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

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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. Effluent 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, despite application of higher effluent treatment levels prior to discharge, 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 have 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 (CECs) in shallow subtidal waters around the CCT coastline (CSIR 2022; Addendum 6), and
- Reconnaissance scale biodiversity surveys of reef and sandy seabed biota at the Camps Bay outfall (CLS SA 2022b, 2022c; Addendum 7 & 8).

This report summarises information obtained in the above studies relevant to the Camps Bay outfall with supporting information from scientific literature. Companion syntheses have been compiled for the Green Point and Hout 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 syntheses are focused on this, and linked impairments in water quality, as defined by toxicity and non-compliance with published water quality guidelines, that may compromise biodiversity and/or human health.

2 Description of Camps 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 Camps Bay outfall was commissioned in 1977 and extends seawards in a north-westerly direction to approximately 1.4 km from Camps Bay beach. It discharges effluent 600 m to the west of Maidens Cove and 800 m to the south-west of Clifton (Figure 2.1). The outfall terminates in 8 diffusers located in 23 m water depth. The design effluent discharge capacity is 5.0 Ml/day, but actual rates can be less than half of this with flow measurements indicating 1.96 Ml/day in the winter/spring and 1.68 Ml/day in the summer/autumn period (PRDW 2021).

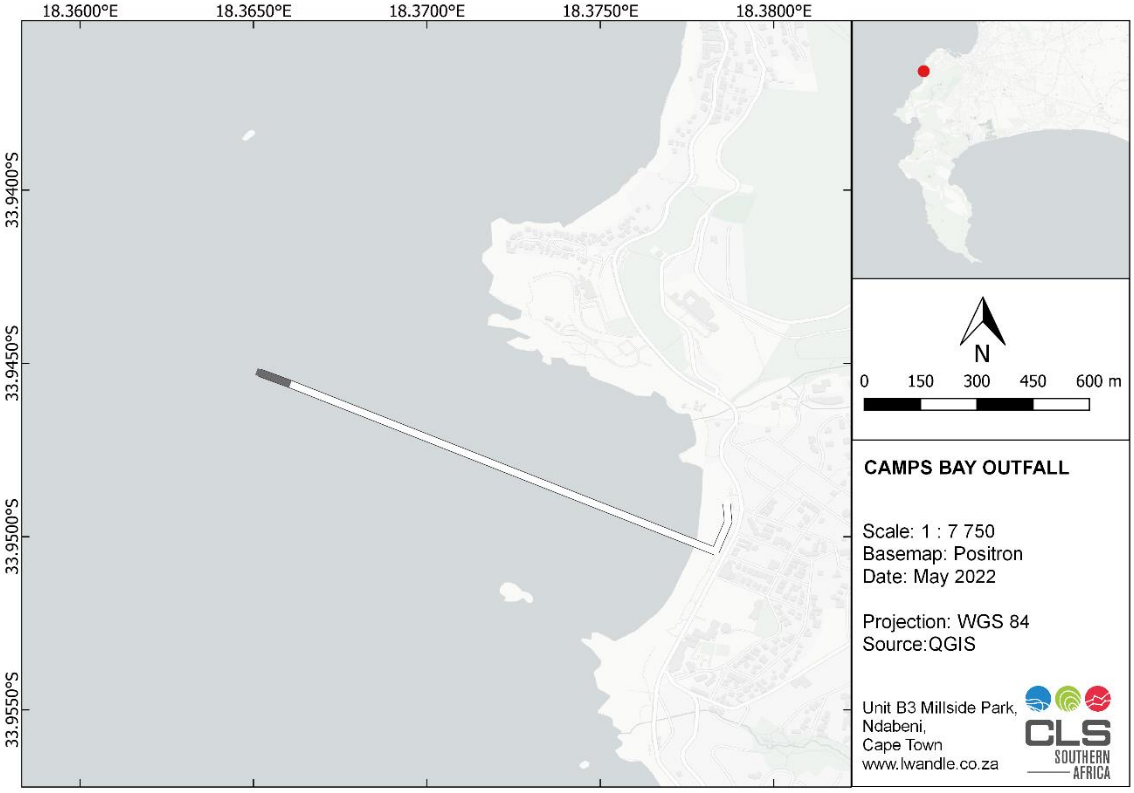

Figure 2.1: Map of the Camps Bay outfall. The grey section of the outfall indicates the location of the eight diffusers.

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 Camps Bay effluent was fully compliant with generally specified limits on pH and orthophosphate, 78% compliant for TSS, 99% for COD, and 88% for total ammonia.

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 Camps Bay outfall. The pre-discharge effluent sampled in 2015 and 2016 was compliant for trace metals, polychlorinated biphenyls (PCBs). phenols, pesticides (Dieldrin, Endrin, DDT), nitrate, and nitrite nitrogen. The effluent was >90% compliant for pH, Kjeldahl nitrogen, orthophosphate, and iron but markedly noncompliant for TSS (1.4%), COD (5.7%), total ammonia nitrogen (0%) and aluminium (37%).

3 Estimates of Required Effluent Dilutions

CSIR (2017) used a mass balance modelling approach to estimate whether the Camps 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. CSIR (2017) notes that this is conservative compared to estimates of 300x and greater made by Toms and Botes (1986). The bulk 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. Exceptions for inorganics were TSS, with a median required dilution of 334x and maximum of 10 740x, and total ammonia nitrogen with a maximum required dilution of 260x. In the case of TSS, 78% of the effluent samples would require <500x dilutions, and for total ammonia nitrogen, 97% of samples <200x.

The radius of the allowable spatial extent of the ZID around the Camps Bay discharge pipe end diffuser bank specified by the CCT is 274 m (CCT *in litt.* 2022). This is based on guidance in Anchor (2016) and the Camps Bay outfall diffuser configuration. This differs from the 106 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 (2021) conducted simulation modelling of plume behaviour after discharge into the receiving environment off Camps 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 21/8/2019 to 3/10/2019) 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 were E. coli $1x10^7$ cfu/100 ml, enterococci $1.3x10^6$ cfu/100 ml, TSS 314 mg/l and 100 units for the tracer.

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

4.1 Predicted plume behaviour

The modelling showed complex behaviour in variable wind conditions in both seasonal periods. Examples taken from the summer/autumn period are north-westerly wind conditions forcing the effluent plume, as indicated by *E. coli* concentrations, shoreward at the surface but offshore at the seabed aligned with the differential current flows (Figure 4.1), and south-easterly winds doing the reverse, i.e., surface flows are offshore, carrying the plume with them while near seabed currents are shoreward, advecting the effluent plume into the nearshore (Figure 4.2). Examples from southerly wind conditions in the winter/spring period show the near-surface effluent being restricted to the southern part of Clifton Bay, with the near seabed plume being carried northwards offshore of Clifton Bay (Figure 4.3). In north-westerly winds, the surface plume is advected southwards whilst that near the seabed is advected offshore (Figure 4.4).

4.2 Predicted effluent plume dilutions and water quality 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 3 480x in winter/spring and 2 700x in summer/autumn. Plume cross sections (Figure 4.5, Figure 4.6) show that 5th percentile dilutions of <500x occur near the seabed, but in the upper water, column are >2 000x. These modelling results indicate that required dilutions for ammonia, COD and TSS should be achieved within the allowable ZID of the Camps Bay outfall. The predictions for ammonia and TSS align with those of CSIR (2017).

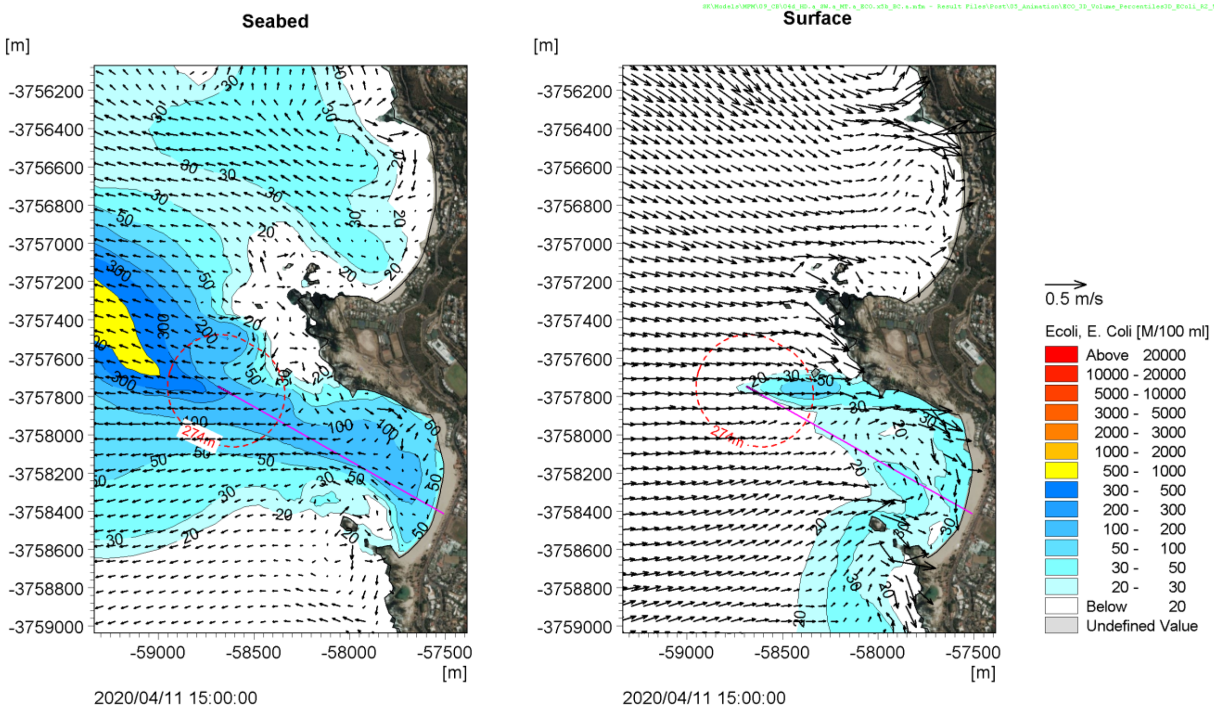


Figure 4.1: Summer/autumn: Current vectors and E. coli *plume at a moment in time during a north-westerly wind condition, from PRDW (2021).*

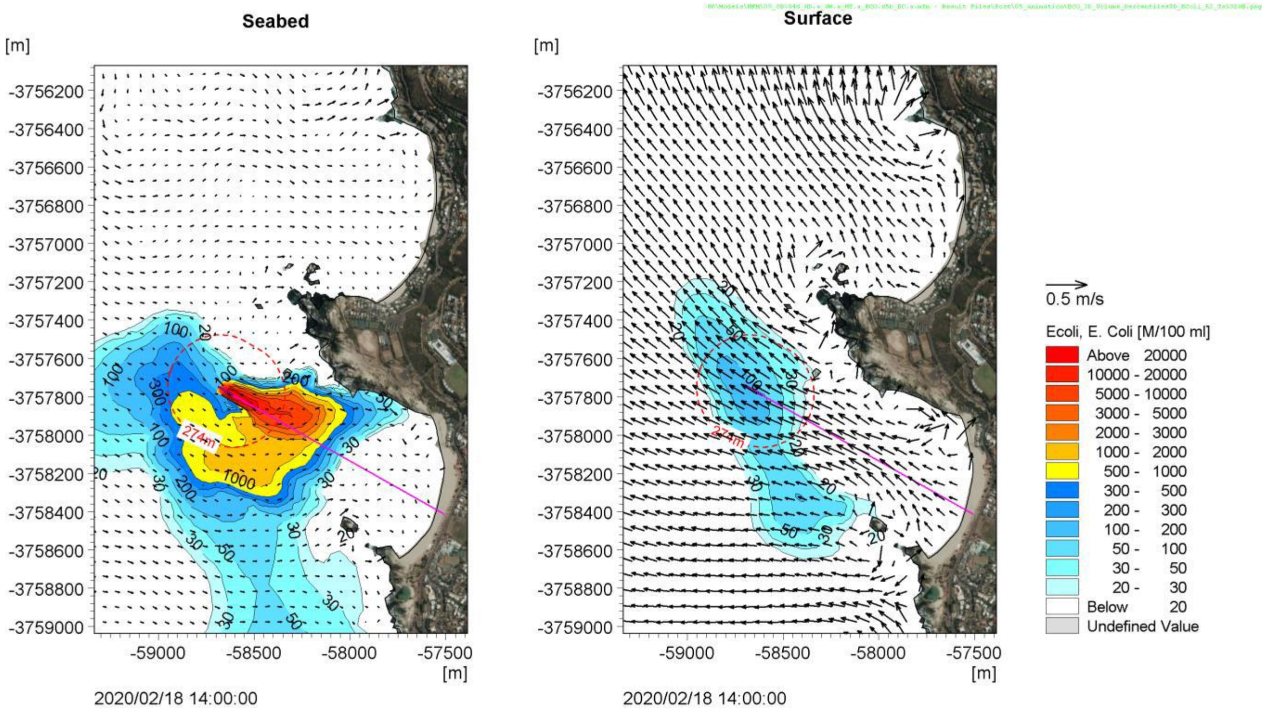


Figure 4.2: Summer/autumn: Current vectors and E. coli *plume at a moment in time during a south-easterly wind condition, from PRDW (2021).*

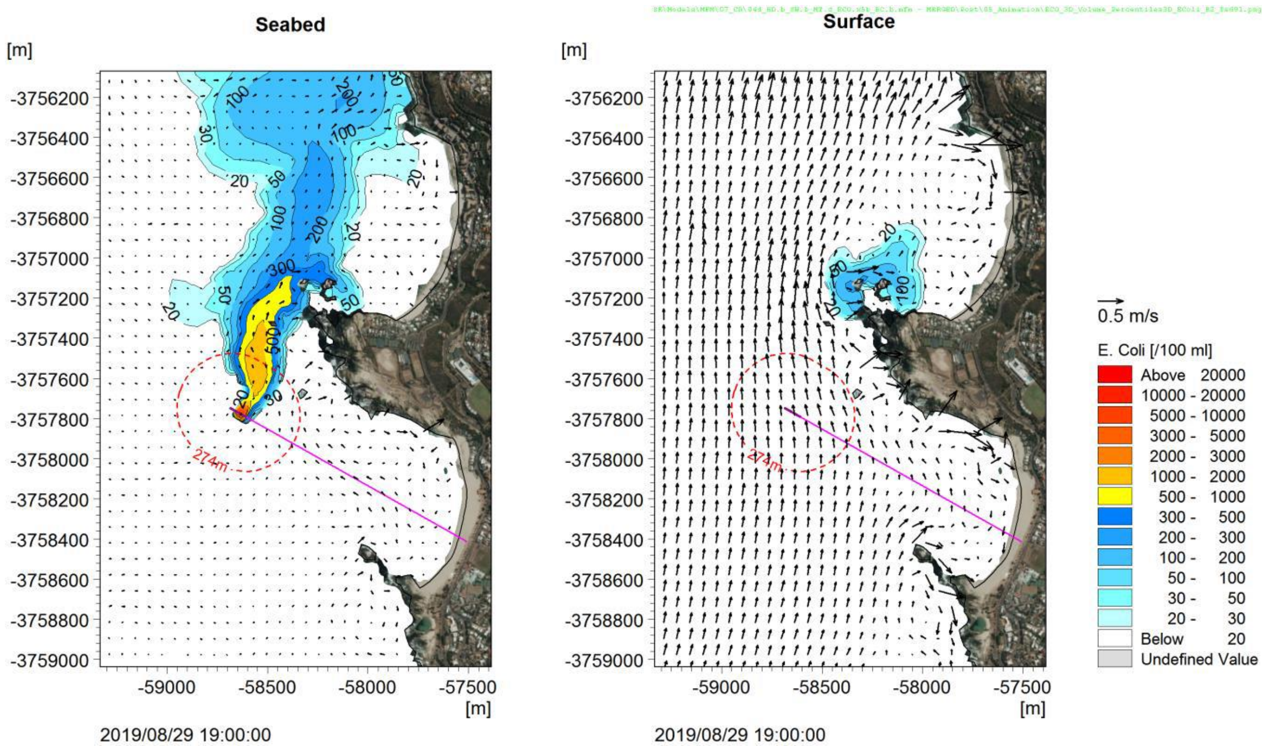


Figure 4.3: Winter/spring: Current vectors and E. coli *plume at a moment in time during a southerly wind condition, from PRDW (2021).*

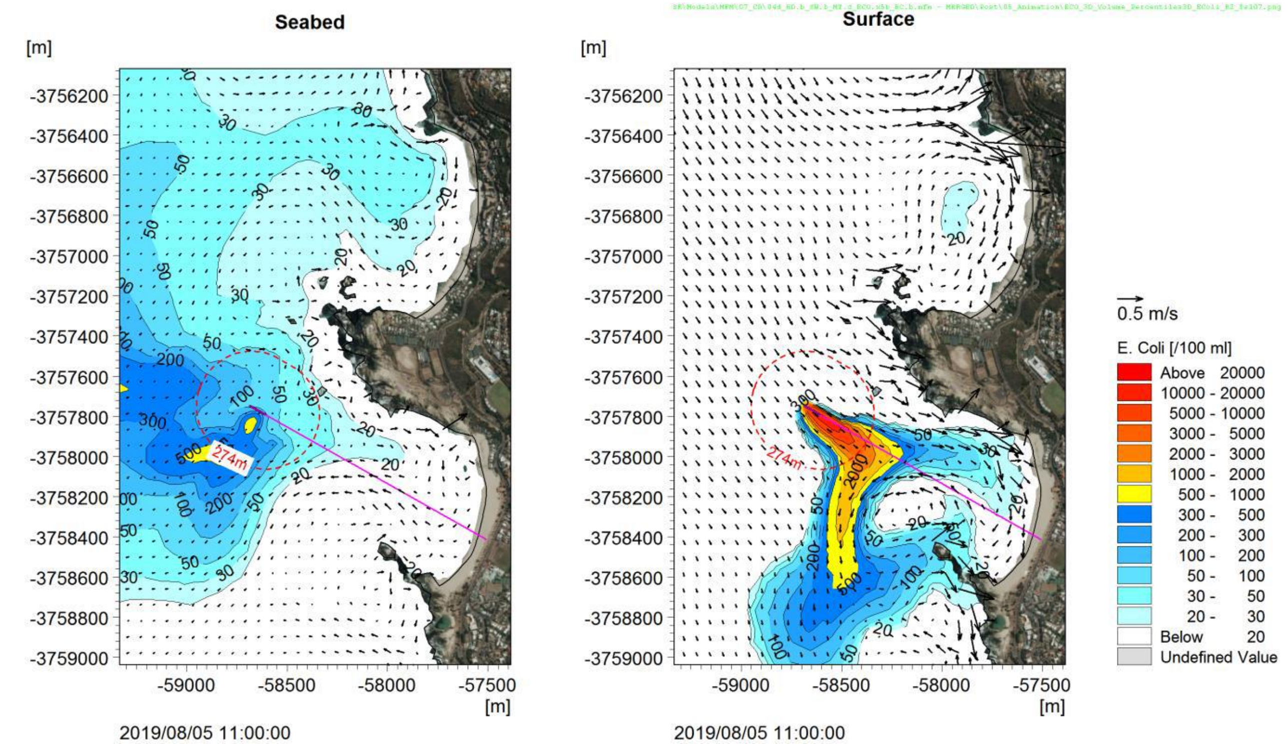


Figure 4.4: Winter/spring: Current vectors and E. coli *plume at a moment in time during a north-westerly wind condition, from PRDW (2021).*

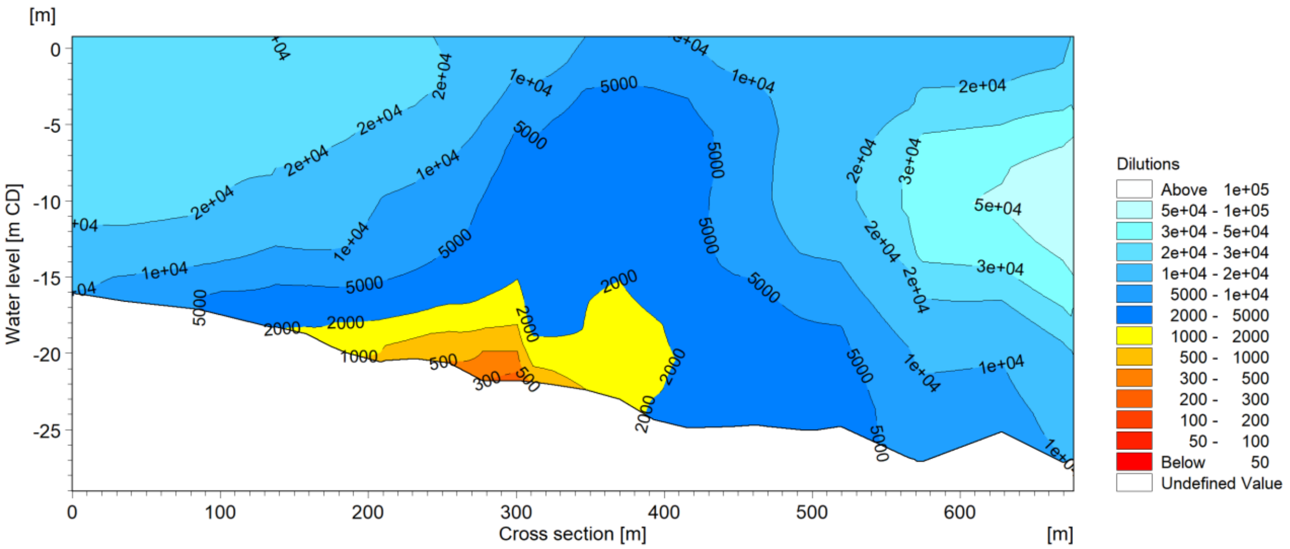


Figure 4.5: Winter/spring: Cross section of 5th percentile number of dilutions along the longest axis of the plume, from PRDW (2021).

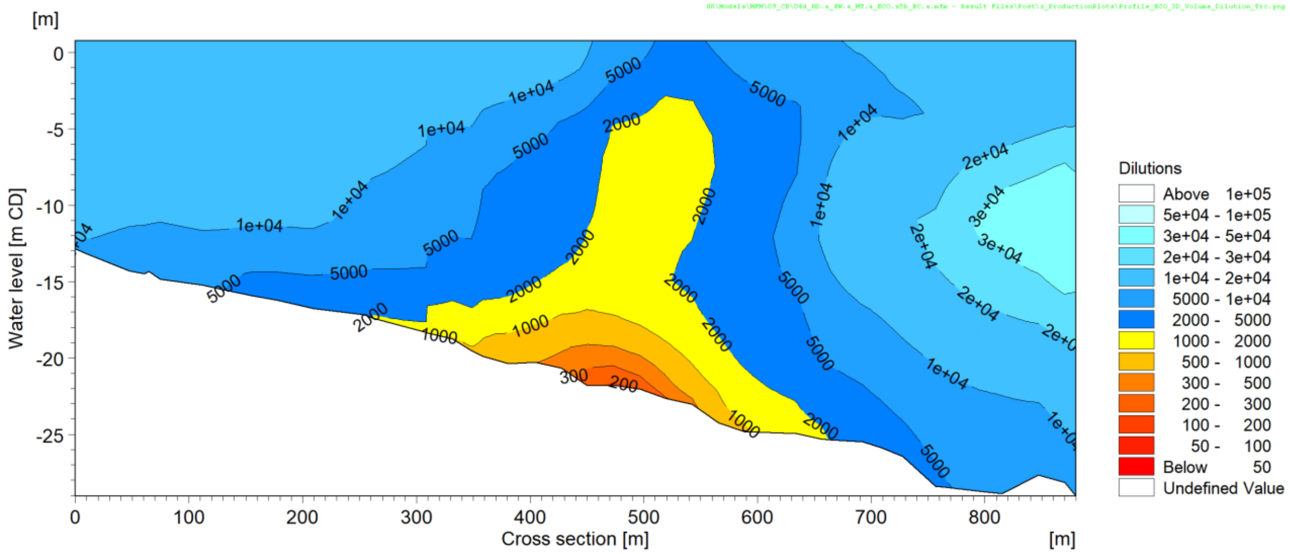


Figure 4.6: Summer/autumn: Cross section of 5th percentile number of dilutions along the longest axis of the plume, from PRDW (2021).

Predicted daylight hour distributions of the faecal indicator bacterium *Enterococcus* show that, for both modelled periods, surface, mid-depth and near seabed 90th percentile concentrations above the water quality guideline of 185 cfu/100 ml will be restricted to within the allowable ZID (PRDW 2021, figures 6.12 to 6.14 and 6.28 to 6.30). Time series data for nearshore locations at Camps Bay, Glen Beach, Maidens Cove and Clifton 4th and 1st beaches show that predicted maximum enterococci counts are below the guideline in the winter/spring modelled period (Figure 4.7), but in the summer/autumn period there were 16 and 3 short term events at Maiden's Cove and Glen Beach respectively where counts were predicted to be higher (Figure 4.8). Given that the overall duration of these predicted elevated counts is less than 10% of daylight time, the water quality guideline would not be exceeded.

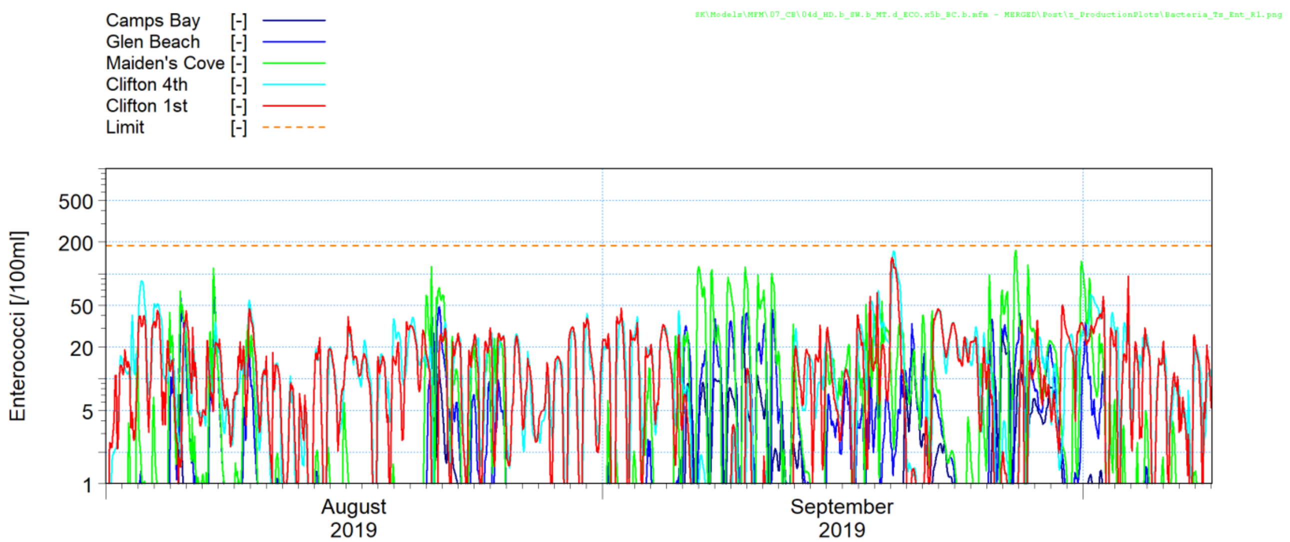


Figure 4.7: Winter/spring: Time series of highest enterococci concentration at any depth at five key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is also shown in orange (from PRDW 2021).

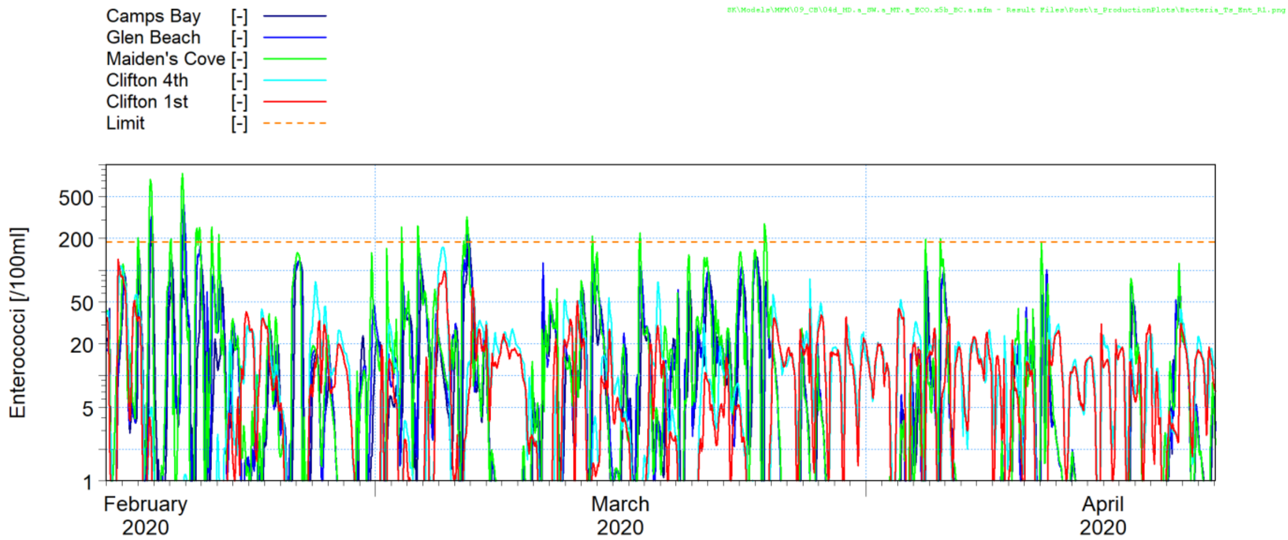


Figure 4.8: Summer/autumn: Time series of highest enterococci concentration at any depth at five key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is also shown in orange (from PRDW 2021).

4.3 Predicted suspended sediment transport and deposition

PRDW (2021) modelled the transport and deposition of suspended solids discharged from the Camps Bay outfall in the winter/spring and summer autumn periods. As shown in Table 4.1 released masses were similar in each period with >95% predicted to deposit offshore, 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. A higher proportion of the discharged mass was predicted to deposit offshore of the -40 m isobath in summer/autumn, while in winter/autumn, higher proportions would be transported out of the model domain or remain in the suspended mode. Less than 5% of the discharged mass was predicted to deposit in the Port of Cape Town. The port receives flows from stormwater drains and contaminants linked to shipping operations and is an environmentally stressed environment as commercial/industrial ports generally are. The contribution of the Camps Bay discharge to this is unknown as there is no complete inventory of discharges and their constituents into the port water body.

Table 4.1:Fate of total suspended solids at the end of 10-week modelling periods (data from PRDW 2021).

	Winter/Spring		Summer/Autumn	
Area	**Mass (kg)**	**% Released**	**Mass (kg)**	**% Released**
Port of Cape Town	1800	4.5%	1100	2.8%
Murray's Bay Harbour	1.09	0.0%	1	0.0%
Granger Bay	13	0.0%	11	0.0%
Hout Bay	0.19	0.0%	2.77	0.0%
Offshore (-40m depth)	2530	6.4%	9260	23.9%
Out of model domain	22100	55.7%	18000	46.4%
Suspended	13240	33.4%	10400	26.8%
Totals	**39684**	**100.0%**	**38775**	**100.0%**

4.4 Predicted acute toxicity MATDs

Predicted dilution rates for individual constituents within discharged domestic effluents do not capture the associated 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 Camps Bay effluent collected at two-month intervals over an eight-month period in 2016. The derived MATDs ranged between 60x and 248x. The predicted 5th percentile dilutions at the allowable ZID boundary (above) exceed these, indicating low overall toxicity risk to organisms of similar or lower sensitivity than sea urchin gametes from the discharge in the receiving environment outside of the ZID. The range is wider than those measured for the Green Point (52x-62x) and Hout Bay (29x-32x) outfalls and implies that there is higher variability in the Camps Bay effluent (CSIR 2017). The reasons for this are not clear.

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 *E. coli* and enterococci[3] in surface waters at offshore fixed station positions around the Camps 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 was based on three approximately shore parallel transects of stations, one offshore of the outfall, one running across the diffuser bank and another closer to the shoreline. This design could provide data on longshore plume behaviour and whether the discharge plume was reaching the nearshore. Sampling was restricted to the sea surface so no details on subsurface plume behaviour were 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.

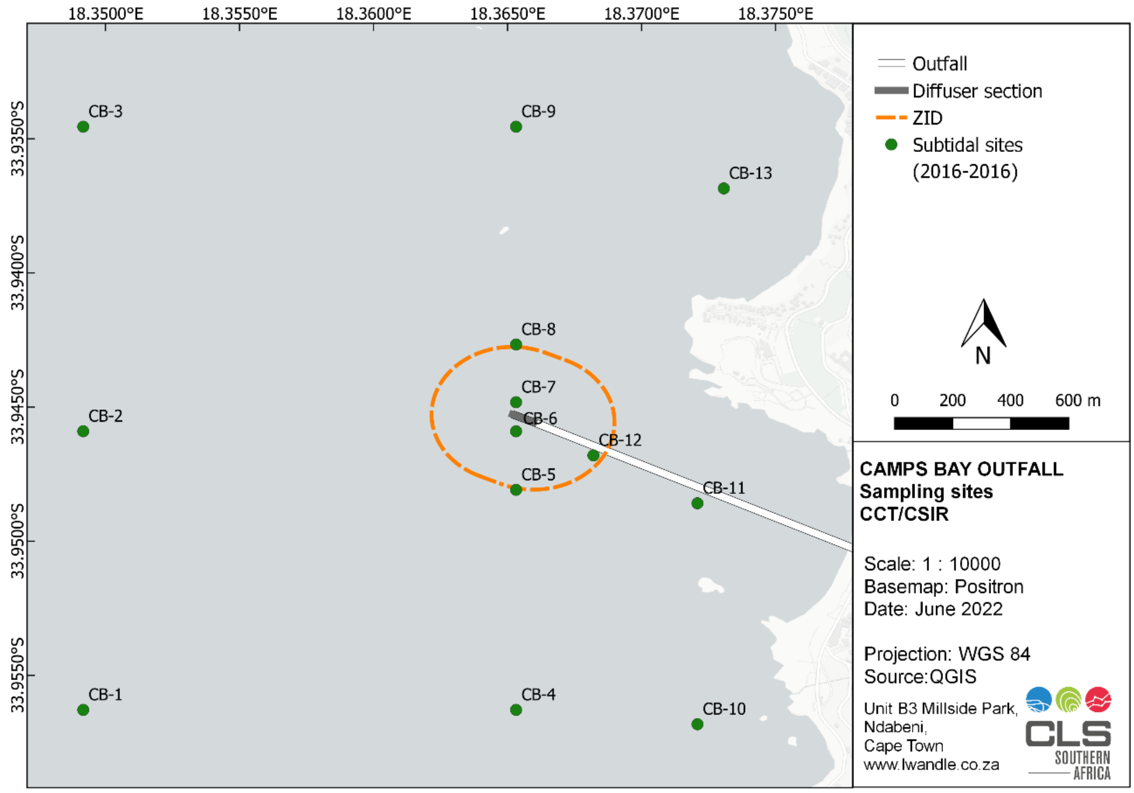


Figure 5.1: Water quality sampling points employed by the CCT for FIB distribution monitoring around the Camps Bay outfall over the period 2016-2018.

CSIR (2017) show monthly interval distribution plots for enterococci from sea surface samples collected in 2016 (their figures 4.16-4.27). In nine of the months, counts were below 100 cfu/100 ml but exceeded 500 cfu/100 ml at stations CB-8 in June, CB-6 in July and CB-7 in July and August. It is apparent from the spatial distributions that the high counts occurred at or close to the diffuser bank of the outfall, and they reduced with distance from this. This apparent rapid dilution is highlighted by CSIR (2017). Geographically, sample stations CB-6 and CB-7 are within the allowable ZID, while CB-5 and CB-8 are close to the ZID boundary. Table 5.1 lists the count data for the entire measurement period (2016-2018) and shows the 90th and 95th percentile values. The apparent rapid dilution is evident in these data and the percentile values. As expected, samples 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 these stations would be classified as excellent as the 95th percentile values are <100 cfu/100 ml (CB-5 = 55 cfu, CB-8 = 33 cfu).

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 full 3-year data set for stations CB-10, CB-11 and CB-13 (Figure 5.1) listed in Table 5.2 indicates 90th percentile counts well below the water quality guideline and that, according to the 95th percentile values, water quality on this screen of nearshore stations would be classified as excellent. No instances of enterococci counts >100 cfu/100 ml at these stations were recorded over the monitoring period.

The CCT sample data are largely in accord with the simulation modelling conducted for Camps 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 than measured distributions.

Table 5.1: Enterococci counts (cfu/100 ml) at sample stations within the allowable ZID (CB-6 & CB-7) and immediately adjacent sample stations (CB-5 & CB-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	CB-6	CB-7	CB-5	CB-8
09-01-18	1	0.5	1	2
13-02-18	0.5	1	0.5	0.5
10-04-18	8	3	3	15
15-05-18	1	7	3	15
21-06-18	1	42	0.5	4
26-07-18	310	18	15	26
17-01-17	4700	9700	66	0.5
14-02-17	650	450	310	0.5
06-03-17	0.5	0.5	0.5	0.5
03-04-17	3	32	28	39
22-05-17	22	6	1	1
06-06-17	0.5	0.5	1	1
18-07-18	5	13	11	21
28-08-17	700	610	10	5
18-09-17	0.5	15	0.5	5
30-10-17	73	60	41	0.5
13-11-17	180	1	10	3
05-12-17	2800	0.5	15	1
25-01-16	0.5	2	0.5	4
29-02-16	0.5	6	6	0.5
05-04-16	2	10	9	6
18-04-16	7	14	11	4
16-05-17	9	29	32	720
28-06-18	4	1	0.5	6
18-07-16	6100	780	31	1
30-08-16	38	3900	4	1
13-09-16	0.5	1	0.5	0.5
17-10-16	7	0.5	0.5	23
22-11-16	2	0.5	20	0.5
06-12-16	0.5	0.5	0.5	0.5
90th Percentile	**910**	**627**	**32.9**	**23.3**
95th percentile	**3845**	**2496**	**54.7**	**33.2**

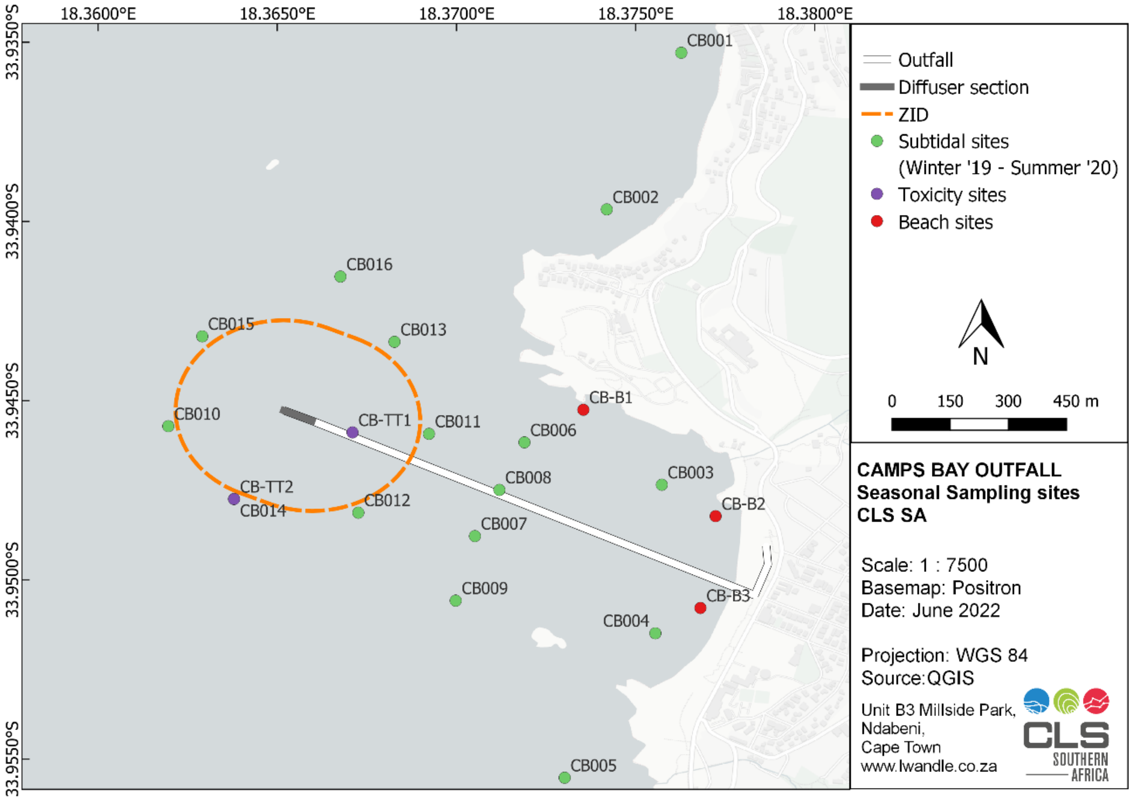
Table 5.2: Enterococci counts (cfu/100 ml) at a screen of nearshore sample stations for surveys in 2016-2018; n = 30. Counts recorded as below the detection limit are included at half of the detection limit to enable the estimation of the percentiles.

Date	Station		
dd/mm/yr	CB-10	CB-11	CB-13
09-01-18	2	4	1
13-02-18	0.5	0.5	0.5
10-04-18	1	3	0.5
15-05-18	5	4	12
21-06-18	0.5	2	0.5
26-07-18	0.5	32	5
17-01-17	7	1	0.5
14-02-17	0.5	2	0.5
06-03-17	0.5	0.5	1
03-04-17	1	7	0.5
22-05-17	0.5	1	2
06-06-17	0.5	0.5	6
18-07-18	33	6	74
28-08-17	71	6	1
18-09-17	5	0.5	3
30-10-17	3	11	0.5
13-11-17	2	1	0.5
05-12-17	3	8	1
25-01-16	0.5	0.5	0.5
29-02-16	0.5	0.5	1
05-04-16	2	5	0.5
18-04-16	2	5	0.5
16-05-17	67	11	1
28-06-18	0.5	7	2
18-07-16	18	3	0.5
30-08-16	0.5	7	2
13-09-16	0.5	52	0.5
17-10-16	0.5	0.5	5
22-11-16	4	1	1
06-12-16	0.5	0.5	0.5
90th Percentile	**19.5**	**11**	**5.1**
95th Percentile	**51.7**	**22.6**	**9.3**

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 Camps Bay outfall over the three years 2019-2022. Two sets of sampling locations were used in these surveys. Figure 5.2 (top panel) shows the sites from which samples were drawn in the winter 2019 and summer 2021 surveys. Based on the PRDW (2021) modelling results, these were modified in the subsequent seasonal surveys to improve the ability to detect discharged effluent impinging on the nearshore through the establishment of a screen of sampling sites extending from Bakoven to Clifton Bay (Figure 5.2, bottom panel). Sea surface, mid-depth and near seabed sampling was conducted in these surveys to gain insight into discharged constituent distributions in the water column.

CLS SA distributional plots show minimal differences in the TSS for surface, mid-depth, and bottom waters but do indicate that generally, surface concentrations are lowest for this variable and orthophosphates and marginally so for ammonia except for the winter 2020 survey. Such patterns, although predicted by modelled discharged effluent plume behaviour, are not evident in the enterococci distributions. This may be due to the relatively wide count bins (~100 cfu/100 ml) used to display the data. Table 5.3 and Table 5.4 examine this based on the entire enterococci data set for the CLS SA surveys. Data from the winter 2019 and summer 2020 surveys have been partitioned into those adjacent to the allowable ZID, a screen of stations approximately midway from the ZID to the shore, nearshore stations in Camps Bay and Clifton Bay, and beach stations (Table 5.3). Data from the subsequent surveys are grouped into those on the allowable ZID boundary, the string of nearshore stations with subsets in the two bays, and beach stations (Table 5.4).



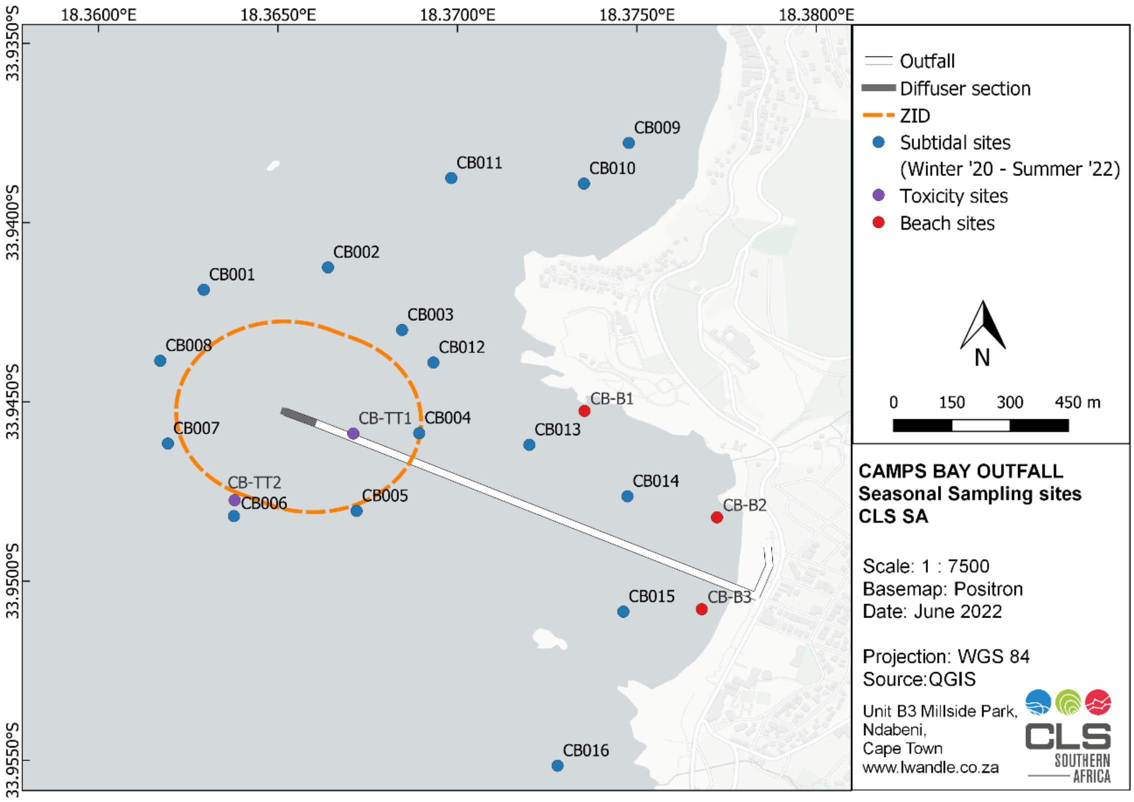


Figure 5.2: Map of the Camps Bay outfall and the locations of water quality sampling sites (subtidal, toxicity and beach) for the seasonal surveys conducted by CLS SA. The top map shows sites sampled from Winter 2019 – Summer 2020, while the bottom map shows sites sampled from Winter 2020 – Summer 2022. The dashed orange line shows the allowable ZID.

Table 5.3: Enterococci count data (cfu/100 ml) obtained in the winter 2019 and summer 2019 surveys at the Camps Bay outfall. The data are partitioned into subsets comprising those adjacent to the allowable ZID boundary (stations CB011-CB016), a screen of stations approximately mid-distant between the discharge pipe end and shoreline (stations CB006-CB009), stations near the shoreline (CB001- CB005) and three beach sites (CB B1- CB B3).

Data Set	n samples	90th Percentile	95th Percentile	Maximum Count Recorded
All stations	507	7	13	102
ZID Boundary stations	210	9	14	102
ZID Boundary Surface	70	6	11	34
ZID Boundary Mid Depth	70	11	14	102
ZID Boundary Bottom	70	10	15	25
Coastal Screen	120	6	20	61
Coastal Screen Surface	40	3	4	61
Coastal Screen Mid Depth	40	7	25	33
Coastal Screen Bottom	40	11	20	29
Embayment stations	150	5	7	16
Embayments Surface	50	4	9	14
Embayments Mid Depth	50	5	7	16
Embayments Bottom	50	5	7	10
Beaches	27	10	16	97

Table 5.4: Enterococci *count data (cfu/100 ml) obtained in the winter 2020 and subsequent seasonal surveys at the Camps Bay outfall. The data are partitioned into subsets comprising those adjacent to the allowable ZID boundary (stations CB001-CB008), a screen of nearshore stations (stations CB009, CB010 & CB013-CB014), and three beach sites (CB B1- CB B3).*

Data Set	n samples	90th Percentile	95th Percentile	Maximum Count Recorded
All stations	1224	11	22	1900
ZID Boundary stations	576	18	34	350
ZID Boundary Surface	192	4	14.9	161
ZID Boundary Mid Depth	192	31	53.75	350
ZID Boundary Bottom	192	13.9	31	172
Coastal Screen	576	8	11	109
Coastal Screen Surface	192	4.9	8.45	109
Coastal Screen Mid Depth	192	8	10	30
Coastal Screen Bottom	192	9	13	32
Clifton Bay	144	5	8.85	30
Camps Bay	216	9	11.25	109
Beaches	72	20.7	41.8	1900

The tables show that:

- Over the monitoring period receiving water quality attains the excellent status according to the DEA (2012) guidelines (95th percentile of the counts <100 cfu/100 ml) for all stations and each of the areal subsets,
- Enterococci counts at or adjacent to the ZID boundary, including the individual maximum count, are within the excellent threshold, implying that the mixing within the ZID area, as is evident in CSIR (2017) along with the Table 5.1 & Table 5.2 comparisons, is currently sufficient in terms of human health risks,
- The excellent water quality classification extends into the nearshore of both Clifton and Camps Bays,
- There is evidence that mid-depth and bottom enterococci counts are higher in the ZID boundary stations than those in the surface, as predicted by the modelling, and
- The 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 a stormwater drain.

The statistically summarised data in Table 5.3 & Table 5.4, 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. The highest enterococci count occurred close to the outfall diffuser bank, but moderately elevated counts were distributed across the survey area, except for offshore, 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. The latter show that effluent is predicted to reach the shorelines of both Camps Bay and Clifton Bay but at dilutions of 20 000x and higher indicating that low enterococci counts should occur, as reflected in Figure 4.7 & Figure 4.8.

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).

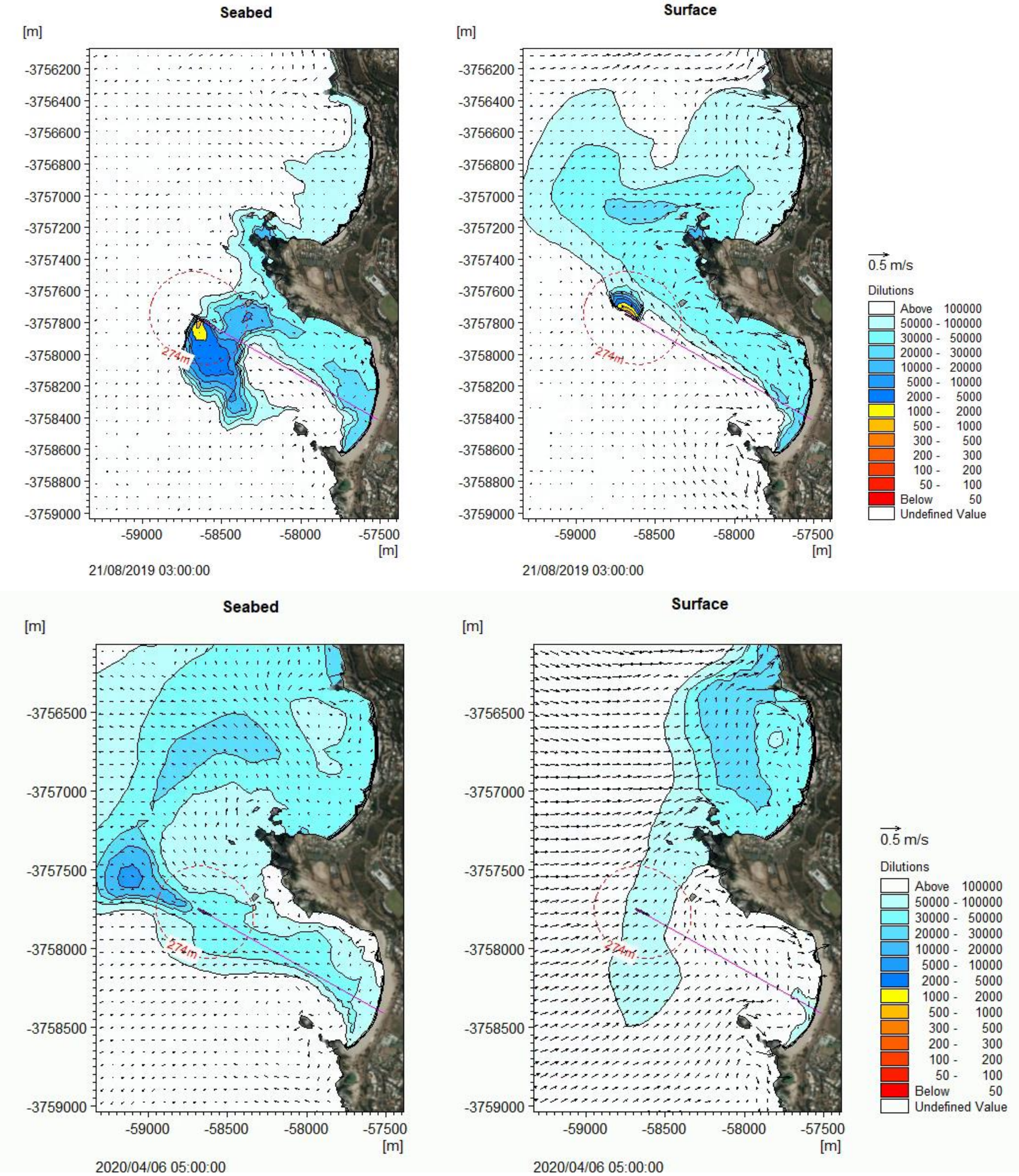


Figure 5.4: Instantaneous plots of effluent dilutions in shoreward flowing surface currents in winter/spring (top panel) and summer/autumn (bottom panel) (from PRDW 2021).

6 Measured Contaminants of emerging Concern (CECs)

From analyses of Camps Bay pre-discharge effluent samples, CSIR (2017) identified 23 CECs comprising pharmaceutical and personal care products. The most prominent amongst these in terms of concentration were paracetamol (acetaminophen), naproxen, diclofenac, triclocarban, irbesartan, levetiracetam, and bezafibrate. Paracetamol 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 paracetamol 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 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, winter and summer surveys and assessment of distributions of CECs in Cape Town's nearshore coastal waters, CSIR (2022) recorded 37 compounds and found that the highest total concentrations occurred at sample sites influenced by wastewater treatment works. Lower concentrations were found at Clifton 4th Beach and Camps Bay Beach, with ofloxacin, valsartan, venlafaxine, ciprofloxacin, alprazolam, citalopram, and bezafibrate being represented at concentrations <5 ng/l, salicylic acid at 179 ng/l, and desloratadine 112 ng/l. Due to low concentrations, hazard coefficients were low. The surveys can be classed as a reconnaissance operation as once-off sampling was conducted in each season. Therefore, the apparent absence of most pharmaceutical compounds from the nearshore of the Camps Bay outfall was probably due to the metocean conditions on the sampling days, as their presence in the discharged effluent has been demonstrated.

7 Biodiversity Risks

The biodiversity risks posed by the effluent discharged through the Camps Bay outfall include acute and chronic toxicity to marine organisms, bioaccumulation of contaminants in mussels and their predators, 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 Camps 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 350x for all constituents rated except for polychlorinated biphenyls (PCBs), which 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 (2021) modelling estimated 5th percentile dilution rates at the allowable ZID boundary indicate that toxicity risks from effluent constituents should 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 5.2). Samples were obtained at intervals over each of the multi-week survey periods. Sixty-two samples were used in the acute toxicity bioassays, with none showing signs of toxicity.

These 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 Camps Bay 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 Camps 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.

7.2 Contaminant body burdens in mussels and rock lobster

Comparisons of trace metal body burdens in mussels collected in the intertidal zone in Camps Bay and other sites on the Atlantic seaboard in 2016, including a baseline reference site at Llandudno, show them to be similar with no apparent influence of the Camps Bay outfall. Further, there are no apparent consistent increases or decreases over time (CSIR 2017). This study also shows that body burdens of the organic compounds, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls, are lower at Camps Bay than other sites on the Atlantic seaboard and concluded that there was no demonstrable link with the effluent discharged through the outfall. Rock lobster are major predators of mussels in the Benguela Current and elsewhere in the oceans and they show similar patterns in their contaminant body burdens. Given low body burdens health risks from consumption of mussels and rock lobster collected at Camps Bay were estimated to be low by CSIR (2017).

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 2.62×10^{10} milliMoles (mM) of ammonia-nitrogen to the sea per year (estimated from data in CSIR, 2017 and PRDW 2020). The Camps Bay outfall discharges 8% of this at 2.07×10^{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 Green Point 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 particulate organic matter accumulation and remineralisation 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 Camps Bay outfall, metocean conditions and seabed topography limit its development and consequences.

8 Effects on Sediment Properties

Sediment texture in the broader area of the Camps Bay outfall is mainly medium to coarse sand with shell fragments and negligible proportions of mud (CLS-SA 2022, CSIR 2017). Fine sand is present in the near field of the outfall diffusers (CLS-SA 2022). Corresponding to grain size the total organic content in the sediments is <1% (CSIR 2017). CSIR surveys in 1985, 1997 and 2003 cited in CSIR (2017) indicate that the contribution from particulate organic matter in the effluent through the outfall to this is negligible.

Sediment trace metal concentrations from historical surveys and that conducted in 2015/2016 are low with low magnitudes of enrichment (<1.5 above baseline, CSIR 2017). This is predictable given the low concentrations of organic material in the sediments and indicates that metals in the effluent being discharged through the Camps Bay outfall are not accumulating to any degree in the Camps Bay area.

Similar to trace metals the organic compounds of total petroleum hydrocarbons, total recoverable hydrocarbons and polycyclic aromatic hydrocarbons, concentrations were low or below the level of detection.

9 Effects on Biodiversity

Two location-specific surveys were conducted on biodiversity in the Camps Bay discharge area; one on distributions of sessile organisms and fish associated with reefs (CLS SA 2022b) and the other on benthic macrofauna in sediment bodies (CLS SA 2022c). Both surveys were based on near field impact and far field control site comparisons to test for near field effects of the discharge on these classes of organisms.

9.1.1 Sessile organisms and fish

The CLS SA survey covered the taxonomic composition of sessile organisms in depth stratified random quadrat counts, presence and abundance of rock lobster in three size classes on belt transects and the fish community (BRUV deployments) in the nearfield of the Camps Bay discharge and far field control sites.

The quadrat counts did not differ statistically between the impact and control sites surveyed regarding percent cover and species diversity indices. The taxa present were those common to Cape west coast kelp forest communities. Rock lobster counts showed high numbers of juveniles adjacent to the Camps Bay outfall with higher proportions of sub-adults and adults in deeper water. This is consistent with known recruitment patterns and size distributions. There were no statistical differences between the sites, partly due to high variability in the observation data. No influence of the discharge was apparent in the distribution patterns. Cape Bream dominated the BRUV deployment fish observations. This species is endemic to southern Africa and is a prominent inhabitant of kelp forests. As in other components of the biodiversity survey, no influence of the Camps Bay outfall and discharged effluent is apparent in the data.

The caveat to the above is that the surveys were reconnaissance in scale and limited to once-off observations. This is problematic with mobile organisms such as fish and rock lobster as local abundance patterns can be affected by metocean conditions and/or other disturbances and change over short intervals (hours – days). Sessile organisms are more suitable in that they cannot escape the changing conditions/disturbances. However, the observed high variability in the quadrat count data indicates that higher sample replication is required and that vertical surfaces, as opposed to flat areas, need to be surveyed to counter the possible confounding effects of the latter being kept clear by kelp fronds sweeping the surfaces. This should be addressed in future monitoring surveys.

9.1.2 Benthic macrofauna

From 36 samples, 43 benthic macrofauna taxa were recorded all of which have been previously recorded in the Benguela Current region. Species diversity was statistically similar between the impact and control sites surveyed, partly due to high within site variability. The nearfield impact site supported different species composition to that of the far field impact site and control sites due to the high abundance of the endemic isopod *Eurydice longicornis*. This site also differed because the sediment particle size was smaller than the other sites but still classified as medium grained sand (0.25-0.425 mm). The source of this is likely the discharge. However, there was no apparent organic loading in the sediment, and the presence of the shallow burrowing isopod indicates little or no dissolved oxygen stress as crustaceans, in general, are sensitive to low oxygen concentrations (Vaquer-Sunyer and Duarte 2008). *E. longicornis* is mobile and carnivorous; its presence and abundance adjacent to the Camps Bay outfall could have been due to the presence of a carcass or other food source and not the effects of the discharged effluent.

There was no other evidence in the benthic macrofauna survey pointing to the effects of the discharge.

10 Conclusions

This report summarises surveys on the Camps 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 Camps 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. Non-compliant constituents are TSS, COD, ammonia nitrogen and aluminium.
- Mass balance and hydrodynamic modelling predict effluent dilution within the receiving environment ZID is sufficient to reach compliance with environmental and recreational water quality guidelines at the ZID boundary.
- The achieved dilutions imply negligible direct toxicity risk to exposed biota outside of the ZID. This is confirmed by direct toxicity testing on mussels within and immediately adjacent to the ZID boundary and the fact that the estimated MATDs from whole effluent toxicity testing are well within the predicted dilutions at the ZID boundary.
- The available distribution data on enterococci show that water quality outside of the ZID in Camps Bay and the nearshore wave swash zone is classified as excellent according to the DEA (2012) guidelines for recreational use. This extends into the nearshore of both Clifton and Camps Bays,

- The highest enterococci counts were recorded in the swash zones of the beaches. The available distributional data do not show connectivity with the offshore discharge implying a local source of pollution.
- Modelled effluent behaviour time series data predict that isolated short term (<1 day) events of enterococci counts above the sufficient category may occur at Maidens Cove, Glen Beach, Camps Bay and Clifton 1st Beach. The risk of illness from effluent discharged through the outfall is thus low but not zero.
- The measured water quality and toxicity test results are aligned with the predictions of the hydrodynamic modelling and are consistent across the measurement periods (2016-2018, 2019-2022). This supports the model as a tool for predicting effluent plume behaviour and applications under-pinning environmental monitoring of the discharge.
- Twenty-three contaminants of emerging concern comprising pharmaceutical and personal care products were identified in Camps Bay pre-discharge effluent, while 37 have been recorded in the nearshore of the Cape metropolitan area with low concentrations of a range of CECs detected at Clifton 4th Beach and Camps Bay Beach. Toxicity effects of these compounds are not well known which represents an unconstrained risk to marine organisms.
- The inorganic nutrients discharged through the outfall, primarily ammonia nitrogen, are a very small fraction of upwelling supplied inorganic nitrogen and its contribution to local and/or regional eutrophication is miniscule.
- Modelling predicts that >95% of the particulate material in the discharged effluent plume will deposit on the seabed offshore of the -40 m depth isobath, be transported out of the model domain, or remain suspended. Less than 5% of the discharged mass is predicted to deposit within the Port of Cape Town. A negligible deposition is predicted for the potential depocenters of Murray's Bay harbour (Robben Island), Granger Bay or Hout Bay.
- The seabed in the Camps Bay outfall area is rocky with isolated sand patches. Sediment textures within these are typically medium to coarse sand with shell fragments. Multi-decadal survey data shows that there is no apparent long-term build-up of inorganic or organic contaminant concentrations in sediments and linked increases in toxicity risks attributable to the Camps Bay outfall.
- Reconnaissance scale surveys of sessile organisms and fish in Camps Bay kelp beds and sand seafloor benthic macrofauna did not show any effects firmly attributable to outfall. Finer sediments were recorded in the outfall near field, which is linkable to the particulates in the discharge. There was no apparent organic loading, and abundant isopods in the area imply little or no dissolved oxygen stress.

The overall conclusion from the suite of surveys conducted by CCT and the somewhat sparse supporting information from independent studies is that the Camps Bay outfall is 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 acknowledged to be 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 actually occurring in recreational users of the nearshore environments around the Camps 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 milligram/litre 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) were predicted to be compliant with the applied water quality guideline concentration (+ 10% above background concentrations; DWAF 1995) in the receiving environment outside of the ZID. However, this guideline is weakly based and very difficult to apply as, amongst other issues, sufficient background data is lacking. Further, marine organisms are fairly 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 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 in 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. Such a design accounts for the longshore (shore parallel) gradient in effluent constituent concentrations and includes a cross shore (perpendicular to shore) gradient to show whether, at the time of measurement, there was onshore transport of the effluent plume/constituents.

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. Field measurements should include:

- Water quality profiling by multi-parameter CTD of pH, turbidity, photosynthetically active radiation (PAR), chlorophyll a, 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 kelp bed habitat at Camps Bay mainly comprises rock outcrops with isolated small sand patches. Strong wave action limits 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. Recent experience at the Camps Bay outfall has demonstrated this. Consequently, possible effects on resident biota should be extrapolated from compliance with water quality criteria and toxicity testing using sea urchin fertilisation success and microalgae growth as metrics.

11.2.3 Discharge effluent zone of influence

The effluent zone of influence can be scaled according to TSS distributions and the deposition footprint. This is available in the PRDW (2021) modelling results. Isotopic ratios ($\delta^{15}N$, ^{13}C) have been used for this tracking ammonia-N take-up in kelp (*Ecklonia*) and carbon sequestration in mussels at the Green Point outfall (Cyrus 2007). Nitrogen take-up was demonstrated but the source may have been sewage contaminated stormwater flows into the nearshore. This may also be a confounding issue in Camps Bay. *Laminaria pallida* is distributed deeper than *Ecklonia* in the southern Benguela and is most abundant from -5 to -8 m depth. This should limit their exposure to shoreside effluent flows and make them more exposed to effluent released through the Camps Bay outfall making this species a candidate for study. Sampling for this survey should be done during summer which is suitable for *Laminaria* growth. Sample sites should be in kelp beds and parallel to the shoreline extending from Bakoven to the southern end of Clifton 4th Beach. As changes in isotopic ratios are essentially time averaged in that the kelp is in balance with its nutrient environment, this survey need only be done once. This will indicate whether there is an influence on nitrogen isotopic ratios in *Laminaria* or not. If the latter applies this is a balance of evidence level indicator of no effect. If influence is shown then this can be either from the outfall or from other sources, i.e., uncertainty on the sources and/or relative contributions of sources will remain.

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 Camps Bay outfall and in the predicted effluent plume trajectories. Given that the PRDW (2021) 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 storm water flows will need to be incorporated. When done successfully the model will constitute a valuable tool in avoiding human health risks for the city.

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