony Forming Units/ml)	126	1769
Enteric pathogens e.g. E.coli (Colony Forming Units/ml)	152	2528
pH (pH units)	7.5	8.3
Temperature (oC)		
Acidity (mg/l)		
Alkalinity (mg/l)	116	190
Aluminium (mg/l)	1.2	5.2
Ammonia (mg/l)	16.5	33.9
Arsenic (mg/l)	0.001	0.003
Barium (mg/l)		
Boron (mg/l)	0.070	0.390
Bromide (mg/l)		
Cadmium (mg/l)	0.001	0.001
Calcium (mg/l)	26	53

Quality Variable and unit of measurement	Average Discharge Concentration per month	Maximum Anticipated Discharge Concentration per month
Chemical oxygen demand (mg/l)	308	607
Chloride (mg/l)	303	1011
Chromium (mg/l)	0.003	0.013
Chromium(vi) (mg/l)		
Cobalt (mg/l)	0.001	0.001
Copper (mg/l)	0.011	0.051
Cyanide (mg/l)		
Fluoride (mg/l)		
Iron (mg/l)	0.410	2.022
Lead (mg/l)	0.001	0.003
Lithium (mg/l)		
Manganese (mg/l)	0.016	0.051
Mercury (mg/l)		
Molybdenum (mg/l)	0.001	0.001
Nickel (mg/l)	0.001	0.003
Phenol (mg/l)		
Potassium (mg/l)	12	35
Radionuclides (mg/l)		
Salinity (ppt)	31.55	31.55
Soap, oil or grease (mg/l)		
Sodium (mg/l)	187	885
Sulphate (mg/l)	73	250
Tin (mg/l)		
Total dissolved solids (mg/l)	132	660
Total Suspended solids (mg/l)	165	620
Total nitrogen (mg/l)	33.3	60.7
Total phosphorus (mg/l)	3.4	6.1
Uranium (mg/l)		
Vanadium (mg/l)	0.001	0.003
Zinc (mg/l)	0.037	0.068

Table 4-3: Estimated brine quality

Description	Units	Quantity
Salinity	ppt	66
Change in temperature	° C	1 - 2
pH		7.3 – 8.2
Suspended Solids	mg/l	1.67 times ambient
Phosphonate antiscalant	mg/l	4.7
Chlorine	mg/l	0.002
Sodium bisulphate (SMS)		3.14
Spent CIP solution (quarterly and blended in over 12 hours) ▪ Peroxyacetic acid ▪ Low pH cleaner ▪ High pH cleaner	mg/l	 ▪ 0.006 ▪ 0.015 ▪ 0.015
Preservative (sodium metabisulfite) (on shutdown/start-up, and blended in over 12 h)	mg/l	0.028
Coagulant (type and concentration shall be confirmed by Supplier. Note, no coagulants which results in colouration of the brine stream shall be permitted.		

The quality of the combined effluent was calculated based on the constituent concentrations in the WWTW stream for a effluent discharge rate of 5 Ml/day and the constituent concentrations in the Brine stream for a discharge rate of 4.8 Ml/day. The combined effluent's quality is listed in Table 4-4 below.

Table 4-4: Future combined effluent's quality for Hout Bay outfall

Quality Variable and unit of measurement	Average Discharge Concentration per month	Maximum Anticipated Discharge Concentration per month
Coliforms (Colony Forming Units/ml)	126	1769
Enteric pathogens e.g. E.coli (Colony Forming Units/ml)	152	2528
pH (pH units)	7.5	8.3
Temperature (oC)	N/A	N/A
Acidity (mg/l)	N/A	N/A
Alkalinity (mg/l)	116	190
Aluminium (mg/l)	1.2	5.2
Ammonia (mg/l)	16.5	33.9
Arsenic (mg/l)	0.001	0.003
Barium (mg/l)	N/A	N/A
Boron (mg/l)	0.070	0.390
Bromide (mg/l)	N/A	N/A
Cadmium (mg/l)	0.001	0.001
Calcium (mg/l)	26	53
Chemical oxygen demand (mg/l)	308	607
Chloride (mg/l)	303	1011
Chromium (mg/l)	0.003	0.013
Chromium(vi) (mg/l)	N/A	N/A
Cobalt (mg/l)	0.001	0.001
Copper (mg/l)	0.011	0.051
Cyanide (mg/l)	N/A	N/A
Fluoride (mg/l)	N/A	N/A
Iron (mg/l)	0.410	2.022
Lead (mg/l)	0.001	0.003
Lithium (mg/l)	N/A	N/A
Manganese (mg/l)	0.016	0.051
Mercury (mg/l)	N/A	N/A
Molybdenum (mg/l)	0.001	0.001
Nickel (mg/l)	0.001	0.003

Quality Variable and unit of measurement	Average Discharge Concentration per month	Maximum Anticipated Discharge Concentration per month
Phenol (mg/l)	N/A	N/A
Potassium (mg/l)	12	35
Radionuclides (mg/l)	N/A	N/A
Salinity (ppt)	31.55	31.55
Soap, oil or grease (mg/l)	N/A	N/A
Sodium (mg/l)	187	885
Sulphate (mg/l)	73	250
Tin (mg/l)	N/A	N/A
Total dissolved solids (mg/l)	132	660
Total Suspended solids (mg/l)	165	620
Total nitrogen (mg/l)	33.3	60.7
Total phosphorus (mg/l)	3.4	6.1
Uranium (mg/l)	N/A	N/A
Vanadium (mg/l)	0.001	0.003
Zinc (mg/l)	0.037	0.068

5 Required dilutions

The term dilution describes the process of reducing the concentration of effluent constituents by mixing the effluent with uncontaminated ambient seawater and therefore achieving acceptable concentration levels for maintaining ecosystems functioning and recreational human activities (e.g. swimming).

To assess the assimilative capacity of the receiving waters, a straight forward first estimate is based on the required dilutions for a specific constituent in the effluent. The required dilution is a function of the effluent concentration and the 'buffer capacity', which is the difference between a guideline value (target value) and the ambient concentration of the specific constant and can be expressed as follows:

$$\mathbf{S = (C_E - C_A) / (C_T - C_A)}$$

Where:

$\mathbf{S}$	= Required dilution
$\mathbf{C_E}$	= Effluent concentration
$\mathbf{C_A}$	= Ambient (background) concentration
$\mathbf{C_T}$	= Target or guideline concentration (Which should not be exceeded)
$\mathbf{(C_T - C_A)}$	= "Buffer capacity"

It is clear that if $\mathbf{C_A}$ approaches $\mathbf{C_T}$, then ($\mathbf{C_T - C_A}$) will approach 0 and subsequently S (Dilution) >>>> (infinite - not achievable).

The required dilutions for the Hout Bay WWTW as well as the combined effluent (Hout Bay WWTW and brine stream) is presented in Tables 5-1 and 5-2 below. Note, only the critical parameters (i.e. highest required dilutions) are listed below.

Table 5-1: Required Dilutions for the WWTW effluent only

Constituent	**Background (Ambient)** C_A	**Guideline** C_T	**Effluent concentration** C_E		**Required dilutions: S**	
			WWTW Max	WWTW Avg	WWTW Max	WWTW Avg
Suspended solids (mg/l)	5	5.5	1000	500	1989	**990**
COD (mg/l)			10000*	2000*		
Dissolved oxygen (mg/ℓ)	7	5 as DO (99%)	4500	920	450	90
	7	6 as DO (95%)	4500	920	900	180
Ammonia (mg/l)	0.015	0.6	384	62	655	106

** There is no Marine Water Quality guideline for COD. The guideline for dissolved oxygen is that the background should not fall below 5 mg/l for 99% of the time. The oxygen demand of an effluent on a receiving water body is dependent on physical mixing characteristics and the natural dissolved oxygen content of the receiving water. Based on natural DO levels and the BOD concentrations in an effluent the calculation for the required dilutions can be done according to Toms (1985): Lusher (1984) suggested that it can be assumed that 20% of the BOD will be demanded within one hour after discharge. Pedro Sérgio Fadini (2004) provided a relation of BOD = 0.46COD for raw effluents. The required dilutions for COD were determined as follows:*

- *Convert COD values to BOD values*
- *The average DO concentrations were taken as 7.2mg/l*
- *The allowable oxygen demand is the background minus 5 mg/l (guideline)*
- *Required dilution equals 20% of the effluent BOD divided by the allowable oxygen demand*

Table 5-2: Required Dilutions for the combined effluent

Constituent	Background (Ambient) C_A	Guideline C_T	Effluent concentration C_E		Required dilutions: S	
			Combined effluent: Max	Combined effluent: Avg	Combined effluent: Max	Combined effluent: Avg
Suspended solids (mg/l)	5	5.5	524	268	1036	**527**
COD (mg/l)			5100*	1020*		
Dissolved oxygen (mg/ℓ)	7	5 as DO (99%)	2300	460	230	46
	7	6 as DO (95%)	2300	460	459	92
Ammonia (mg/l)	0.015	0.6	196	32	334	54
Salinity (ppt)	35	33 - 36	63.8	63.8	47	16

The discharge parameters adopted for the existing effluent (domestic and industrial wastewater) and the envisaged desalination brine applied in the modelling are outlined in Table 5-1.

Table 5-1: Discharge configurations applied in the near- and far-field modelling.

		Wastewater Treatment Works (WWTW)	Combined effluent
Discharge Characteristics	Flow Rate WWTW discharge (m^3/s)	0.058	0.058
	Flow Rate brine discharge (m^3/s)	-	0.056
	Flow Rate combined effluent (m^3/s)	**0.058**	**0.113**
	No. of Discharge Ports	15	15
	Equivalent Port Diameter (mm)	0.085	0.085
	Port Exit Velocity (m/s)	0.68	1.32
	Port Orientation	45 degrees from the vertical axis	45 degrees from the vertical axis
	Discharge Elevation (m above the seabed)	1	1
	Salinity (ppt)	4.1	33.3
	Temperature (°C)	10	10
	Density (kg/m^3)	**1000.0**	**1023.9**
	Excess suspended solids (mg/l)	**495**	**263.5**
	Excess ammonia (mg/l)	59.985	30.597
	Excess arsenic (mg/l)	1.998	1.018
	Excess lead (mg/l)	1.999	1.020

Table 5-2: Water quality target criteria and required dilution to be achieved in the near- and far-field modelling.

		Wastewater Treatment Works (WWTW)	Combined effluent
Target Criteria 300m From Point of Discharge	Excess suspended solids (mg/l)	0.500	0.500
	Excess ammonia (mg/l)	0.585	0.585
	Excess arsenic (mg/l)	0.010	0.010
	Excess lead (mg/l)	0.012	0.012
Required Dilution to meet Target Criteria	**Excess suspended solids**	**990**	**527**
	Excess ammonia	103	52
	Excess arsenic	200	102
	Excess lead	169	86

6 Overview of existing marine outfall

Hout Bay's marine outfall is located in the mouth of a marine bay at an approximate water depth of 37 m. This outfall consists of a curved pipeline of about 2.2 km long with an internal diameter of 364 mm and is made of High density polyethylene (HDPE). The final 150 m of the outfall pipeline corresponds to a multi-port diffuser, where the initial 100 m of the diffuser contains 10 ports with an internal diameter of 0.078 mm and the last 50 m (offshore end) has 5 ports with an internal diameter of 0.1 mm.

A sketch of the Hout Bay's marine outfall configuration is provided in Figure 6-1.

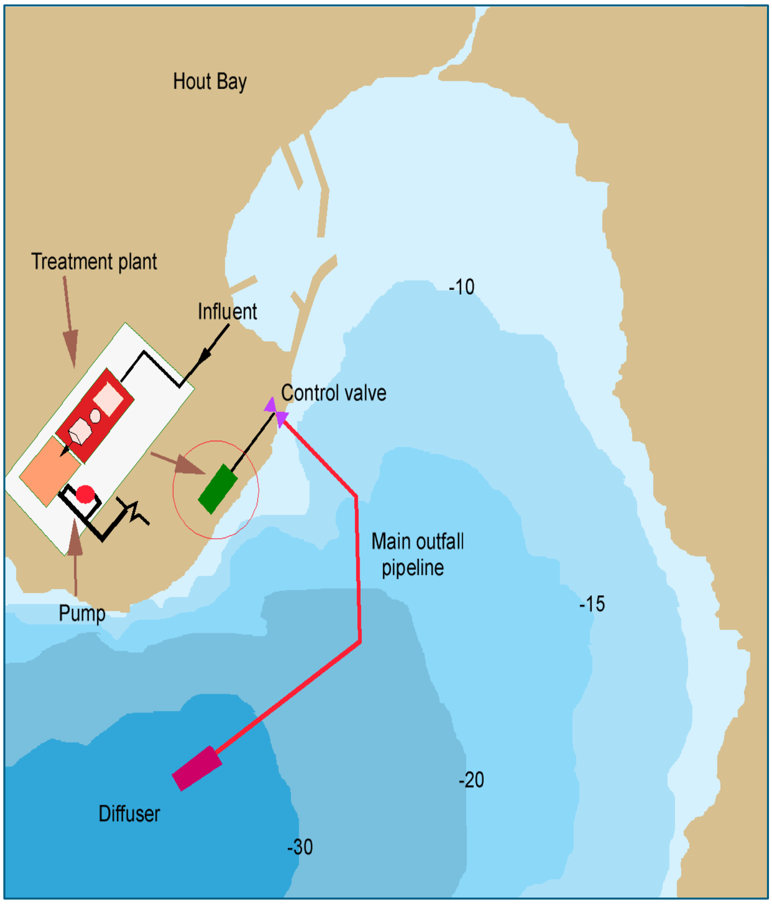

Figure 6-1: Hout Bay's marine outfall configuration

The outfall location and geometry, discharge density, initial effluent constituent concentrations, brine constituent concentrations and discharge flow rates are based on the current discharge permit specification and the water quality surveys undertaken for Hout Bay site during 2015/2016 (CSIRc, 2017) and August 2017.

7 Near-field modelling

Effluent plume dispersion models are routinely used by regulators and environmental scientists to predict the dilution, motion, and geometry of discharge plumes. A near-field plume model predicts the mixing and dilution of an effluent within the initial mixing zone near the discharge location, up to the point where far-field dispersion processes start to dominate. The mixing zone analysis in this study was undertaken using the Cornell Mixing Zone Expert System (CORMIX) (Doneker & Jirka, 2007).

7.1 Cornell Mixing Zone Expert System (CORMIX)

7.1.1 Model background

CORMIX is a near-field model for the analysis, prediction, and design of outfall mixing zones resulting from the discharge of pollutants into diverse water bodies. It contains mathematical models of point source discharge mixing within an intelligent computer-aided design. CORMIX is a steady state model based upon a set of empirical equations derived from field and laboratory tests. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone, including compliance with regulatory constraints.

The initial mixing of an effluent discharged into a receiving water body is dominated by momentum-driven mixing processes which are not adequately resolved in so-called far-field models such as DHIs MIKE3 or Delft-3D, where dispersive processes dominate.

This section discusses the setup of the model, followed by the presentation and discussion of the near-field modelling results for the effluent discharge plume scenarios considered: the existing WWTW discharge and various potential combinations of brine and WWTW discharge, as outlined in section 6.

The near-field modelling undertaken for this project comprised the analysis of the dispersion of the various effluent plumes under various current magnitudes that correlates to weak, average and strong conditions.

The term “residual concentration” refers to a concentration above the ambient seawater conditions.

7.1.2 Model set-up

CORMIX requires that each separate discharge component, for example, the suspended solids or ammonia, be modelled individually.

Both the discharge and ambient ocean densities have been determined using the El-Dessouky & Ettouney (2002) that calculates density in terms of salinity, temperature and pressure (constant ambient pressure of 1 atm applied in all scenarios).

A water depth of 37 m was applied to all the scenarios modelled as per the existing marine outfall specifications (Section 6).

To estimate the effect of wind speeds and corresponding heat loss coefficients on the effluent discharge dispersion, a conservative approach was followed based on the recommendations provided by the CORMIX modelling software, which applies the findings of Jirka, Adams, & Stolzenbach (1981). A base wind speed of 2 m/s with a heat loss coefficient of 20 W/(m^2, °C) was considered for all the modelled scenarios.

A CORMIX alignment angle, ɣ, of 0° and 90° has been applied to the majority of the modelling scenarios, i.e. the current is assumed to run either parallel or perpendicular to the diffuser. A parallel current situation is the most likely alignment due to the alignment of the outfall diffuser.

The discharge plume is expected to be positively buoyant, as the effluent density is typically lower than ambient, therefore surface currents would be expected to have a significant effect on the plume transport and dispersion. According to CSIR (1986), the average speed for surface currents is approximately 0.16 m/s and decreases to between 0.08 m/s and 0.1 m/s. Three current magnitude scenarios were tested in the near-field modelling that corresponds to:

- Weak ambient conditions: 0.05 m/s
- Average ambient conditions: 0.2 m/s
- Strong ambient conditions: 0.4 m/s

The set-up of CORMIX applied in the project assumes stationary conditions for both the discharge and ambient receiving water and neglects dynamic effects such as pooling and current reversals. The application of CORMIX also negates the potential mixing effects of wave action at the study site, adding a degree of conservation to the effluent dispersion results.

7.1.3 Results

The near-field modelling indicates that the total suspended solids criteria of 0.5 mg/l above ambient at 300 m from the point of discharge is not exceeded or almost compliant for the scenarios modelled with average and strong current velocities except from the combined effluent 1.

The water quality dilution requirement is met for most of the scenarios modelled when the far-field dispersion processes start to dominate the plume behaviour.

Table 7-1 summarizes the near-field modelling results for the total suspended solids taking into account the various effluent discharge combinations outlined in section 6 under various current magnitudes that correlate to weak, average and strong conditions.

Additional results from the simulations are presented in the subsections that follow in the form of plots depicting the effluent plume dilution and the plume geometry.

Table 7-1: Overvi ew of the near-field current magnitude simulations using CORMIX model.

Test No	Description	Flow (Ml/day)	Flow (m^3/s)	Current velocity (m/s)			Ambient Density (kg/m^3)		Discharge Density (kg/m^3)	Near-Filed Region (initial dilutions for multiport diffuser)				Regulatory Mixing Zone (radius of 300 m)			Required Dilution	Comment
				Condition	Surface	Bottom	Surface	Bottom		Horizontal distance	Plume height	Concentration (mg/l)	Dilution	Horizontal distance	Concentration (mg/l)	Dilution		
0.01	Baseline effluent (WWTW discharge)	5	0.058	Weak	0.05	0.01	1026.18	1026.93	1000	85.6	8.7	1.267	395	300	1.102	454	**990**	Not compliant
0.02	Baseline effluent (WWTW discharge)	5	0.058	Average	0.2	0.05	1026.18	1026.93	1000	95.5	4	0.978	511	300	0.527	**950**	**990**	Almost compliant
0.03	Baseline effluent (WWTW discharge)	5	0.058	Strong	0.4	0.1	1026.18	1026.93	1000	116.1	2.7	0.591	846	300	0.545	**918**	**990**	Almost compliant
0.04	Combined effluent	9.8	0.113	Weak	0.05	0.01	1026.18	1026.93	1023.9	83.9	8.6	1.474	179	300	1.274	207	**527**	Not compliant
0.05	Combined effluent	9.8	0.113	Average	0.2	0.05	1026.18	1026.93	1023.9	89.1	4.2	1.27	207	300	0.563	468	**527**	Not compliant
0.06	Combined effluent	9.8	0.113	Strong	0.4	0.1	1026.18	1026.93	1023.9	103.8	2.8	0.731	360	300	0.663	397	**527**	Not compliant

7.1.3.1 Baseline effluent (WWTW discharge)

The low current magnitude condition for the baseline effluent discharge results in the least amount of total suspended solids dilution, i.e. it is the "worst case" for the effluent plume dispersion, as shown in Table 7-1 and Figure 7-1.

Figure 7-1 demonstrates that 300 m downstream from the discharge point the plume centreline has a total suspended solids dilution slightly larger than 900 for the average and strong current speed conditions; whilst for the low current magnitude conditions the dilution is less than 500.

The plume geometry along the trajectory centreline is provided in Appendix A.

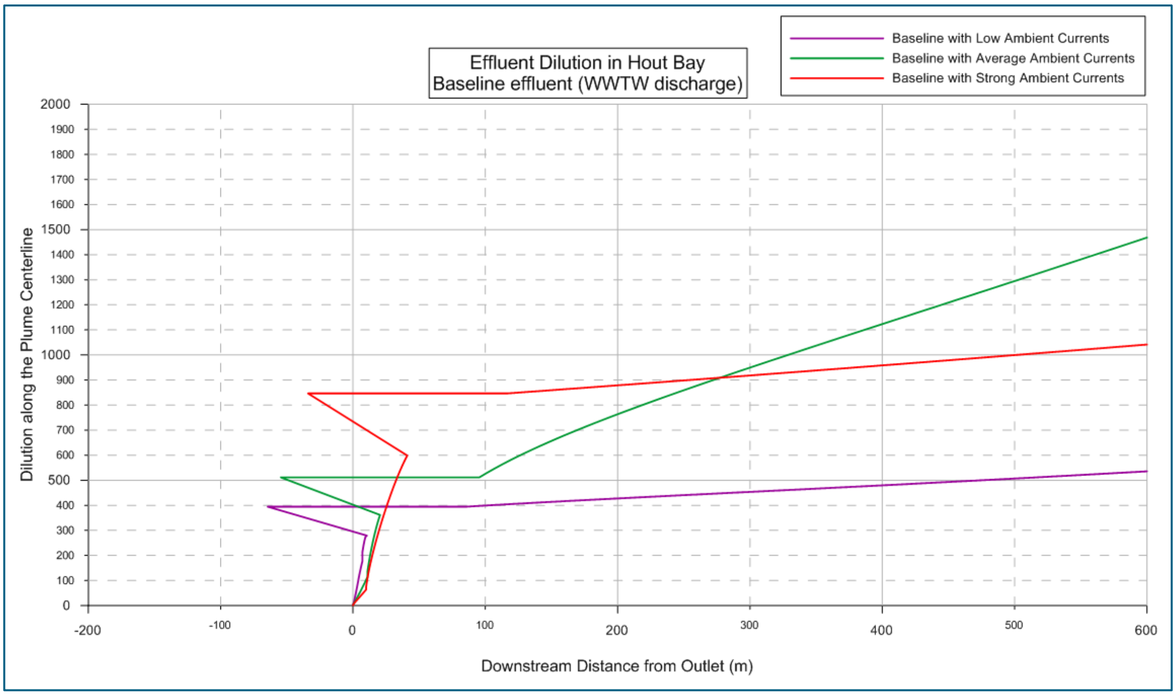

Figure 7-1: Total suspended solids dilution of the baseline effluent along the plume centreline for the low, average and strong current magnitude conditions.

7.1.3.2 Combined effluent

The low current magnitude condition for the combined effluent discharge scenario 1 results in the least amount of total suspended solids dilution, i.e. it is the "worst case" for the effluent plume dispersion, as shown in Table 7-1 and Figure 7-2.

Figure 7-2 demonstrates that 300 m downstream from the discharge point the plume centreline has a total suspended solids dilution smaller than 500 for all the current magnitude scenarios modelled.

The plume geometry along the trajectory centreline is provided in Appendix A.

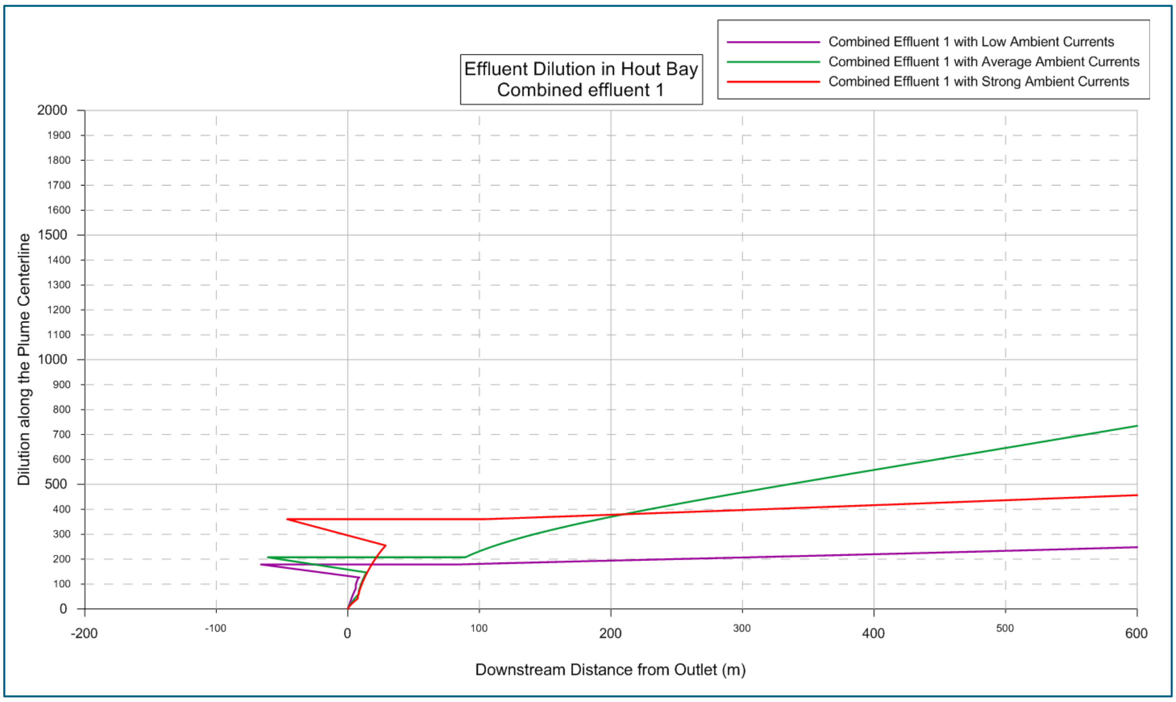

Figure 7-2: Total suspended solids dilution of the combined effluent 1 along the plume centreline for the low, average and strong current magnitude conditions.

8 Far-field modelling

8.1 Hydrodynamic Model Background

In the absence of detailed local current and water level measurements, hydrodynamic modelling is an appropriate tool to estimate the hydrodynamic conditions at the project site. Due to the relatively homogenous nature of the annual climatic conditions at the project site, a period of one month was simulated using a three-dimensional numerical model.

A background description of the Deltares Delft3D-Flow software applied in this study is included in Appendix B.

8.2 Model set-up

8.2.1 Computational grid

A series of nested grids were set up to assess the effluent dispersion offshore from the Hout Bay's marine outfall location.

Nesting is a modelling technique in which a larger coarse resolution model encloses a smaller high resolution model, and as the larger model runs it generates hydrodynamic and transport boundary conditions that can be applied to the smaller model.

The grids were used for the hydrodynamic modelling required for the project. The details of the grids are provided in Table 8-1, and the location of the curvilinear and rotated fine hydrodynamic grid in relation to the study site is described in Figure 8-1.

Table 8-1: Computational grid details.

Grid Description	Grid Length (km)	Grid Width (km)	Cell resolution (m)	No. of Vertical Layers
Coarse	210	150	850 x 700	1
Hout Bay Coarse	60	26	280 x 180	1
Hout Bay Medium	10	9.5	95 x 80	1
Hout Bay Fine	4.4	3.5	32 x 16	10

The bathymetry for the model was interpolated to the computational grid using the Delft3D-QUICKIN module. Accurate bathymetry data is an essential input for this kind of numerical modelling. For the present project, the depth information was compiled from the sources outlined in Section 2.2. The model bathymetry for the fine grid is presented in Figure 8-2.

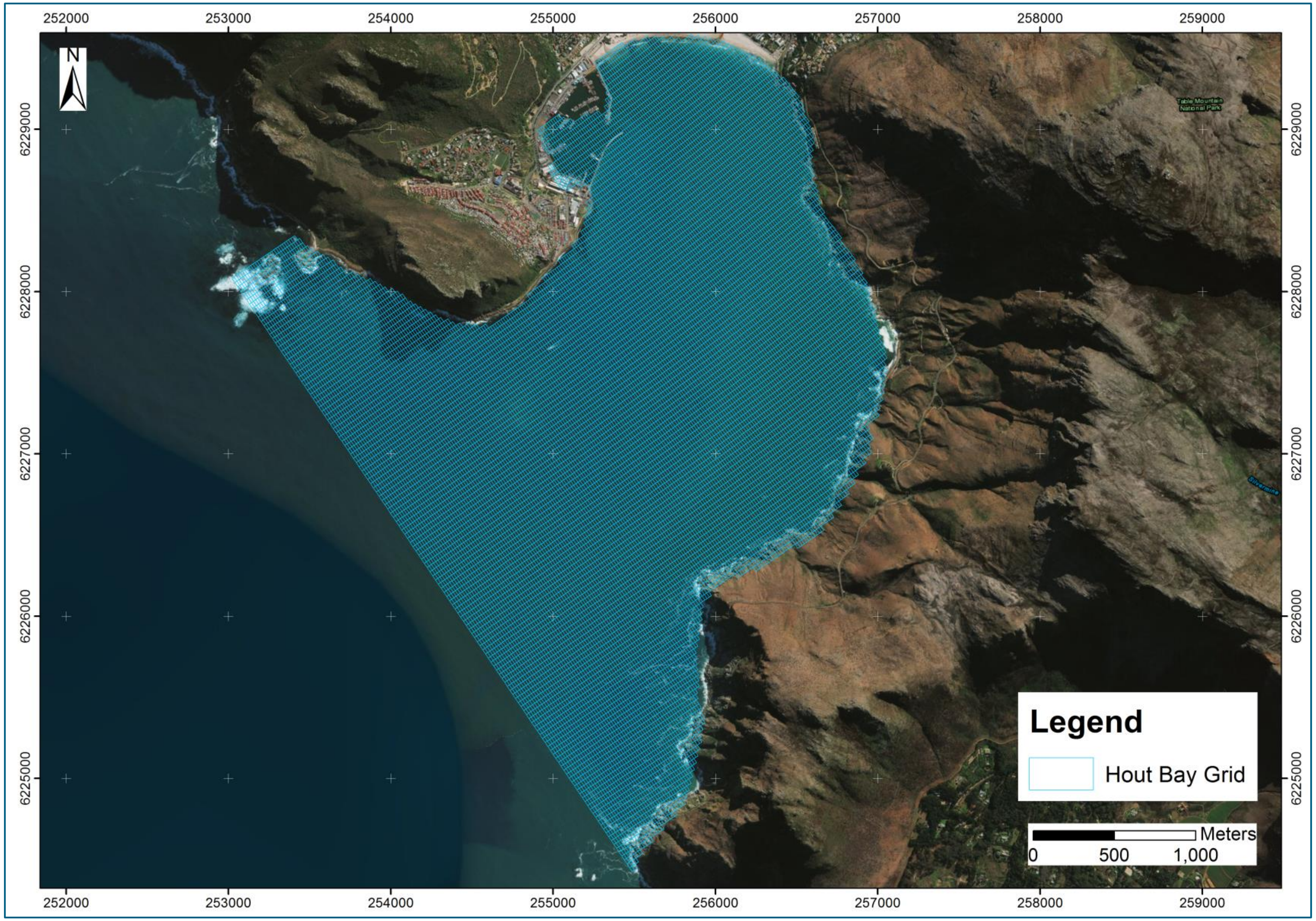

Figure 8-1: Fine modelling grid coverage.

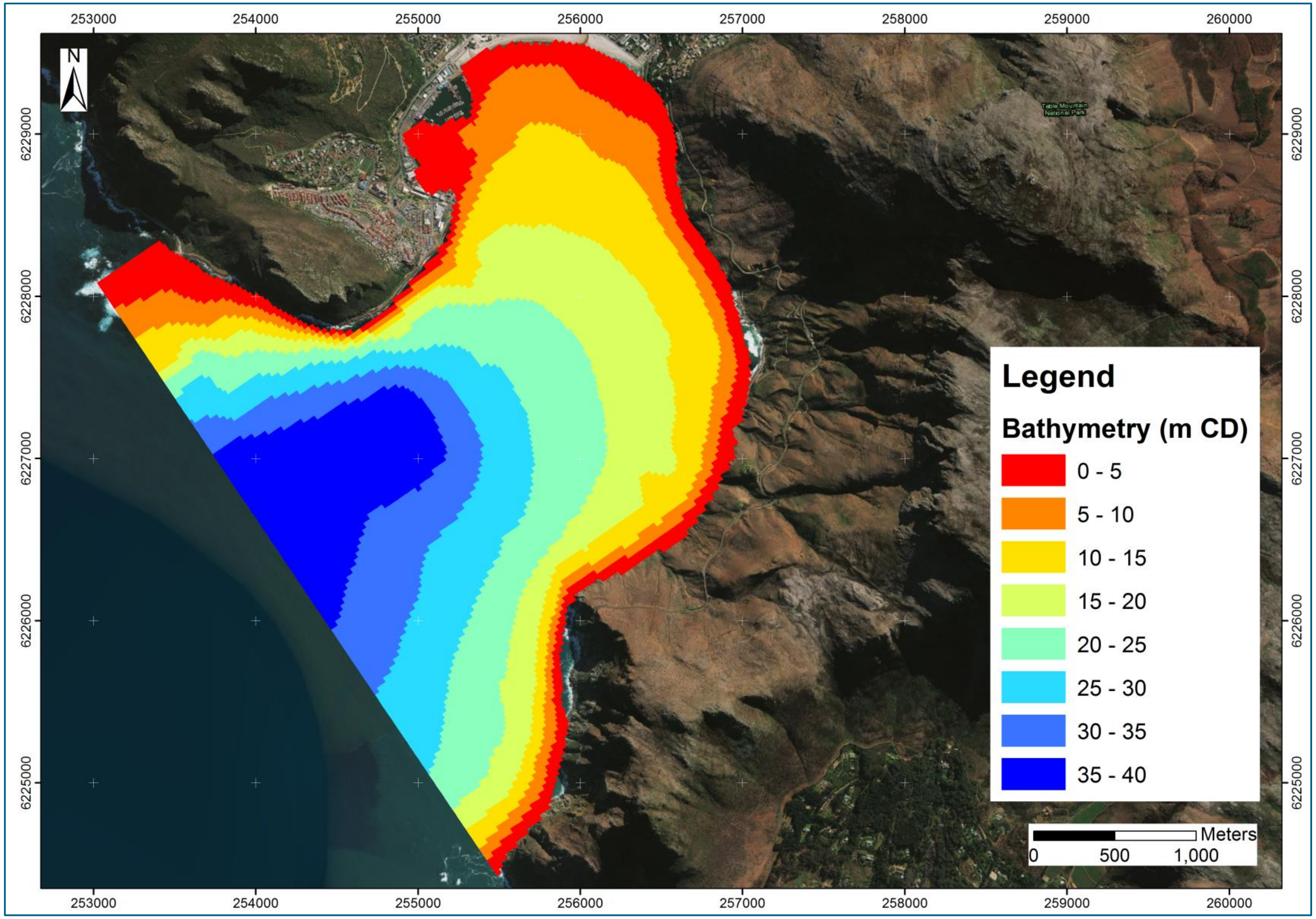

Figure 8-2: Fine modelling grid coverage with bathymetry.

8.2.2 Water levels

The water levels modelled in the fine resolution grid were derived from the coarse resolution, outer grid. Astronomic tidal constituents for the open boundaries of the coarse grid were extracted from the TPXO 7.2 Global Inverse Tidal Model, with the principal constituents presented in Table 8-2.

Table 8-2: Astronomic tidal constituents used in the model.

Constituent	Amplitude (m)	Phase (°)
M2	0.489	34.0
S2	0.219	55.4
N2	0.106	25.7
K2	0.062	50.3
K1	0.055	121.1
O1	0.016	232.4
P1	0.015	116.0
Q1	0.008	221.1
MF	0.0010	0.2
MM	0.0008	262.2
M4	0.0039	37.4
MS4	0.0013	28.9
MN4	0.0001	320.4

Figure 8-3 depicts the modelled water levels in the nearshore region of Hout Bay for the duration of the simulation.

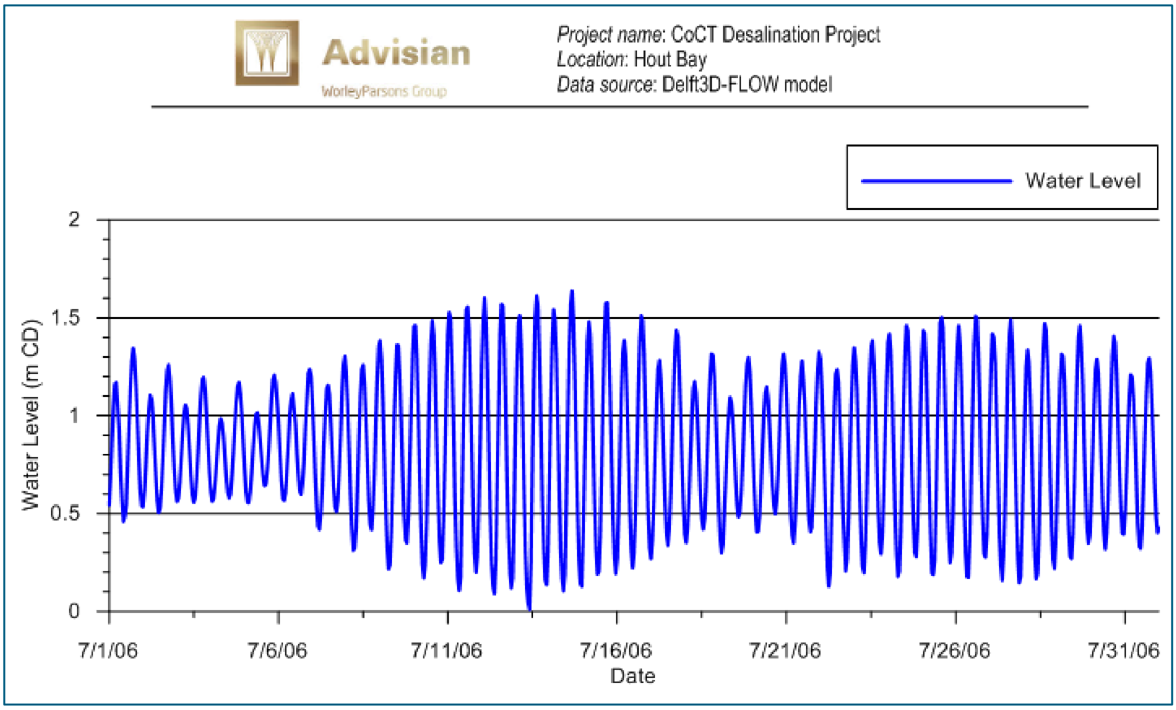

Figure 8-3: Modelled water levels in the nearshore region of the project area.

The calibration of the model with water level recordings be collected from the site, should they be collected, would greatly assist in improving the accuracy of the model.

8.2.3 Air temperature

The Delft3D-FLOW Excess Temperature module was selected to compute the heat exchange flux at the air-ocean interface. This module requires the background air temperature, which was extracted from the Simon's Town meteorological data covering the period 2002 to 2007 (Advisian, 2015). Figure 8-4 depicts the air temperature input for the nearshore region used in the dispersion simulation.

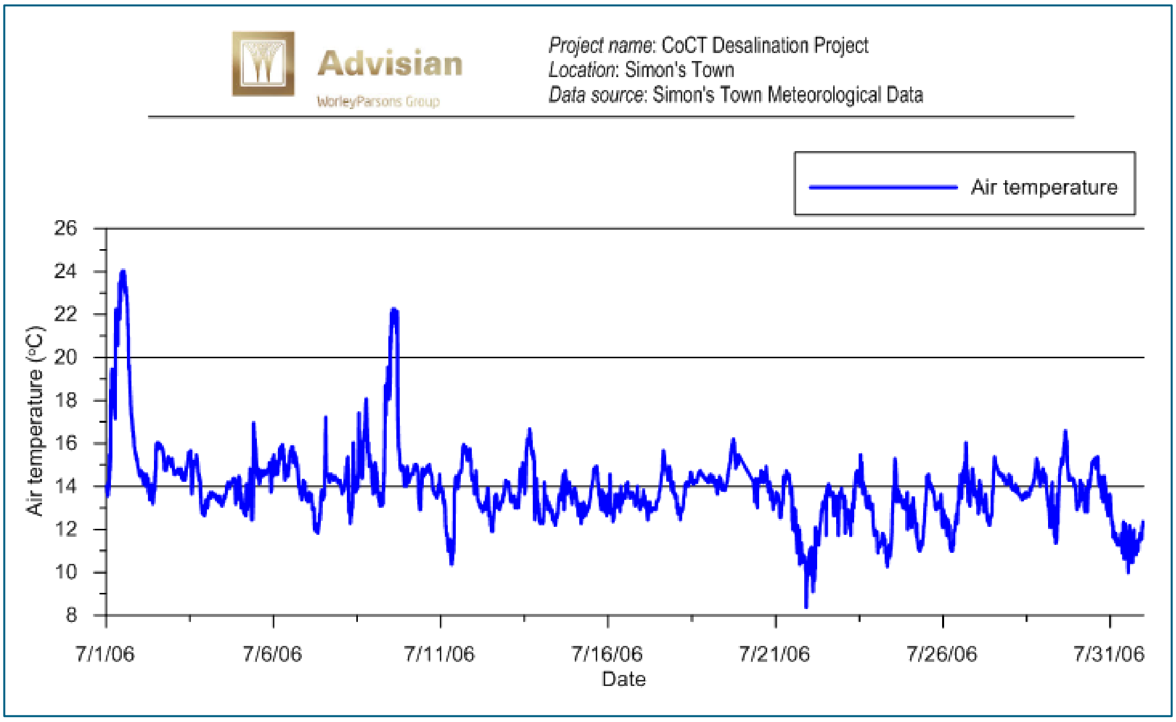

Figure 8-4: Air temperature extracted from the Simon's Town weather station dataset for the month-long simulation period. Source: Advisian (2015)

8.2.4 Modelled discharges

As stated in the Hout Bay marine outfall specifications the day-to-day wastewater discharge comprise of domestic and industrial wastewater. In order to comply with the environmental requirements, the envisaged desalination plants wastewater discharge will be connected to the existing marine outfall discharge to meet the legal discharge limits.

The discharge parameters adopted for the existing effluent (domestic and industrial wastewater) and the envisaged desalination brine applied in the modelling are outlined in Section 4, as well as the target water quality criteria and required dilutions.

According to the Hout Bay marine outfall specifications and the near-field modelling results (Sections 6 and 7.1.3), the TSS is the effluent component discharge that requires larger dilutions to comply with the water quality requirements for a coastal discharge and in most of the near-field scenarios modelled the water quality has been achieved in the far-field domain. Therefore, the worst combined effluent discharge scenario (i.e. combined effluent 1) was considered in the far-field model.

The effluent is discharged close to the near-bed, which corresponds to the tenth vertical layer of the model. Therefore, the discharge depth at the outfall is approximately 1.85 m from the seabed, in a water depth of approximately 37m CD.

8.2.5 Initial conditions

Table 8-3 summarizes the initial conditions applied to the simulation.

Table 8-3: Initial conditions for month-long model simulation.

Condition	Value
Water Level	0.54 m
Ambient Salinity (near-bed)	34.8 ppt
Ambient Temperature (near-bed)	8.4 °C
Suspended Solids	5 mg/l

8.2.6 Hydrodynamic setup parameters

Setup parameters used in the hydrodynamic model are presented in Table 8-4.

Table 8-4: Delft3D-FLOW hydrodynamic model setup parameters.

Parameter	Value
Wind drag coefficient	$6.3x10^{-3} + 7.2x10^{-2}$
Horizontal eddy viscosity	Uniform, 10 m^2/s
Background vertical eddy viscosity	No
Bed friction formulation	Chézy
Friction coefficient	65
Correction for sigma coordinates	Activated
Horizontal Forester filter	Activated
Vertical Forester filter	No
Time step	12 s

8.3 Results

8.3.1 Exceedance Plots

A mixing zone is defined as an area in which an effluent discharge will have an effect on ambient water quality. The boundary of the mixing zone is determined as the point at which there is no detectable change between the effects of effluent dilution and ambient water quality.

For the total suspended solids component of the effluent discharge, a value of 0.5 mg/l of excess concentration was used to determine the extent of the mixing zone. This excess concentration value was set as the water quality target based on the South African guideline (see Table 3-1). Exceedance plots describing the 98^{th} duration compliance for the total suspended solids concentration contours of 0.1 mg/l, 0.5 mg/l and 1 mg/l were extracted from the far-field model.

These exceedance plots have been produced by comparing the worst discharge combination (i.e. combined effluent 1) with the ambient conditions at Hout Bay prior to any wastewater discharge in the site.

Figure 8-5 provides the plume extent for an excess in total suspended solids concentration above ambient of 0.5 mg/l. According to this snapshot, the total plume extent for the mixing zone is approximately 5,000 m^2.

For the one-month period of simulation the area of the effluent plume excess total suspended solids differentials in the near-bed layer for the 98% exceedance compliance are provided in Table 8-5, whilst Figure 8-6 depicts the plan view area plots for the 98% exceedance compliance.

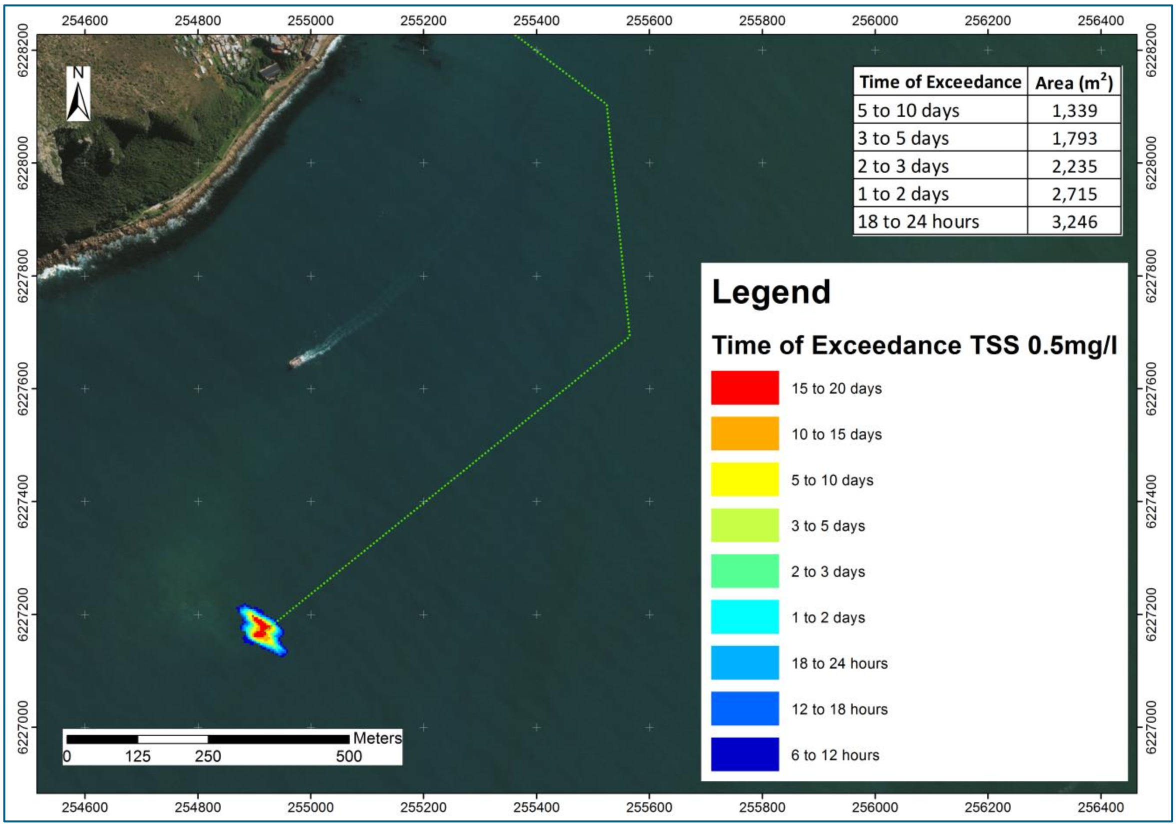

Figure 8-5: Plume extent for an excess concentration of 0.5 mg/l of total suspended solids at the near-bed.

Table 8-5: Total suspended solids exceedance cumulative areas for the simulated conditions.

TSS concentration Threshold Value (mg/l)	98th Percentile Exceedance Area (km^2)
0.5 – 1	0
0.1 – 0.5	0.015

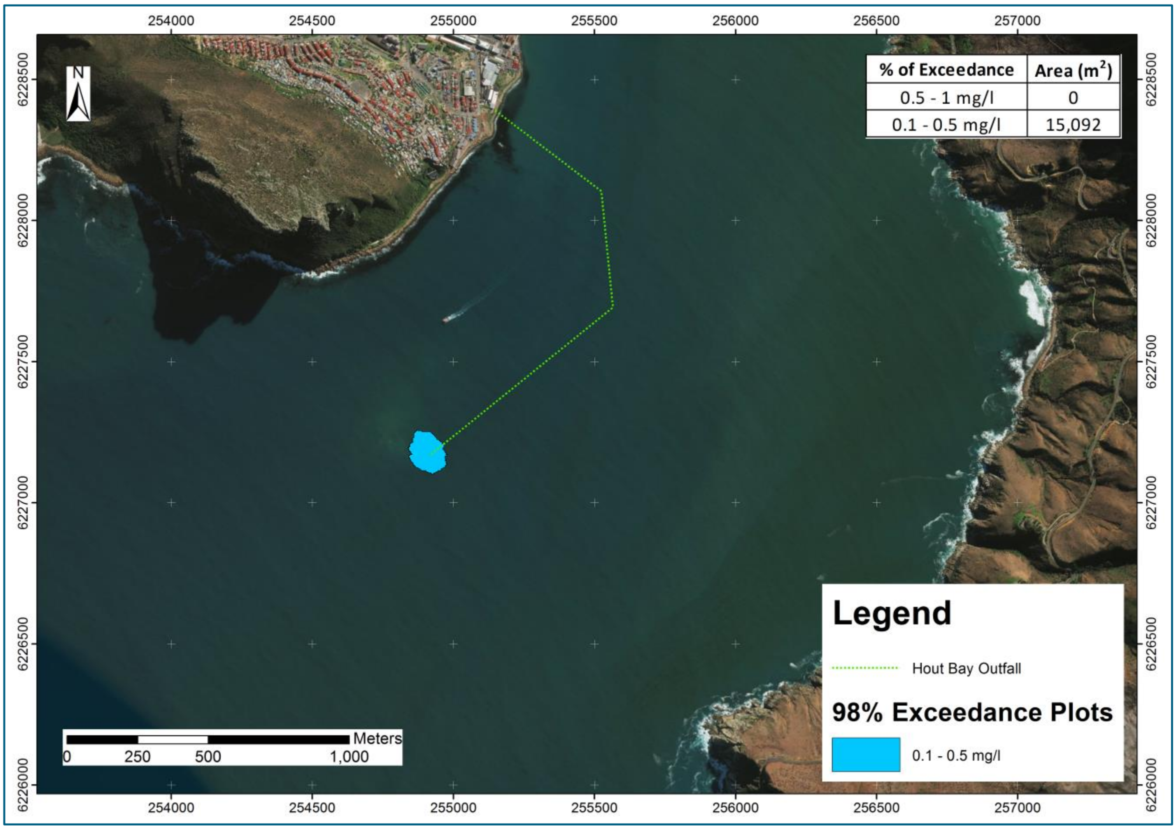

Figure 8-6: Contour plot depicting the total suspended solids differentials at the near-bed for the 98th exceedance.

9 Conclusions

The weak current magnitude condition, 0.05 m/s, results in the least amount of total suspended solids dispersion for the various combinations of effluent discharge considered, with an estimated dilution 300 m downstream of the outfall ranging between 207 and 454.

The near-field modelling indicates that the total suspended solids criteria of 0.5 mg/l above ambient at 300 m from the point of discharge is not exceeded or almost compliant for the scenarios modelled with average and strong current velocities except from the combined effluent 1. However, as seen by the near-field modelling results, the plume dispersion behaviour is dominated by the far-field processes, therefore the near-field modelling results should be considered too conservative.

- Rapid reductions in the excess total suspended solids concentration are expected, as indicated by the near-field and far-field modelling results.
- The discharge plumes for all the discharge scenarios modelled remain positively buoyant; as the outfall is located close to the seabed and the discharged effluent density is lower than the ambient density.

- Exceedance of the target value of a 0.5 mg/l TSS differential within 300 m from the discharge location is not expected based on the interpretation of the far-field modelling results.
- The far-field modelling results indicate that the water quality target of an excess of 0.5 mg/l concentration for the suspended solids component is achieved within a mixing zone of approximately 5,000 m^2.
- The combined effluent discharges are compliant with the water quality target based on the South African guideline more than 98% of the time.

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Appendix A Near-field modelling results

Appendix B Modelling software description

Appendix C CSIR Water Quality Analysis