Environmental Summary Report on Modelling and Measurement Programmes: Hout Bay Outfall

Prepared for:

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

Reference: CLS-SA-21-51 SPR HB

V3.0 – 26/08/2022

Limited distribution/Diffusion limitée

Unit B3 Millside Park, Ndabeni, Cape Town, South Africa, 7405
Tel +27 (0)21 705 0819
www.lwandle.com

CONDITIONS OF USE OF THIS REPORT

1. This report is the property of the client who may publish it provided that:
   a) CLS Southern Africa is acknowledged in the publication;
   b) The report is published in full or, where only extracts therefrom or a summary or an abridgment thereof is published, prior written approval is obtained from CLS Southern Africa for the use of the extracts, summary or abridged report; and
   c) CLS Southern Africa is indemnified against any claims for damages that may result from publication.
2. CLS Southern Africa will not publish this report or the detailed results without the client's prior consent. CLS Southern Africa is, however, entitled to use technical information obtained from the investigation but undertakes, in doing so, not to identify the sponsor or the subject of this investigation.
3. The contents of the report may not be used for purposes of sale or publicity or in advertising without prior written approval of CLS Southern Africa.

CHRONOLOGY ISSUES

Version	Date	Object	Written by	Checked by	Approved by
1	24/06/2022	CLS-SA-21-51 SPR HB	L. Holton R Carter	B. Clark B. Newman	B. Spolander
2	26/07/2022	CLS-SA-21-51 SPR HB	R Carter	B. Clark B. Newman	B. Spolander
3	26/08/2022	CLS-SA-21-51 SPR HB	R Carter	B. Clark B. Newman	B. Spolander

DISTRIBUTION

Company	Means of distribution	Names
City of Cape Town	Electronic	G. Oelofse

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

The City of Cape Town (CCT) discharges partially treated municipal effluent through ocean outfalls located off Green Point, Camps Bay, and Hout Bay on the Atlantic seaboard. The treatment applied is primarily screening at 3 mm to remove grit, plastics, paper, and larger objects from the effluent streams. Effluent discharged through the Green Point outfall is derived from households, small businesses and other sources in the city area extending from Woodstock to Bantry Bay, that discharged through the Camps Bay outfall primarily comes from Clifton, Camps Bay and Bakoven, whilst the Hout Bay outfall serves the Hout Bay urban area. Each of the outfalls replace earlier shallow water (Green Point and Camps Bay) or even intertidal (Badtamboer in Hout Bay) effluent discharge systems.

The employment of large ocean outfalls to dispose of domestic effluent is not uncommon internationally with internet searches revealing that *inter alia* Australia hosts 109 such discharges, New Zealand 16, Sao Paulo Province, Brazil eight, California USA 15 and Florida USA Palm Beach, Broward and Miami-Dade Counties, six. These have a commonality in discharge volumes with the CCT outfalls but differ in pre-discharge treatment levels with higher treatment levels being applied. As examples Sao Paulo uses preliminary treatment but adds chlorination to reduce human health risks (Ortiz et al. 2016), Florida, California, Australia, and New Zealand employ secondary treatment (Blackwell and Gemmill 2019), which, in Australia, allows the recovery of fresh water for other uses (Water Corporation 2019). Further, current recommendations on Australian policy arising from cost/benefit analyses indicate that tertiary treatment, with freshwater recovery, before discharge will be required in future (Blackwell and Gemmill 2019).

Ocean outfalls are contentious issues locally, nationally, and internationally with concerns including among other things, disruptions to local and regional marine ecology, elevated health risks due to human exposure to pathogenic bacteria and/or viruses, as pathways of excreted pharmacological compounds into the marine food chain and, in arid and semi-arid regions such as the Western Cape, loss of fresh water.

In response to such concerns and authorisation requirements, CCT conducts receiving environment monitoring in the vicinity of the three outfalls. Recent activities included:

- Monthly monitoring of faecal indicator bacteria (FIB) concentrations, comprising *Escherichia coli* and *Enterococcus* in surface waters at offshore fixed station positions around the three discharges over the period 2016-2018,
- Characterisations of the effluents being discharged, estimates of mixing zones and distributions of effluent constituents in the receiving environments (CSIR 2017; Addendum 1),
- Hydrodynamic modelling of discharge plume behaviour for each of the outfalls (PRDW 2021; Addendum 2),
- Multi-year seasonal receiving environment water quality monitoring around the outfalls over the period 2019-2022 (CLS SA 2020, 2021 and 2022a; Addendum 3-5),
- A baseline survey of Chemicals of Emerging Concern (CEC's) in shallow subtidal waters around the CCT coastline (CSIR 2022; Addendum 6), and
- Reconnaissance scale biodiversity surveys on the reef and sandy seabed biota at the Camps Bay outfall (CLS SA 2022b, 2022c; Addendum 7 & 8).

This report summarises the information obtained in the above studies relevant to the Hout Bay outfall with supporting information from scientific literature. Companion summaries have been compiled for the Green Point and Camps Bay outfalls.

It is axiomatic that post-installation, the main environmental risk from marine outfalls is the discharged effluent, its constituents and behaviour in the receiving environment. The summaries are focused on this, and linked impairments in water and sediment quality, as defined by toxicity and non-compliance with published environmental quality guidelines, that may compromise biodiversity and/or human health.

2 Description of the Hout Bay Outfall

Ocean outfalls are designed to safely dispose of domestic effluent to sea minimising the negative aesthetic effects of effluent plume visibility near the coastline and reduce potential deleterious ecological and/or human health effects of the discharged effluent by taking advantage of increased effluent dilution offered by deep water. In South Africa outfalls are licenced structures that are required to meet conditions of their authorisations in terms of effluent constituents, concentrations, and discharge rates.

2.1 Configuration and discharge rates

The Hout Bay outfall was commissioned in 1993 and extends seawards east and then south-west to 2 162 m offshore and discharges effluent in 39 m depth (Figure 2.1). The pipeline is mainly buried but is exposed over its seaward 650 m. The outfall terminates in 15 diffusers, with 10 currently in operation. The design effluent discharge capacity is 9.6 Ml/day, but actual average rates are 5.32 Ml/day in winter/spring and 5.05 Ml/day in summer/autumn (PRDW 2020).

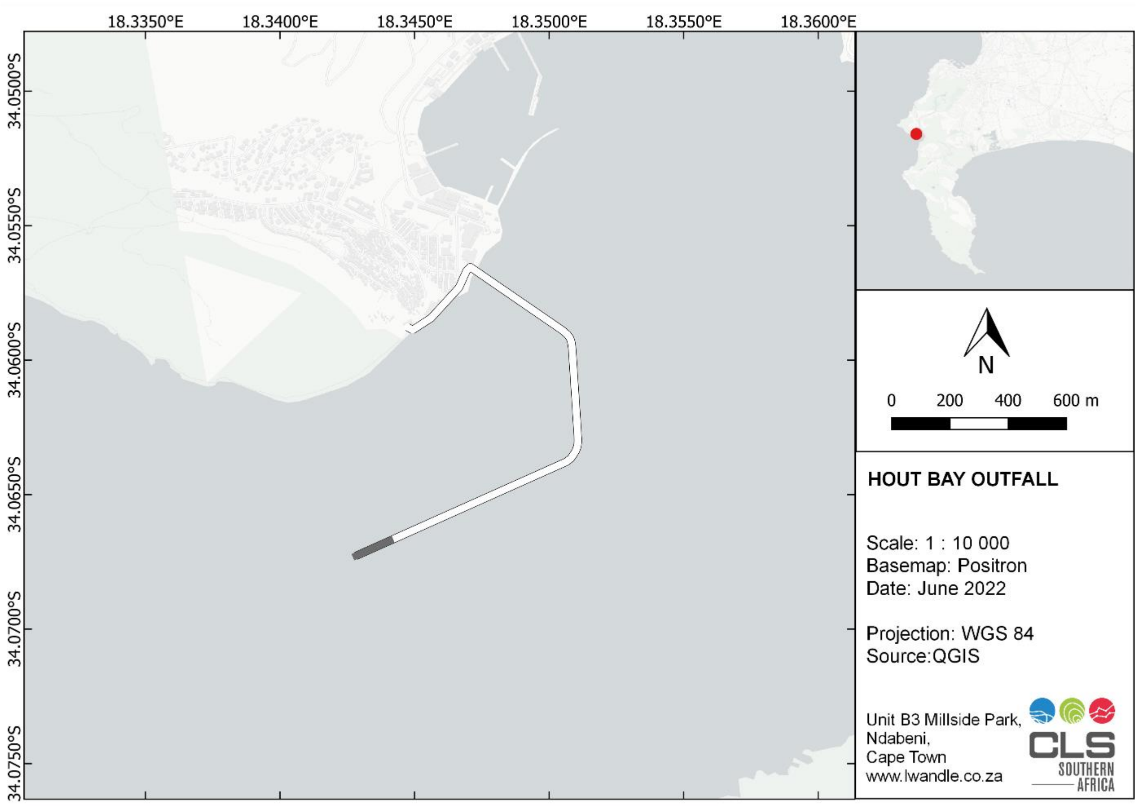

Figure 2.1: Map of the Hout Bay outfall. The grey section of the outfall indicates the location of the 15 diffusers.

2.2 Effluent constituents and compliance

Domestic effluent is a complex and variable mixture of inorganic and organic chemicals that have probably never been fully characterised. Constituents and properties of general concern usually included as licence conditions for outfalls include pH, and concentrations of total suspended solids (TSS), total ammonia, total Kjeldahl nitrogen (= organic nitrogen plus ammoniacal nitrogen), chemical oxygen demand (COD) and orthophosphate (CSIR 2017). Results of analyses of final effluent samples (i.e., immediately pre-discharge) collected daily from March 2015 to September 2016 are reported in CSIR (2017). During this period, the Hout Bay effluent was fully compliant with generally specified limits on pH, 80% compliant for TSS, 91% for COD, 79% for total ammonia and for orthophosphate 96% compliant.

CSIR (2017, their Table 2.2) lists General and Special concentration limits under consideration by the Department of Environmental Affairs (DEA, now Department of Forestry, Fisheries and Environment) for effluent constituents[1]. General limits would apply to ocean outfalls in >10 m depth and >500 m offshore and are thus applicable to the effluent discharged through the Hout Bay outfall. The pre-discharge effluent sampled in 2015 and 2016 was compliant for trace metals, polychlorinated biphenyls (PCBs), phenols, pesticides (Dieldrin, Endrin, DDT) and nitrate and nitrite nitrogen. The effluent was 87% compliant for pH, 64% for Kjeldahl nitrogen, and 91% for orthophosphate, but markedly noncompliant for TSS (1.1%), COD (9.2%), total ammonia nitrogen (0.2%) and aluminium (50%).

3 Estimates of Required Effluent Dilutions

CSIR (2017) used a mass balance modelling approach to estimate whether the Hout Bay discharge would be compliant with receiving water quality guideline concentrations for inorganic chemicals (DWAF 1995) and the California Ocean Plan[2] for organic compounds outside of a zone of initial dilution (ZID). A minimum initial dilution of 200x at the ZID boundary was applied. Most of the inorganic and organic chemical constituents identified in the effluent had median required dilutions of <200x, i.e., receiving environment water quality thresholds for these chemicals should not be compromised outside the ZID boundary. TSS was an exception for inorganics with a median required dilution of 258x and a maximum of 37 590x. For ammonia, the median required dilution was 110x, but the maximum needed was 1 774x. In the case of TSS, 62% of the samples required dilutions >200x; for ammonia, this was lower at 9.8%; i.e., most effluent samples would be compliant after 200x dilution for ammonia, whilst the majority (62%) would not be compliant for TSS. Of the organic compounds listed, polychlorinated biphenyls (PCBs) were estimated to require a median dilution of 3 684x to meet the listed water quality target (0.02 μg/l). This is assessed in section 7.1.

The radius of the allowable spatial extent of the ZID around the Hout Bay outfall diffuser bank specified by the CCT (CCT in litt. 2022) is 272 m. This is based on guidance in Anchor (2016) and the Hout Bay outfall diffuser configuration. This differs from the 134 m radial distance from the diffusers calculated by CSIR (2017) on the same basis, indicating that the guidance is, to an extent, open to interpretation. The plume simulation modelling (PRDW 2021) and linked water quality surveys (CLS SA 2020, 2021, 2022a) were based on the CCT allowable ZID dimension. Performance against this in terms of compliance with water quality guideline concentrations for effluent constituents is evaluated in discharge plume simulation modelling and water quality measurements below.

4 Effluent Plume Simulation Modelling

PRDW (2020) conducted simulation modelling of plume behaviour after discharge into the receiving environment off Hout Bay. A 3D model was employed (DHI MIKE) that allows coupling of near and far-field plume behaviour within a dynamic mesh and incorporating water quality and suspended sediment sub-models. Discharge plume behaviour was simulated for winter/spring (actual period 1/8/2019 to 9/10/2019) and summer/autumn (13/2/2020 to 23/4/2020), the former representative of non-upwelling conditions and the latter upwelling conditions. The variables modelled were the faecal indicator bacteria (FIB), comprising *Escherichia coli* and enterococci, total suspended solids (TSS), and a conservative tracer to determine achieved dilutions. The pre-discharge effluent concentrations modelled

[1] Staatskoerant, 23 August 2019, No. 42657.
[2] http://www.waterboards.ca.gov/water_issues/programs/ocean/

were E. coli 1x10^{7} cfu/100 ml, enterococci 1.3x10^{6} cfu/100 ml, TSS 455 mg/l and 100 units for the tracer.

4.1 Predicted plume behaviour

The plume modelling showed complex behaviour in variable wind conditions in both seasonal periods. Examples taken from the winter/spring period are southerly wind conditions forcing the effluent plume, as indicated by *E. coli* concentrations, offshore out of Hout Bay but then northwards, with the mid-depth plume being more extensive than the surface plume (Figure 4.1). The differential plume sizes predicted indicate the discharged material being trapped mid-depth. In north-westerly wind conditions, the effluent plume can exit Hout Bay and flow south-west with negligible impingement on the shoreline (Figure 4.2). In the example given, the surface plume is larger than that at mid-depth, implying minimal mid-depth trapping. In the modelled summer/autumn period, south-easterly winds advect the effluent plume out of Hout Bay and then in a north-westerly direction, while at mid-depth, the plume is advected eastwards but remains mainly in the western extremity of the bay (Figure 4.3). Mid-depth *E. coli* concentrations in this condition are considerably higher than in the surface layer, consistent with current shear in a two-layered water column. In north-westerly winds, the effluent plume can be advected south-westwards out of Hout Bay (Figure 4.4). Sub-surface trapping may occur.

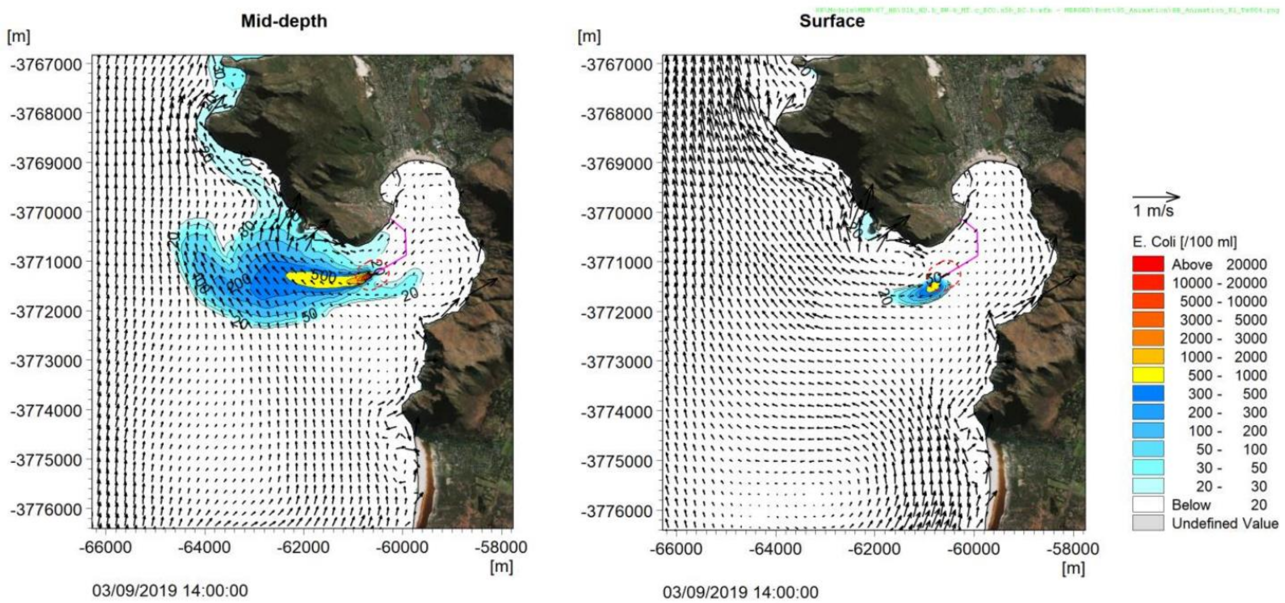

Figure 4.1: Winter/spring: Current vectors and E. coli *plume at a moment in time during a southerly wind condition (from PRDW 2020).*

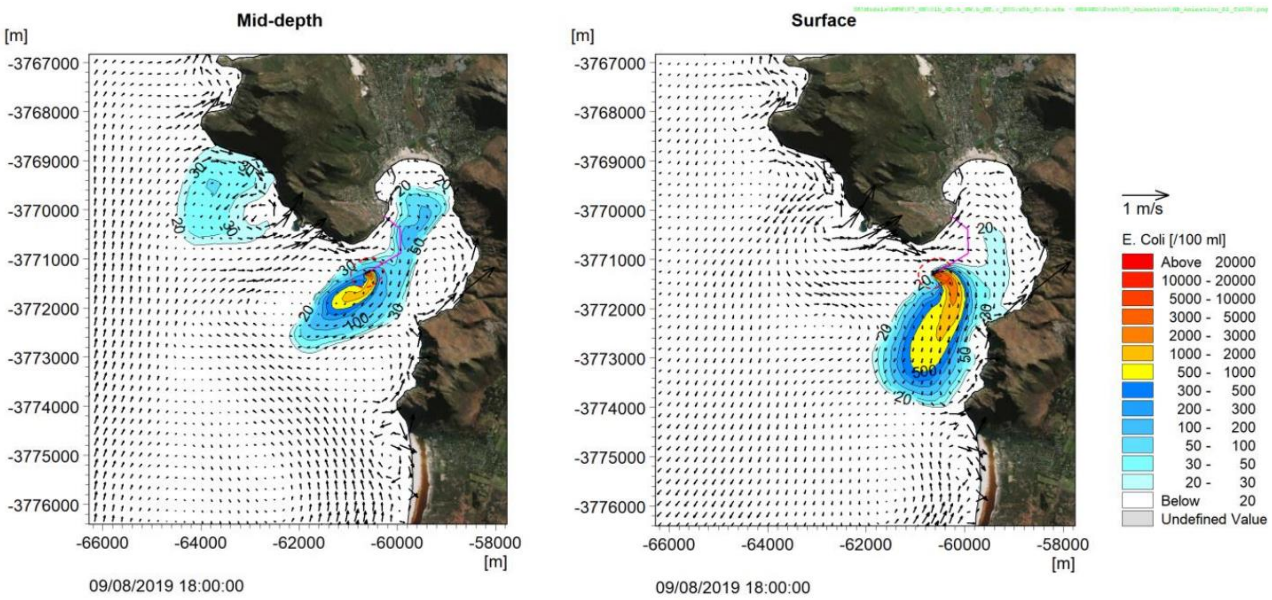

Figure 4.2: Winter/spring: Current vectors and E. coli *plume at a moment in time during a north-westerly wind condition (from PRDW 2020).*

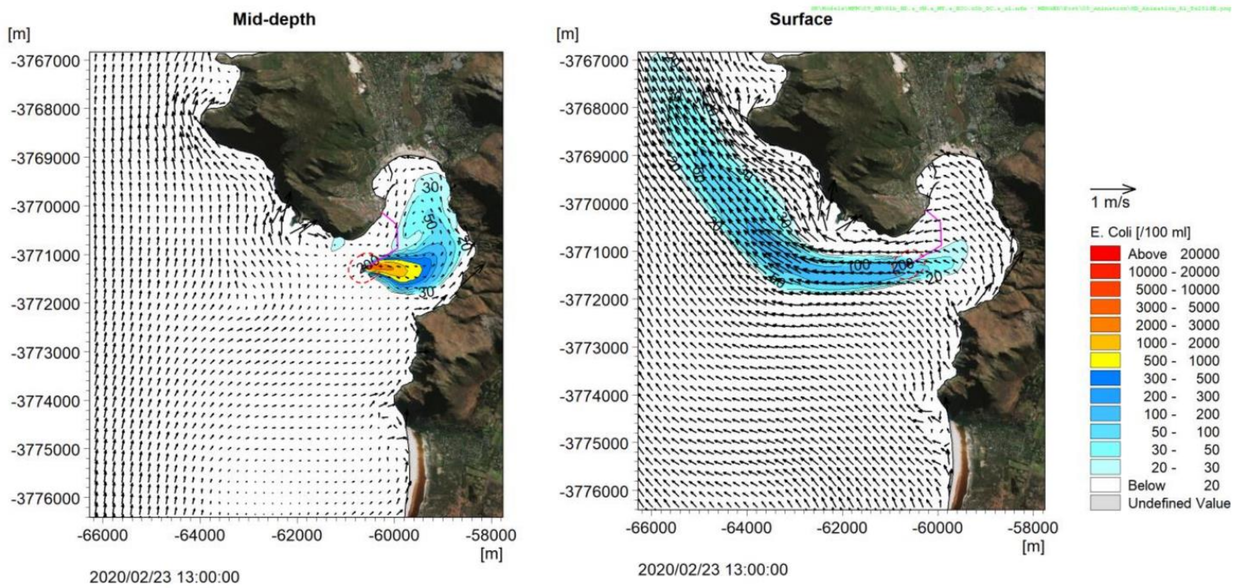

Figure 4.3: Summer/autumn: Current vectors and E. coli *plume at a moment in time during a south-easterly wind condition (from PRDW 2020).*

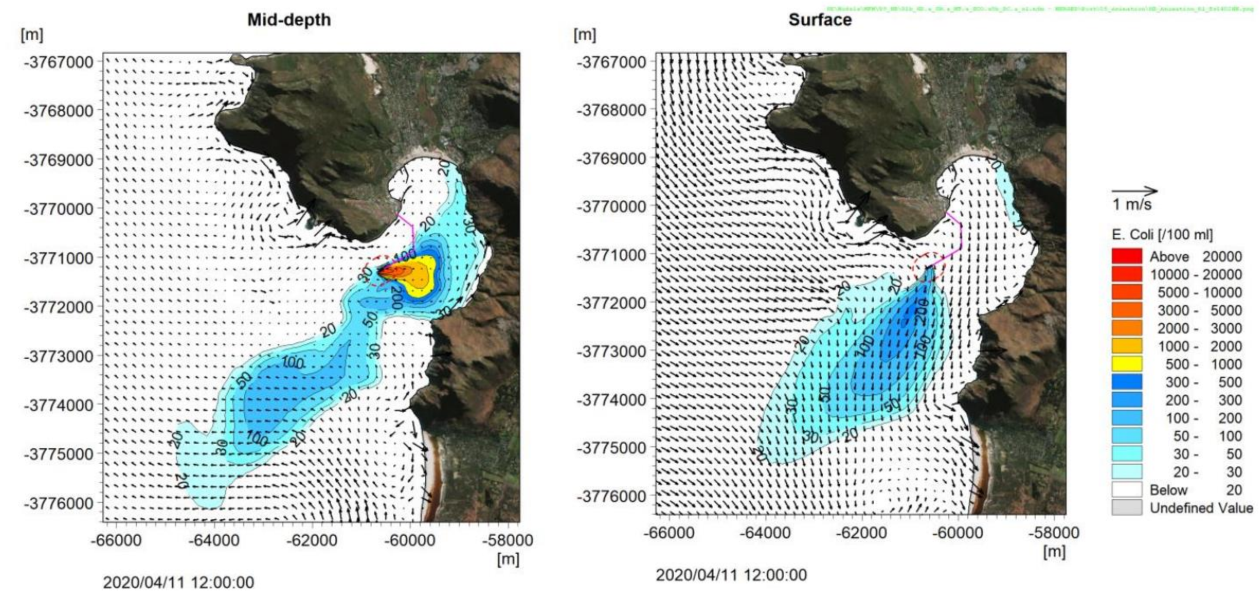

Figure 4.4: Summer/autumn: Current vectors and E. coli *plume at a moment in time during a north-westerly wind condition (from PRDW 2020).*

4.2 Predicted effluent plume dilutions and water quality guideline compliance

Effluent plume dilutions predicted from the modelling indicate that, at the boundary of the allowable ZID, the 5th percentile dilution factor, i.e., that close to the minimum, is 1 500x in winter/spring and 1 950x in summer/autumn. Plume cross sections (Figure 4.5, Figure 4.6) show that 5th percentile dilutions of <300x occur in the mid to lower water column but are 5 000x to >10 000x in the upper water column. These results indicate that required dilutions for ammonia and COD should be achieved within the allowable ZID but that the TSS guideline will be met <200 m beyond the ZID boundary. The predictions for ammonia and TSS align with those of CSIR (2017).

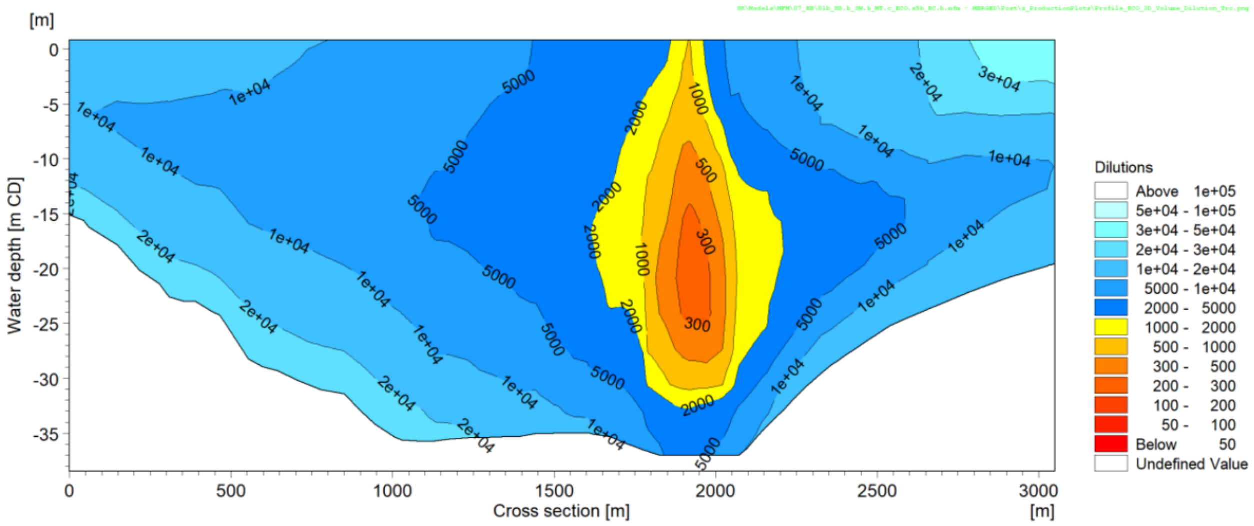

Figure 4.5: Winter/spring: Cross section of 5th percentile number of dilutions along the longest axis of the plume, from PRDW (2020).

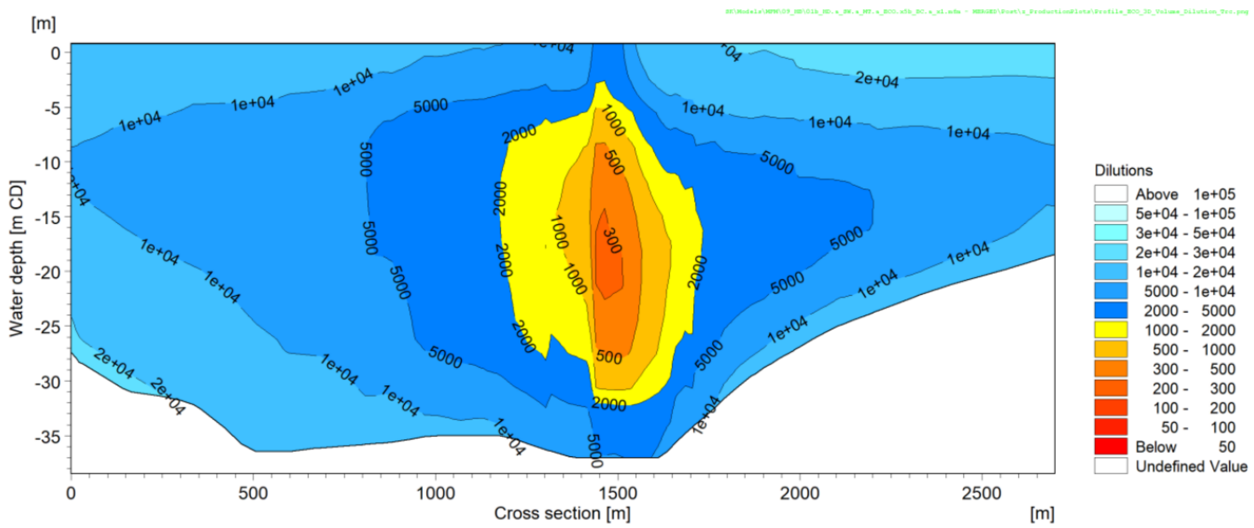

Figure 4.6: Summer/autumn: Cross section of 5th percentile number of dilutions along the longest axis of the plume (from PRDW 2020).

Predicted daylight hour distributions of the faecal indicator bacterium *Enterococcus* show that, for both modelling periods, surface and near seabed 90th percentile concentrations above the water quality guideline of 185 cfu/100 ml will be restricted to within the ZID (PRDW 2020, figure 6.12 & figure 6.14, and 6.28 & 6.30). At mid-depth, the guideline is predicted to be exceeded to the east and west of the boundary for distances up to 400 m (PRDW 2020, figure 6.13 & figure 6.29). Modelled time series data for selected sites show that, at the event scale at the Dungeons surf site, enterococci concentrations higher than the guideline are predicted to occur on five occasions in the winter/spring period and twice in summer/autumn. In both seasons, exceedances are predicted to be short-term (< 1-day) implying that the water quality guideline will not be exceeded. Maximum counts <500 cfu/100 ml are predicted (Figure 4.7, Figure 4.8).

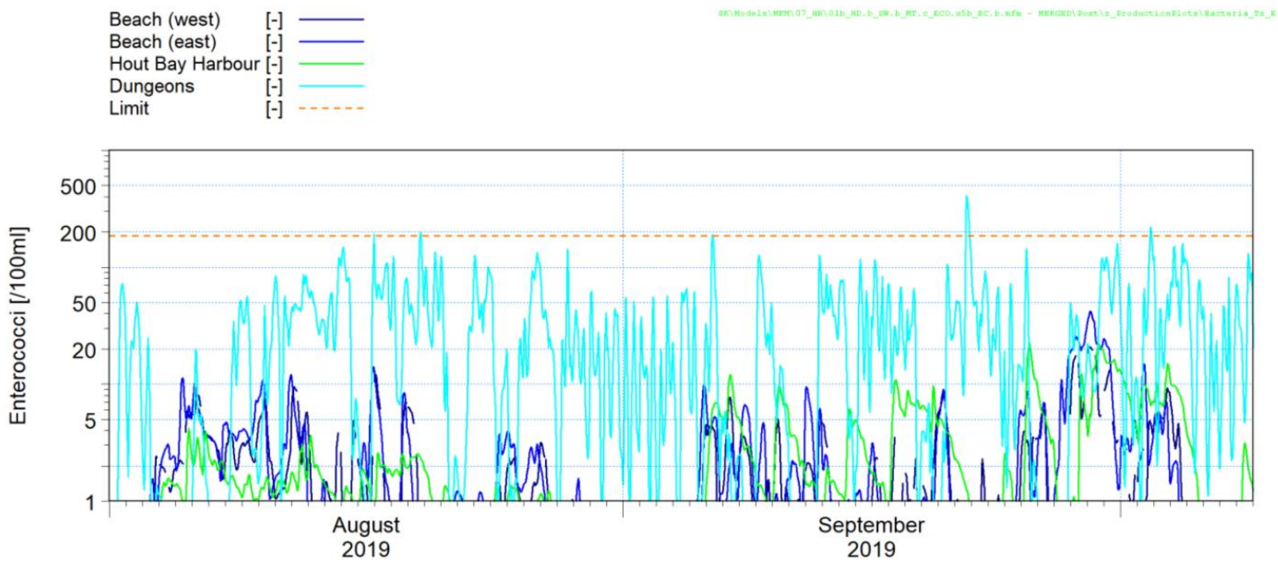

Figure 4.7: Winter/spring: Time series of highest enterococci concentration at any depth at four key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is also shown in orange (from PRDW 2020).

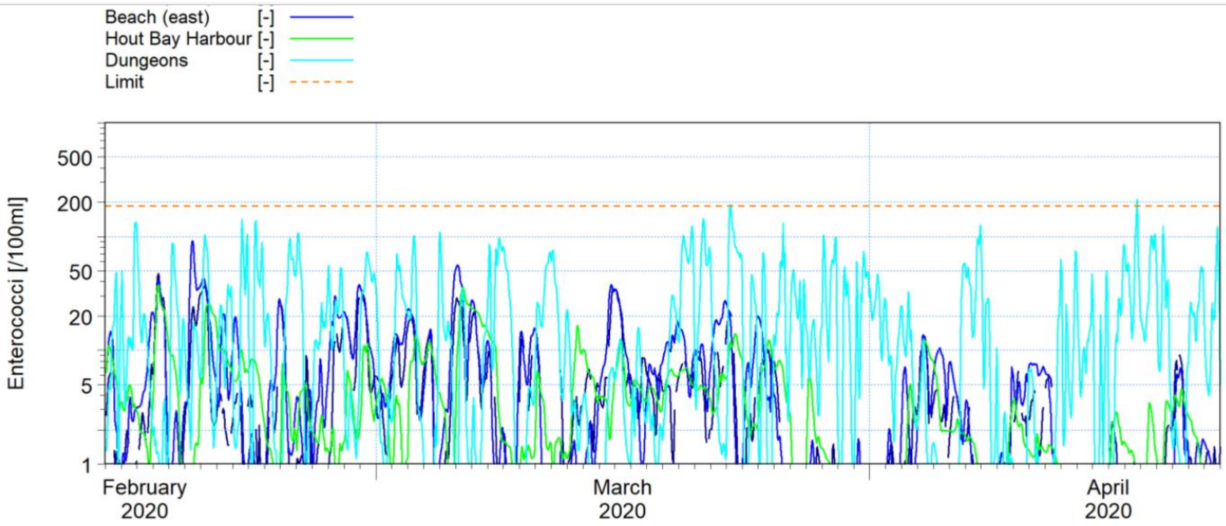

Figure 4.8: Summer/autumn: Time series of highest enterococci concentration at any depth at four key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is also shown in orange (from PRDW 2020).

4.3 Predicted suspended solids transport and deposition

PRDW (2020) modelled the transport and deposition of suspended solids discharged from the Hout Bay outfall in the winter/spring and summer autumn periods. As shown in Table 4.1 released masses were similar in each period with >98% predicted to deposit offshore beyond the 40 m isobath, be transported out of the model domain, extending ~110 km from Grotto Bay in the north to south of Cape Point and ~30 km offshore of the CCT Atlantic seaboard, or remain suspended. Less than 1% of the discharged mass was predicted to deposit in Hout Bay harbour. The harbour receives flows from storm water drains and contaminants linked to mainly commercial fishing operations and may be an environmentally stressed environment. The contribution of the Hout Bay discharge to this is unknown as there is no complete inventory of discharges and their constituents into the harbour water body.

Table 4.1: Fate of total suspended solids fate at the end of 10-week modelling periods (data from PRDW 2020).

	Winter/Spring		Summer/Autumn	
Area	**Mass (kg)**	**% Released**	**Mass (kg)**	**% Released**
Port of Cape Town	2 300	1.4%	325	0.2%
Murray's Bay Harbour	1.38	<0.1%	0.74	<0.1%
Granger Bay	11	<0.1%	3.32	<0.1%
Hout Bay	145	<0.1%	256	0.1%
Offshore (-40m depth)	28 300	16.9%	32 700	18.5%
Out of model domain	91 300	54.5%	109 000	61.4%
Suspended	45 600	27.2%	35 100	19.8%
Totals	**168000**	**100.0%**	**177000**	**100.0%**

4.4 Predicted acute toxicity MATDs

Predicted dilution rates for individual constituents within discharged domestic effluents do not capture the full toxicity risk imposed on the receiving environment. This can be estimated through whole effluent toxicity testing on suitable test organisms or life stages of organisms. Such tests provide data for the derivation of minimum acceptable toxicant dilutions (MATD) for the effluents tested. CSIR (2017) conducted acute whole effluent toxicity testing measuring sea urchin fertilisation success after exposures to serial dilutions of the pre-discharge Hout Bay effluent collected at two-month intervals over an eight-month period in 2016. The derived MATDs fell into the narrow range of 29x-32x. These will be met within the allowable ZID where 5th percentile dilutions of >1 500x are predicted to be achieved. This indicates a low overall toxicity risk to organisms of similar or lower sensitivity than sea urchin gametes from the discharge in the receiving environment. The narrow MATD range implies that there is low variability in the Hout Bay effluent

5 Measured Water Quality

Simulation modelling in its various forms allows predictions of discharged effluent behaviour. However well ground-truthed the applied model may be, these remain predictions and require water quality measurements in the field to test their reliability. The water quality measurement data available for this are:

- The monthly monitoring by CCT of faecal indicator bacteria (FIB) concentrations, comprising *Escherichia coli* and enterococci[3] in surface waters at offshore fixed station positions around the Hout Bay outfall over the period 2016-2018, with analyses of the distributions of these constituents in the receiving environment (CSIR 2017), and
- The multi-year seasonal receiving environment water quality monitoring around the outfall over the period 2019-2022 (CLS SA 2020, 2021 and 2022a).

The station grid employed for the CCT sampling is shown in Figure 5.1.The sampling design could provide data on longshore plume behaviour, penetration into the offshore environment and possible presence in the interior of Hout Bay. Sampling was restricted to the sea surface so details on subsurface plume behaviour were not obtained.

[3] Taxonomic revisions of faecal streptococci isolates show that they predominantly comprise *Enterococcus* species (Pinto et al, 1999). CSIR (2017) and the CCT provide streptococci counts which are considered as equivalents to the enterococci counts in CLS SA survey data.

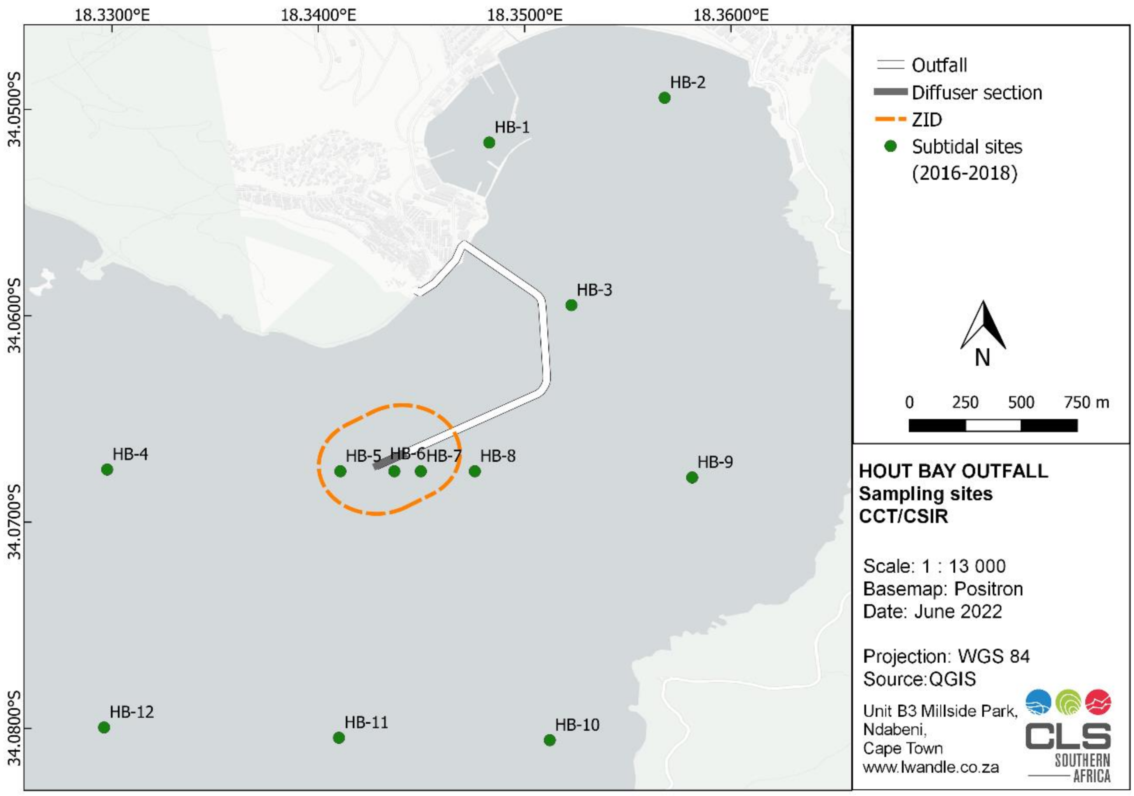

Figure 5.1: Water quality sampling points employed by the CCT for FIB distribution monitoring around the Hout Bay outfall over the period 2016-2018.

CSIR (2017) show monthly interval distribution plots for enterococci for sea surface samples collected in 2016 (their figures 4.28-4.39). In eight of the months, counts were below 100 cfu/100 ml, one month had a single station where counts were >100 - <500 and three months where counts >500 cfu/100 ml were recorded. The spatial distributions show that the high counts occurred at or close to the outfall diffuser bank, and they reduced with distance from this. This apparent rapid dilution is highlighted by CSIR (2017). Geographically, sample stations HB-6 and HB-7 are within the allowable ZID, while HB-5 and HB-8 are close to the ZID boundary. Table 5.1 lists the count data for the entire measurement period (2016-2018) and estimates the 90th and 95th percentile values. The apparent rapid dilution is evident in these data and in the 90th percentile values. As expected, samples from within the ZID are non-compliant with the 90th percentile 185 cfu/100 ml water quality guideline, whereas those close to the ZID boundary are. Under the DEA (2012) classification scheme, water quality at HB-5 would be classified as sufficient, while HB-8 would class as excellent (95th percentile is <100 cfu/100 ml).

The distribution plots in CSIR (2017) based on the CCT 2016 sample data do not show enterococci counts >100 cfu/100 ml at locations other than those adjacent to the outfall diffuser bank. The complete 3-year data set for stations HB-1 to HB-3, typifying the interior of Hout Bay (Table 5.2), indicates 90th percentile counts well below the water quality guideline and that, according to the 95th percentile values, water quality would be rated as excellent at stations HB-1 and HB-3. Three instances of enterococci counts >100 cfu/100 ml at these sample stations were recorded over the monitoring period.

The CCT sample data are largely in accord with the simulation modelling conducted for Hout Bay. Note that sampling from small vessels offshore of the western seaboard is limited to relatively calm sea conditions due to safety considerations. Discharge plume dispersion is expected to be lowest under such conditions compared to rougher seas. Thus, if the plume is encountered during sampling, dilution could be low and, for enterococci counts at least, concentrations high, possibly biasing results. Simulation modelling periods do not have this problem, and model outputs are possibly more accurate over the range of metocean conditions than are measured distributions.

Table 5.1: Enterococci counts (cfu/100 ml) at sample stations within the allowable ZID (HB-6 & HB-7) and immediately adjacent sample stations (HB-5 & HB-8) for surveys in 2016-2018; n = 30. Counts recorded as below the detection limit are included at half of the detection limit to enable the estimation of the percentiles.

Sample Date	Station			
dd/mm/yr	HB-6	HB-7	HB-5	HB-8
16-01-18	4	14	0.5	1
26-02-18	2600	3800	1	4
29-05-18	11	9	32	19
26-06-18	4	114	32	28
24-07-18	5100	3400	0.5	680
23-01-17	17	19	92	3
21-02-17	4400	5	1	6
14-03-18	2	2	0.5	4
04-04-17	15	0.5	1	4
09-05-17	1	1	0.5	0.5
27-06-17	0.5	9	10	44
17-07-17	100	3	6	1
22-08-17	2400	430	190	39
19-09-17	4	3	12	3
24-10-17	12	44	1	8
27-11-17	38	0.5	2	12
12-12-17	0.5	3	11	0.5
25-01-16	0.5	3	3	0.5
02-02-16	44	0.5	1	32
01-03-16	4300	0.5	1	32
30-03-16	1	1	2	8
19-04-16	21	2	13	0.5
17-05-16	0.5	3	4	0.5
28-06-16	9	113	9	14
19-07-16	760	200	390	22
29-08-16	0.5	0.5	0.5	0.5
12-09-16	1	0.5	0.5	0.5
10-10-16	0.5	0.5	0.5	0.5
29-11-16	8	9	0.5	13
13-12-16	8	3	137	8
90th Percentile	2770	223	96.5	32.7
95th Percentile	4355	2063.5	166.15	41.75

Table 5.2: Enterococci counts (cfu/100 ml) at stations in the interior of Hout Bay for surveys in 2016-2018; n = 29. Counts recorded as below the detection limit are included at half of the detection limit to enable the estimation of the percentiles.

Sample Date	Station		
dd/mm/yr	HB-1	HB-2	HB-3
16-01-18	7	2	1
26-02-18	1	6	4
29-05-18	29	89	31
26-06-18	18	7	14
24-07-18	10	2	4
23-01-17	102	17	12
21-02-17	8	0.5	0.5
14-03-18	7	1	4
04-04-17	66	1	0.5
09-05-17	3	6	1
27-06-17	15	30	5
17-07-17	60	27	24
22-08-17	78	370	42
19-09-17	25	5	17
24-10-17	6	10	4
27-11-17	80	1140	0.5
12-12-17	9	0.5	1
02-02-16	6	1	1
01-03-16	12	0.5	0.5
30-03-16	71	42	5
19-04-16	26	0.5	1
17-05-16	43	5	0.5
28-06-16	23	68	18
19-07-16	67	26	32
29-08-16	4	7	2
12-09-16	74	4	0.5
10-10-16	10	8	3
29-11-16	14	0.5	14
13-12-16	15	5	7
90th Percentile	**75**	**72**	**25**
95th Percentile	**79**	**258**	**32**

The CCT water sampling was restricted to the surface layer (CSIR 2017). Therefore, when the discharged effluent may be trapped subsurface, as shown in the modelling, the surface sample data may indicate more benign conditions than what may be the case through the water column

CLS SA carried out summer and winter water quality surveys at and adjacent to the Hout Bay outfall over the three-year period 2019-2022, The sampling locations are shown in Figure 5.2 along with the CCT estimated allowable ZID. The purpose of this sampling design was to characterise water quality at the ZID boundary and on screens of stations between the outfall and the nearshore. In these surveys, surface, mid-depth and near seabed sampling was conducted to gain insight into discharged constituent distributions in the water column.

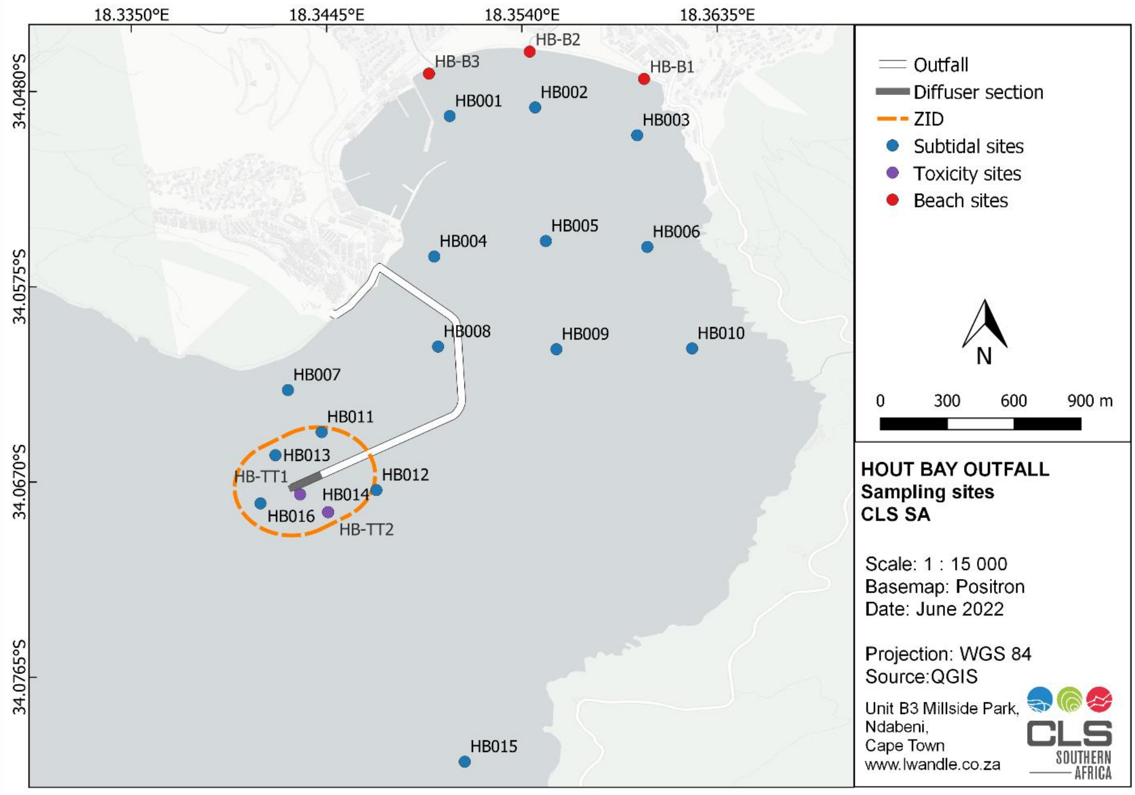

Figure 5.2: Map of the Hout Bay outfall and the locations of water quality sampling sites (subtidal, toxicity and beach) for the seasonal surveys conducted by CLS SA.

CLS SA distributional plots show variable differences in surface, mid-depth, and bottom waters for enterococci but generally higher concentrations in bottom waters for TSS and orthophosphates. The latter distributions, although predicted by modelled discharged effluent plume behaviour, are not evident in the enterococci distributions where surface concentrations can exceed those at mid-depth and below. This may be due to the relatively wide count bins (~100 cfu/100 ml) used to display the data. Table 5.3 examines this based on the entire enterococci data set for the CLS SA surveys. These data have been partitioned into those adjacent to the allowable ZID, those in the interior of Hout Bay, nearshore stations, and beach stations.

Table 5.3: Enterococci count data (cfu/100 ml) obtained in seasonal surveys at the Hout Bay outfall. The data are partitioned into subsets comprising those adjacent to the allowable ZID boundary (stations HB011-HB014, HB016), samples in the interior of the bay (HB005-HB010), nearshore samples (HB001-HB003) and three beach sites (HB-B1-HB-B3). Red text shows values >185 cfu/100 ml.

Data Set	n samples	90th Percentile	95th Percentile	Maximum Count Recorded
All stations	1728	77	120	12000
ZID Boundary stations	510	70.0	107.3	440.0
ZID Boundary Surface	170	50.2	80.0	134.0
ZID Boundary Mid Depth	170	132.6	189.1	440.0
ZID Boundary Bottom	170	43.1	67.2	241.0
Hout Bay Interior	612	77.9	102.9	460.0
Interior Surface	204	56.4	98.0	460.0
Interior Mid Depth	204	92.0	119.3	252.0
Interior Bottom	204	77.7	99.1	240.0
Hout Bay Nearshore	306	56.0	101.3	940.0
Nearshore Surface	102	130.9	198.0	940.0
Nearshore Mid Depth	102	33.9	58.3	340.0
Nearshore Bottom	102	46.7	72.9	193.0
Beaches	99	504.0	1105.0	12000.0

The table shows that:

- Over the monitoring period receiving water quality attains the sufficient status according to the DEA (2012) guidelines (90th percentile of the counts <180 cfu/100 ml) but falls short of the excellent status (95th percentile <100 cfu/100 ml),
- There is clear evidence that mid-depth enterococci counts are higher than those in the surface and bottom water samples in the ZID boundary and Hout Bay interior samples which is consistent with the modelling results. The nearshore samples differ as the highest counts are in the surface samples. This is consistent with a freshwater source, e.g., estuary and/or stormwater, and
- Reinforcing the above highest counts are recorded in the swash zones of the beaches. The distributional data in the CLS SA reports and that summarised in the table do not show connectivity with the offshore discharge implying a local source of pollution, possibly the Hout Bay (Disa) River estuary.

The statistically summarised data in Table 5.3, although following requirements for water quality classification (DEA 2012), do not show event scale distributions where discharged effluent affects bay areas outside of the ZID. Such an event is shown in Figure 5.3. Highest counts occurred close to the outfall diffuser bank, but elevated counts were distributed across the survey area, except for the outer bay, indicating a more pervasive influence of the outfall than is evident in the tabulated data above. These event scale distributions are also evident in the modelled plume behaviour; e.g., *E. coli* distributions in Figure 4.1 to Figure 4.4 and effluent plume dilutions in Figure 5.4. These sets of figures show that effluent is predicted to reach the shoreline in Hout Bay and the Dungeons surf spot but at dilutions of 10 000x and higher indicating that low enterococci counts should occur, as reflected in Figure 4.7 & Figure 4.8.

It is extremely unlikely that the levels of complexity shown in the predicted plume behaviour plots will be captured in field survey campaigns.

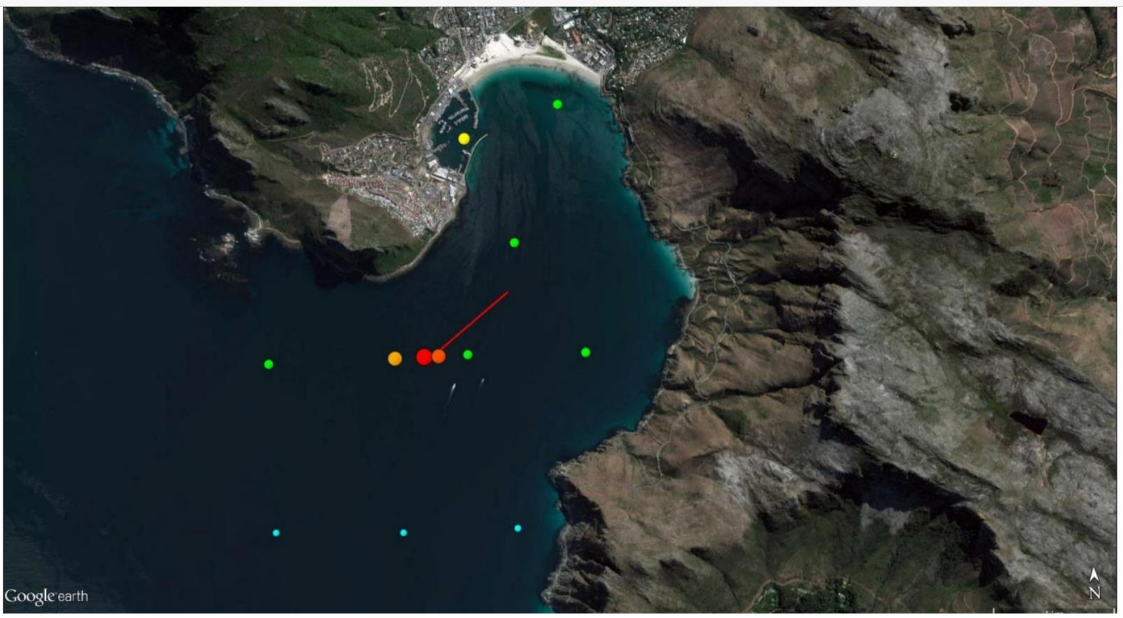

Figure 5.3: Bubble plot of enterococci counts in sea surface water samples 19/7/2016. Blue indicates cfu/100 ml counts <20, green counts >20-≤50, yellow counts >50-≤100, orange counts >100-≤500 and red counts >500 (from CSIR 2017).

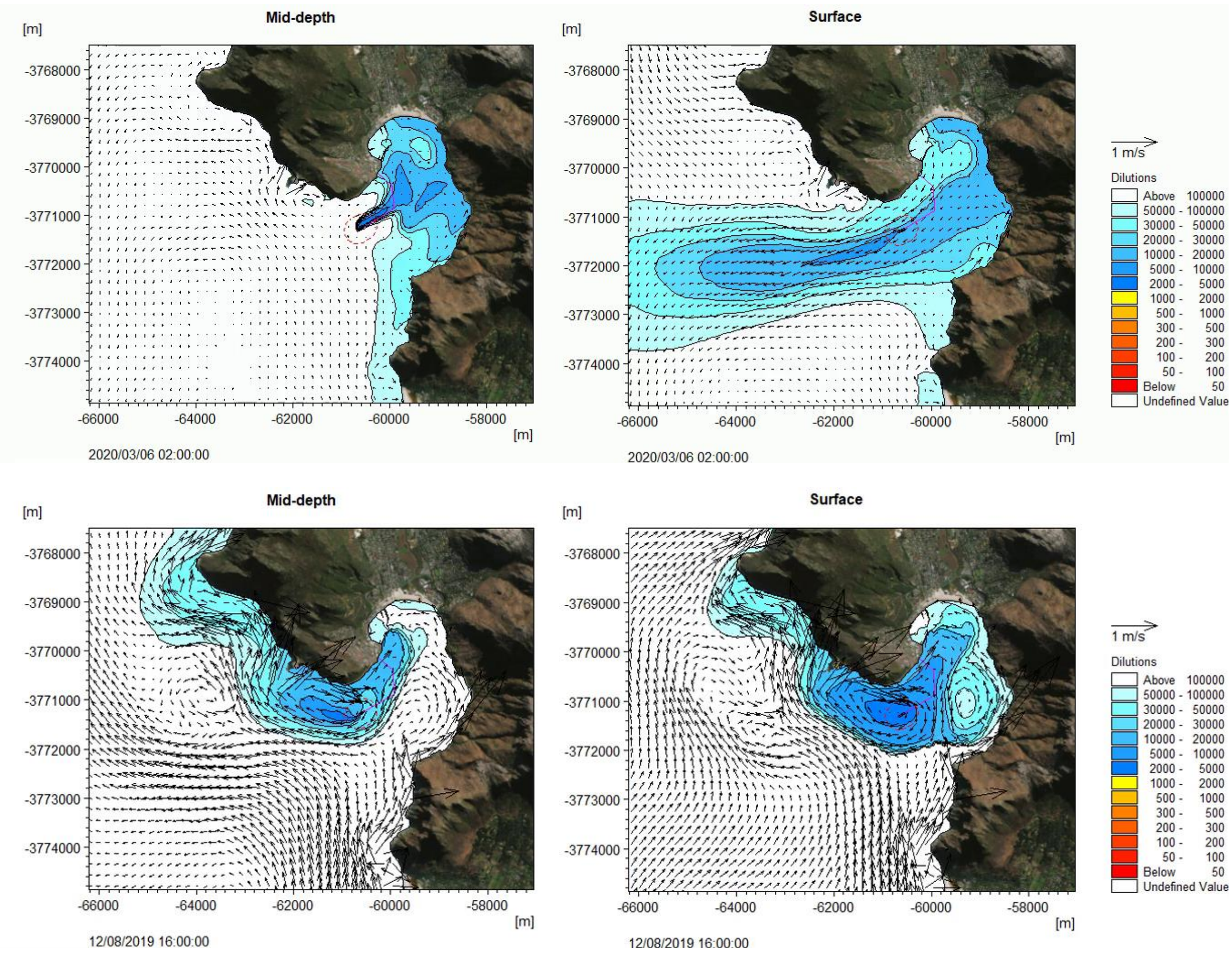

Figure 5.4: Instantaneous plots of effluent dilutions in variable currents in summer/autumn (top panel) and winter/spring (bottom panel) (from PRDW 2020 plume animations).

6 Measured Contaminants of Emerging Concern (CECs)

From analyses of Hout Bay pre-discharge effluent samples, CSIR (2017) identified 27 CECs comprising pharmaceutical and personal care products. The most prominent amongst these in terms of concentration were acetaminophen (paracetamol), naproxen, diclofenac, triclocarban, irbesartan, levetiracetam, and bezafibrate. Acetaminophen concentrations approached mg/l levels, with the others lower at <5 µg/l. Research in other coastal areas such as the Baltic Sea reveals a similar suite of CECs with acetaminophen top of the 'top-twenty' concentration list for untreated wastewater (Zandaryaa and Kamenetsky. 2021). Internationally, the primary source of such chemicals in the coastal ocean is considered to be via wastewater discharges (Vidal-Dorsch et al. 2012), a contributing factor being that conventional sewage treatment technologies do not generally remove them.

In a follow-up survey and assessment of distributions of CECs in Cape Town's nearshore coastal waters, CSIR (2022) recorded 36 compounds and found that the highest total concentrations occurred at sample sites influenced by wastewater treatment works and/or uncontrolled flows from unserved population centres. The Hout Bay (Disa) River estuary receives such flows, and, on the day of sampling, this location had high FIB counts (enterococci 2 000 cfu/100 ml) and showed measurable concentrations of acetaminophen (5 782 ng/l), ibuprofen (22 ng/l), codeine (24 ng/l), naproxen (73 ng/l), hydrochlorothiazide (70 ng/l), and atenolol (52 ng/l). At the adjacent Hout Bay beach sampling site, FIB counts were below the detection limit, as were pharmaceutical compounds for all but acetaminophen, bezafibrate, ofloxacin, salicylic acid, azithromycin, sulfamethoxazole, trimethoprim, and alprazolam. This distribution indicates that pharmaceutical compounds in the Hout Bay nearshore have a high probability of coming from the Hout Bay River and, together with enterococci distribution data discussed above, a low probability of being derived from the Hout Bay outfall.

Toxicity effects of pharmaceutical compounds on marine organisms have been demonstrated (Fabbri and Franzellitti 2016), as has their presence in mussels and fish locally (Petrik et al. 2017). Direct toxicity has been shown in sea urchin (*Paracentrodus lividus*) embryo-larval development at the nanogram concentration level and in microalgae at the mg/l level (Fabbri and Franzellitti 2016), so local effects in the Hout Bay discharge area may be occurring in organisms of similar or higher sensitivity. However, this has not been evident in the toxicity tests conducted in the receiving environment of the Hout Bay outfall discussed in this synthesis.

The CSIR (2022) survey can be classed as a reconnaissance operation as sampling was once-off in each season. It did demonstrate the importance of shoreline discharges in CEC distributions. The Hout Bay Point outfall effluent has also been shown to be a significant source (above) contributing to CECs in the local coastal ocean.

7 Biodiversity Risks

The biodiversity risks posed by the effluent discharged through the Hout Bay outfall include acute and chronic toxicity to marine organisms, bioaccumulation of contaminants in mussels and their main predator, and eutrophication in nearshore waters primarily due to ammonia-nitrogen and particulate organic material in the discharge.

7.1 Acute and chronic toxicity

CSIR (2017) estimated the required dilutions for Hout Bay effluent inorganic and organic constituents to meet water quality target concentrations (their Table 2.3 in Chapter 2). Required median dilutions were less than 300x for all constituents rated except for polychlorinated biphenyls (PCBs), which, as stated above, required 3 684 dilutions based on a receiving environment target concentration of 0.02 µg/l. This, however, is an artefact as measured concentrations were below the limit of detection (Dr B Newman, CSIR pers comm). The estimated required dilutions and the PRDW (2020) modelling estimated 5th percentile dilution rates at the allowable ZID boundary indicate that toxicity risks from effluent constituents look to be limited.

The CLS SA water quality surveys included drawing sea surface water samples for acute toxicity testing at sites within and immediately outside of the discharge allowable ZID boundary (Figure 2.11). Samples were obtained at intervals over each of the multi-week survey periods. Eighty-three samples were used in the toxicity bioassays, with none showing signs of toxicity.

The CLS SA surveys included chronic toxicity testing through *in situ* exposures of mussels in and outside of probable effluent plumes for identifying differential effects on growth rates and trace metal body burdens. The results have been reported in Sedick et al. (2021). Mussel growth rates varied seasonally, being lower in the summer/autumn periods than in the winter/spring period. This was attributed to lower water temperatures from summer upwelling and energy allocation to spawning as opposed to growth. Growth rates in the deployed mussels in the nearfield of the outfall were marginally higher than those deployed in far field control sites. This was attributed to higher concentrations of particulate organics in the effluent plume than outside of it.

Trace metal accumulation varied seasonally with the observed loss of nickel and zinc, i.e., reduced body burdens, higher in winter/spring than in the summer/autumn period. The authors note that this may be an artefact of the delays in mussel moorings recovery due to issues related to COVID and the occurrence of a spawning event. Mussels did increase body burdens of copper, but this happened in both impact and control mooring locations and thus cannot be confidently linked to the effluent discharge. Copper content remained below food quality guidelines and did not exceed body burdens reported in the international literature for 'unimpacted' sites.

Toxicity effects of pharmaceutical compounds on marine organisms have been demonstrated (Fabbri and Franzellitti 2016), as has their presence in mussels and fish locally (Petrik et al. 2017). Direct toxicity has been shown in microalgae at the mg/l concentration level and sea urchin (*Paracentrodus lividus*) embryo-larval development at the nanogram/l level (Fabbri and Franzellitti 2016), so local effects may be occurring in organisms of similar or higher sensitivity. However, this has not been evident in the toxicity tests conducted in the receiving environment of the Hout Bay outfall.

The above, together with the similarity in acute toxicity test results obtained by CSIR (2017) and the CLS SA survey, reinforce the conclusion that toxicity risks in the effluent receiving environment are low at the acute level for organisms of equal or lower sensitivity than sea urchin gametes and at the chronic level for analogues of mussels. Toxicity risks posed by CECs are yet to be quantified to a reliable extent.

7.2 Contaminant body burdens in mussels and rock lobster

Comparisons of trace metal body burdens in mussels collected on the open coast inshore of the Hout Bay outfall in 2015/2016 with those from western seaboard sites distant from the outfall did not show influences of the discharged effluent, a pattern that has apparently been stable over time (figures 6.4 & 6.6 in CSIR 2017). Polycyclic aromatic hydrocarbon concentrations in mussels were high at 6.22 µg/kg (wet weight) compared to 0.042-1.21 µg/kg recorded at other Cape Peninsula locations. CSIR (2017) attribute this to contamination from a local source as levels in mussels collected from the nearby Hout Bay harbour were 15.58 µg/kg. These would have been exposed to fuel and lubricants spilled from local vessels. The body burdens of polychlorinated biphenyls, display mostly similar trends to trace metal burdens (figure 6.11 in CSIR 2017). These data show that effluent from the Hout Bay outfall is not influencing contaminant body burdens in mussels to the degree that levels are different to other western seaboard sampling sites.

Rock lobster are major predators of mussels in the Benguela Current and elsewhere in the oceans and are thus a pathway from possibly contaminated mussels to humans. Comparisons of trace metal body burdens in mussels and rock lobster collected at Hout Bay (figure 6.4, sites M6 vs C6 in CSIR 2017) show no clear link with the effluent discharged through the outfall. Further, hazard coefficients based on trace metal, polycyclic aromatic hydrocarbon and polychlorinated biphenyl concentrations in local rock lobster indicate that systemic health risks from consuming rock lobster are extremely low and require an inordinate level of rock lobster consumption to be realised.

7.3 Eutrophication

Eutrophication of coastal water bodies from receiving excess inorganic nutrients from coastal watersheds and effluent discharges is a common phenomenon with some major systems being affected, including Chesapeake Bay, the Baltic Sea, northern Gulf of Mexico, East China Sea, amongst others (e.g., Malone and Newton, 2020). The nutrient enrichments lead to accelerated phytoplankton growth, their subsequent senescence and deposition to the seabed where organic matter remineralisation depletes dissolved oxygen concentrations. This can result in anoxic conditions with major deleterious ecological effects. Rock lobster 'walkouts' in Elands Bay is an extreme consequence of the development of anoxic conditions. On average, the three western seaboard ocean outfalls (Green Point, Camps Bay, and Hout Bay) discharge 2.62 x 10^{10} milliMoles (mM) of ammonia-nitrogen to the sea per year (estimated from data in CSIR, 2017 and PRDW 2020). The Hout Bay outfall discharges 21% of this at 5.53 x 10^{9} mM N which can fuel phytoplankton production in the region and contribute particulate organic loading to organic matter remineralisation processes on the seabed with linked oxygen demand.

Upwelling in the region is the major source of inorganic nutrient supply to the euphotic zone. The Atlantic seaboard outfalls lie in the Cape Point upwelling cell, the southernmost of the major upwelling nodes on the west coast (e.g., Flynn et al. 2019). Nitrogen supply to the euphotic zone in upwelling events is estimated to range between 0.66 x 10^{13} and 1.51 x 10^{13} mM N with a mean across 10 upwelling events in the period 1984-1994 of 1.07 x 10^{13} mM N (Waldron et al. 1997). There are approximately 19 upwelling events of varying intensities and durations per year in the Southern Benguela Current region (Waldron and Probyn 1992) which may therefore inject 2.0 x 10^{14} mM N to the euphotic zone. This is 5-orders of magnitude greater than the estimated nitrogen supply from the Hout Bay outfall which is thus a very minor proportion of the overall nitrogen supply underpinning phytoplankton production in the region.

Despite upwelling supplying nutrients to the Cape Point cell euphotic zone accumulation and remineralisation of particulate organic matter on the underlying seabed is low as shown by low apparent oxygen utilisation (AOU) and associated limited increases in on-shelf nutrient concentrations (Flynn et al. 2019).

From the above it is concluded that contributions of discharged effluent ammonia nitrogen to regional eutrophication is at most minuscule and that, in the vicinity of the Hout Bay outfall, metocean conditions and seabed topography limit its development and consequences.

8 Effects on Sediment Properties

Sediment textures in Hout Bay outside of the harbour are predominantly sand and sand-gravel mix with mud being all but absent (CSIR 2017). This is attributable to strong currents, as predicted by modelling (e.g., Figure 5.4) preventing deposition of fine particles. As a result of this organic content of the Hout Bay sediments is typically low (<1% by weight).

Consistent with the low organic content and mud fraction in the sediments historical surveys summarised in CSIR (2017) and their surveys conducted in 2015/2016 indicate marginal enrichment factors (<1.5) above indicative baselines. The 2015/2016 surveys also show low concentrations of total petroleum hydrocarbons, total recoverable hydrocarbons, and polycyclic aromatic hydrocarbons outside of the harbour area. Polychlorinated biphenyls, if present, were below the detection limit throughout Hout Bay.

A range of metrics designed to determine toxicity risks to benthic fauna were analysed by CSIR (2017) allowing the conclusion that the detected contaminants were unlikely to present such risks. Their review of previous sampling campaigns in 2005/2006 and 2010/2011 show that this was true in these periods as well. The data indicate that there is no or minimal long-term build-up of contaminant concentrations in the sediments and linked increases in toxicity risks attributable to the Camps Bay outfall.

9 Effects on Biodiversity

No recent biodiversity surveys in the Hout Bay area can be used to track effects or not of the offshore discharge. There are other disturbances in Hout Bay linked to harbour operations, fish processing, river flows and stormwater discharges that would complicate and possibly confound efforts to demonstrate deleterious influences from the offshore discharge. Kelp forests occur in the rocky subtidal and impacts on the kelp bed community were not demonstrated at the Camps Bay outfall (CLS SA 2022b). Effects on sand seafloor benthic macrofauna at this site were also limited (CLS SA 2022c). However, it is not safe to extract these findings and apply them to the Hout Bay situation as there are likely to be differences in seabed sediment and reef distributions and areas impinged on by the discharge effluent plume. Hence, the biodiversity effects of the discharge are currently unknown.

10 Conclusions

This report summarises surveys on the Hout Bay outfall receiving environment and hydrodynamic modelling of discharge plume behaviour conducted by the CCT in the recent past along with pertinent supporting information from the scientific literature. The focus of the summary is on evidence of environmental quality impairment defined by discharged effluent toxicity and compliance/non-compliance with established environmental quality guidelines relating to biodiversity and human health risks. The following conclusions, specific to the Hout Bay outfall current and recent past effluent properties and discharge rates, are drawn from the measurement and modelling programmes:

- The discharged effluent is largely compliant with typical permission conditions and meets General Standard concentration limits for trace metals, polychlorinated biphenyls (PCBs), phenols, pesticides (Dieldrin, Endrin, DDT) and nitrate and nitrite nitrogen. Markedly non-compliant constituents are TSS, COD and ammonia nitrogen and aluminium.
- Mass balance and hydrodynamic modelling predict effluent dilution within the ZID is sufficient to reach compliance with environmental water quality guidelines, except for TSS, and negate effluent toxicity. The hydrodynamic modelling indicates that TSS would be compliant within 200 m of the ZID boundary.
- Hydrodynamic modelling predicts that dilutions within the ZID are not totally sufficient to negate the human health risk of the effluent plume as, although 90th percentile near surface and seabed enterococci counts at the surface and near seabed will be compliant with the DEA (2012) sufficient guideline of 185 cfu/100 ml, mid-depth concentrations will exceed this. Non-compliance may extend for distances of 400 m east and west of the ZID boundary. In a few short-term event scale events enterococci concentrations above 185 cfu/100 ml may occur at the Dungeons surf site, however, due to the short term the guideline itself should not be compromised. Consequently, despite water quality guidelines not being exceeded outside of the ZID, except at mid-depth, the predicted human health risks, although low, are not zero.
- Measured enterococci counts in the receiving environment confirm the modelling results in that, in the surface and bottom samples, they are within the guideline limits at the ZID boundary. Dissimilar to the modelling this is also the case at mid-depth, but the measured data do show elevated counts here.

- Measured enterococci counts at screens of stations shoreward of the outfall classify as sufficient in terms of water quality. Highest counts and degree of non-compliance were recorded in the beach swash zone with the measured peak count of 20 000 cfu/100 ml. This is a health risk. Distributional data imply a local source of pollution for this.
- CECs are present in the effluent discharged through the outfall and are expected to be in the receiving environment. Toxicity effects of these compounds are not well known which represents an unconstrained risk to marine organisms.
- As borne out by toxicity testing high dilutions achieved within the ZID limit toxicity at both acute and chronic levels. This dilution also limits bioaccumulation of trace metal and organic compounds, in terms of body burdens, in mussels and rock lobster and there is no evidence of a link with the effluent discharged through the Hout Bay outfall.
- The inorganic nutrients discharged through the outfall, primarily ammonia nitrogen, comprise a very small fraction of upwelling supplied inorganic nitrogen and its contribution to local and/or regional eutrophication is miniscule.
- Sediment texture in the Hout Bay outfall receiving environment is sand and gravelly sand. Proportions of mud fractions are low as is the organic content of the sediments. Trace metal and organic contaminants have typically low concentrations. Multi-decadal survey data shows that there is no or minimal long-term build-up of inorganic or organic contaminant concentrations in sediments and linked increases in toxicity risks attributable to the Hout Bay outfall.
- There are no recent biodiversity surveys on the effects of the outfall or in Hout Bay itself. The former at least should be rectified even though limited surveys at the Camps Bay outfall indicate effects of the outfall should be of limited intensity or extent.

The overall conclusion from the suite of surveys conducted by CCT and the somewhat sparse supporting information from independent studies is that the Hout Bay outfall is mostly meeting its design objectives in reducing potential deleterious ecological and/or human health effects of discharged effluent by taking advantage of increased effluent dilution offered by deep water. It has not fully achieved a reduction in effluent plume visibility to the point of it not being a public concern. This can be countered by higher effluent treatment levels being applied prior to discharge. CECs are also a concern, mainly due to their largely unknown toxicity effects on marine organisms.

11 Recommendations

Recommendations are grouped into initiatives resolving uncertainties arising from this synthesis and receiving environment monitoring. Ensuring dissemination of monitoring information to Cape Town citizens is not addressed but is a critically important issue.

11.1 Uncertainties

11.1.1 Actual human health risk

The enterococci count data analysed indicate a non-zero risk of effects on human health according to recreational water quality guidelines. To determine whether faecal material related illnesses are occurring in recreational users of the nearshore environments around the Hout Bay outfall requires epidemiological data. The CCT should attempt to gather such data through its various health departments as an adjunct to the environmental monitoring activities.

11.1.2 Effluent toxicity

Effluent toxicity testing and toxicity tests conducted in the effluent receiving environment were based on fertilisation success rates in sea urchin embryos. These are commonly used for these purposes (e.g., Sydney Water 2010). The acquired data on pharmaceutical compounds (CECs) indicate that the toxicity testing should be extended to microalgae as the Haptophyte *Isochrysis galbana* has demonstrated growth inhibition at the mg/l concentration level (Fabbri and Franzellitti 2016). Such levels are not expected in the receiving environment but due to the centrality of phytoplankton in marine food chains toxicity to this taxonomic group needs to be examined in whole effluent toxicity testing. Information from such tests needs to be incorporated in MATD estimates.

11.1.3 Total suspended solids compliance

Total suspended solids (TSS) concentrations were predicted to be non-compliant with the applied water quality guideline concentration (+ 10% above background concentrations; DWAF 1995) in the receiving environment outside of the ZID. This guideline is weakly based and very difficult to apply as, amongst other issues, sufficient background data is lacking. Further, marine organisms are tolerant to elevations in TSS as species sensitivity distributions (SSD) indicate that concentrations up to 500 mg/l will still be protective of ~70% of the taxa tested (Smit et al. 2008). These include zooplankton, molluscs, crustacea, fish and algae.

TSS also affects the underwater light field, and a subsidiary water guideline is that concentrations should not reduce the euphotic depth by >10%. This also requires comparisons against background data that are not available. Further, on any one day or measurement cycle other factors may complicate making such estimates such as variable cloud cover, sea surface roughness also affect euphotic depth. Controlling for such factors in field measurements is well-nigh impossible. The ecological relevance of minor changes in euphotic depth is moot as micro- and macroalgae can modify internal chlorophyll-a concentrations as well as accessory pigments in response.

A more scientifically robust and ecologically relevant guideline is the SSD estimated 5% hazard coefficient (HC_5) concentration of 17.9 mg/l, based on acute toxicity responses in marine taxa to barite exposures (Smit et al 2008). This absolute value is predicted to be protective of 95% of species exposed to the effluent plume. The recommendation is that this be used as the receiving environment permissible threshold and that the non-compliance of TSS be re-evaluated.

11.1.4 Actual discharge plume dimensions

The congruence between field measurements and modelling predicted plume behaviour is limited to observations at the allowable ZID boundary and across the water column. These do not reveal the geographic extent of the plume nor gradients in apparent dilution with distance from the discharge. As it is possible that the actual ZID is smaller than the calculated allowable ZID, it would help in understanding scales of effects to resolve this. This can be done by, e.g., particle backscatter estimates by a high frequency ADCP on a series of synoptic scale surveys on closely spaced transects across the modelling determined long axis of the effluent plume. Information from this can strengthen the applied model and add confidence to its application.

11.2 Receiving environment monitoring

Aspects requiring monitoring are:

- Compliance with water quality guidelines and responses,
- Effects or not on resident biota,
- Zone of influence of the discharged plume, and
- Areas of human health risk from the discharge.

Approaches for these are outlined below. Details should be developed in the individual action plans.

11.2.1 Compliance with water quality guidelines and responses

The effluent constituents that may generate compliance risks in terms of water quality are TSS, ammonia and faecal indicator bacteria. The latter are typically *E. coli* and enterococci. Following World Bank advice (in DEA 2012) the latter should be the focus.

Measurements in the receiving environment need to be conducted in the near field water column (encompassing the prescribed allowable ZID) and into the far field (~3 000 m distant from diffuser banks). Near field measurements will be aimed at determining compliance with South African water quality guidelines, far field measurements will be used to determine constituent ‘background’ concentrations. The sample grid should be a ‘cross’ design with the longest arms aligned with the main axis of the effluent plume, as defined by modelling. This is mainly shore parallel. It is important that sampling is conducted as close as possible to the diffuser banks to enable estimates of relative achieved dilutions at ZID boundary stations. Estimates of achieved absolute dilutions will be enabled by concurrent measurements of effluent constituents. Measurements should include:

- Water quality profiling of temperature, conductivity (salinity), pH, turbidity, PAR, chlorophyll a (as an explanatory variable for PAR attenuation), dissolved oxygen from sea surface to near seabed,
- Water sampling at 5 m depth intervals through the water column for TSS, dissolved inorganic nitrogen (DIN, comprising ammonia, nitrates and nitrite), orthophosphate and enterococci, and
- Euphotic zone depth estimates by Secchi disk. These will complement PAR profiling.

Surveys should be conducted annually in summer to align with most recreational use of the coastal marine environment.

11.2.2 Effects on resident biota

The Hout Bay effluent pipeline traverses and lies on a mainly sand seabed enabling use of benthic infauna community structure as a metric for assessing the scales of effects of the effluent on resident biota. The survey should be based on a gradient design, with sample replication, on orthogonal lines aligned with the modelled main axis of the effluent plume and normal to this. Sample spacing should be semi-logarithmic starting adjacent to the diffuser bank and then at 100 m, 200 m, 400 m, 800 m etc. distances to 3 200 m. Coupled with these should be two control sites with three sample locations each located in similar depth ranges but outside of the modelled effluent plume footprint. Three sample replicates need to be taken at each location. Sampled sediments need to be analysed for particle size distributions, organic content and organic matter ^{15}N and ^{13}C isotopes. The latter are to be assessed as indicators of effluent derived organic matter. Standard sampling and subsampling procedures need to be implemented with benthos being extracted from grab sediment samples by sieving through a 1 mm mesh. This mesh size has been used extensively in local benthos surveys allowing comparisons with data from these.

Kelp beds are distributed around the rock platforms near the Dungeons surf site. Strong wave action here will limit local deposition of particulate organics and effects from this such as inundation and results of organic enrichment, e.g., reductions in dissolved oxygen concentrations, are not expected. Further, the nearshore of the Atlantic seaboard, in general, has been exposed to domestic effluent and stormwater flows for at least decades and the effects, if any, of such will have modified the local kelp bed community already. Therefore, conducting a multiple BACI survey design is likely to be a) difficult and b) subject to confounding issues. Previous experience at the Camps Bay outfall has demonstrated this. Consequently, possible effects on resident biota should be extrapolated from toxicity testing using sea urchin fertilisation success and microalgae growth as metrics. These surveys can be conducted at three-year intervals.

11.2.3 Discharge effluent zone of influence

The effluent zone of influence can be scaled according to TSS distributions, the deposition footprint (available in the PRDW (2020) modelling results) and isotopic ratios ($\delta^{15}N$, $\delta^{13}C$) and anomalies therein on the benthos sampling grid. This approach has been applied in tracking effluent effects in Table Bay (Dr P Monteiro, CSIR, pers. comm). This survey need only be done once.

11.2.4 Areas of human health risk

The area of human health risk due to direct contact through water-based recreation is defined by the modelled surface layer distribution of enterococci counts ≥ 185 cfu/100 ml. There are various nodes of such recreation in the nearshore of the coastline adjacent to the Hout Bay outfall and in the predicted effluent plume trajectories. Given that the PRDW (2020) modelling has been verified to an extent by the measurement data reviewed here and that this will be strengthened with routine water quality guideline compliance monitoring (above) it should be applied to predict human health risks at these nodes. This will be an advisory service to the CCT and can be protective of the recreational users.

For this to be efficient risks of faecal contamination emanating from other sources such as stormwater flows will need to be incorporated. When done successfully the model will constitute a valuable tool in avoiding/constraining human health risks for the city.

12 References

Anchor 2016. Assessment framework for the management of effluent from and based sources discharged to the marine environment. Prepared for Department of Environmental Affairs, South Africa.

Blackwell B., Gemmill J. 2019. Coastal Outfall System Upgrades in Australia: Benefits, Costs, and Improved Transparency - Final Report, 4 March 2019 Clean Ocean Foundation, Wonthaggi, Victoria, 71 pp.

CLS SA 2020. City of Cape Town marine outfalls seawater quality monitoring: Annual Report 01. Report reference: LT 839 Annual SPR 01 V2.0, December 2020. 380 pp,

CLS SA 2021. City of Cape Town marine outfalls seawater quality monitoring: Annual Report 02. Report reference: LT 839 Annual SPR 02. 132 pp.

CLS SA 2022a. CLS SA 2021. City of Cape Town marine outfalls seawater quality monitoring: Annual Report 03. Report reference: LT 839 Annual SPR 03. 89 pp.

CLS SA 2022b. Marine biodiversity assessment: Camps Bay outfall. Report reference: CLS SA-21-51.BEN-SPR CB. V1.0 – 24/05/2022. 23pp.

CLS SA 2022c. Benthic assessment: Camps Bay outfall. Report reference: CLS SA-21-51.BIO-SPR CB. V1.0 – 20/05/2022. 23pp.

CSIR 2017. Cape Town Outfalls Monitoring Programme: Surveys made in 2015/2016. CSIR Report CSIR/NRE/ECOS/IR/2017/0035/B.

CSIR 2022 Preliminary assessment of pharmaceutical compounds in Cape Town coastal waters. CSIR Report CSIR/SPLA/EM/ER/2022/000X/C.

DEA 2012. South African water quality guidelines for coastal marine waters. Volume 2: Guidelines for recreational use (summary). Department of Environmental Affairs, Republic of South Africa. 12pp.

DWAF 1995. South African water quality guidelines for coastal marine waters. Volume 1: Natural environment. 332 pp.

Fabbri E. and Franzellitti S. 2016. Human pharmaceuticals in the marine environment: focus on exposure and biological effects in animal species. Environmental Toxicology and Chemistry 35: 799-812.

Flynn R. F., Granger J., Veitch J. A., Siedlecki S., Burger J. M., Pillay K., & Fawcett S. E. 2020. On-shelf nutrient trapping enhances the fertility of the southern Benguela upwelling system. Journal of Geophysical Research: Oceans, 125, e2019JC015948. https://doi.org/10.1029/2019JC015948.

Malone T. C. and Newton A. 2020. The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. Front. Mar. Sci. 7:670. doi: 10.3389/fmars.2020.00670

Metro Vancouver Liquid Waste Services Environmental Management and Quality Control 2019. The 2018 Greater Vancouver Sewerage and Drainage District Environmental Management and Quality Control Annual Report. Burnaby, BC: Metro Vancouver.

Ortiz J., Braulio N., and Pedrera Yanes, J. 2016. Wastewater Marine Disposal through Outfalls on the coast of São Paulo State Brazil: An overview. Revista DAE. 64. 29-46. 10.4322/dae.2016.015.

Petrik L., Green L., Abegunde A. P., Zackon M., Sanusi C.Y. and Barnes J. 2017. Desalination and seawater quality at Green Point, Cape Town: A study on the effects of marine sewage outfalls. South African Journal of Science, 113(11-12), 10pp

Pinto B., Pierotti R., Canale, G. and Reali D. 1999. Characterization of ‘faecal streptococci’ as indicators of faecal pollution and distribution in the environment. Letters in Applied Microbiology, 29: 258-263.

PRDW 2020. Sampling and analysis of the City of Cape Town's marine outfalls at Green Point, Camps Bay and Hout Bay. Final report on dispersion model calibration and results for Camps Bay. PRDW report S2101-RP-CE-008-R0. 86pp.

Sedick S., Hutchings K., and Clark B.M. 2021. City of Cape Town, Effluent Pipelines Biomonitoring, Annual Report no. 1865/4 prepared by Anchor Research & Monitoring (Pty) Ltd. 36pp.

Smit M. G., Holthaus K.I., Trannum H.C., Neff J.M., Kjeilen-Eilertsen G., Jak R.G., Singsaas I., Huijbregts M.A., Hendriks A.J. 2008. Species sensitivity distributions for suspended clays, sediment burial, and grain size change in the marine environment. Environ Toxicol Chem.; 27(4):1006-12. doi: 10.1897/07-339.1. PMID: 18333685.

Sydney Water 2010. Sewage treatment impact monitoring program. Report version: 2010 December update. 85pp.

Vidal-Dorsch D. E., Bay S.M., Maruya K., Snyder S.A., Trentholm R. A., and Vanderford B. J. 2012. Contaminants of emerging concern in municipal wastewater effluents and marine receiving water. Environmental Toxicology and Chemistry 31(12): 2674-2682.

Waldron H. N. and Probyn T. A. 1992. Nitrate supply and potential production in the Benguela upwelling system. In Benguela Trophic Functioning. Payne, A. I. L., Brink, K. H., Mann, K. H. and R. Hilborn (Eds). South African Journal of Marine Science, 12: 29–39.

Waldron H. N., Probyn T. A. and Brundrit G. A. 1997. Preliminary annual estimates of regional nitrate supply in the southern Benguela using coastal sea level fluctuations as a proxy for upwelling. South African Journal of Marine Science, 18: 93-105.

Water Corporation 2019. Perth long term ocean outlet monitoring program (PLOOM): 2018-2019 Annual Report. Report Number R-1120_05-1/Rev0.

Zandaryaa S. and Frank-Kamenetsky D. 2021. A source-to-sea approach to emerging pollutants in freshwater and oceans: pharmaceuticals in the Baltic Sea region. Water International 46(2), 195-210.