Environmental Summary Report on Modelling and Measurement Programmes: Green Point Outfall

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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, 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 2020, 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; Addendums 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 Green Point outfall with supporting information from scientific literature. Companion summaries have been compiled for the Camps Bay 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 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 Green Point 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 Green Point outfall was commissioned in 1993 and extends 1 670 m offshore from Mouille Point (Figure 2.1). The outfall terminates in 16 diffusers located at 28 m water depth. The design effluent discharge capacity is 40.0 Ml/day, but average actual rates are 23.8 Ml/day in winter/spring and 18.1 Ml/day in summer/autumn (PRDW 2020).

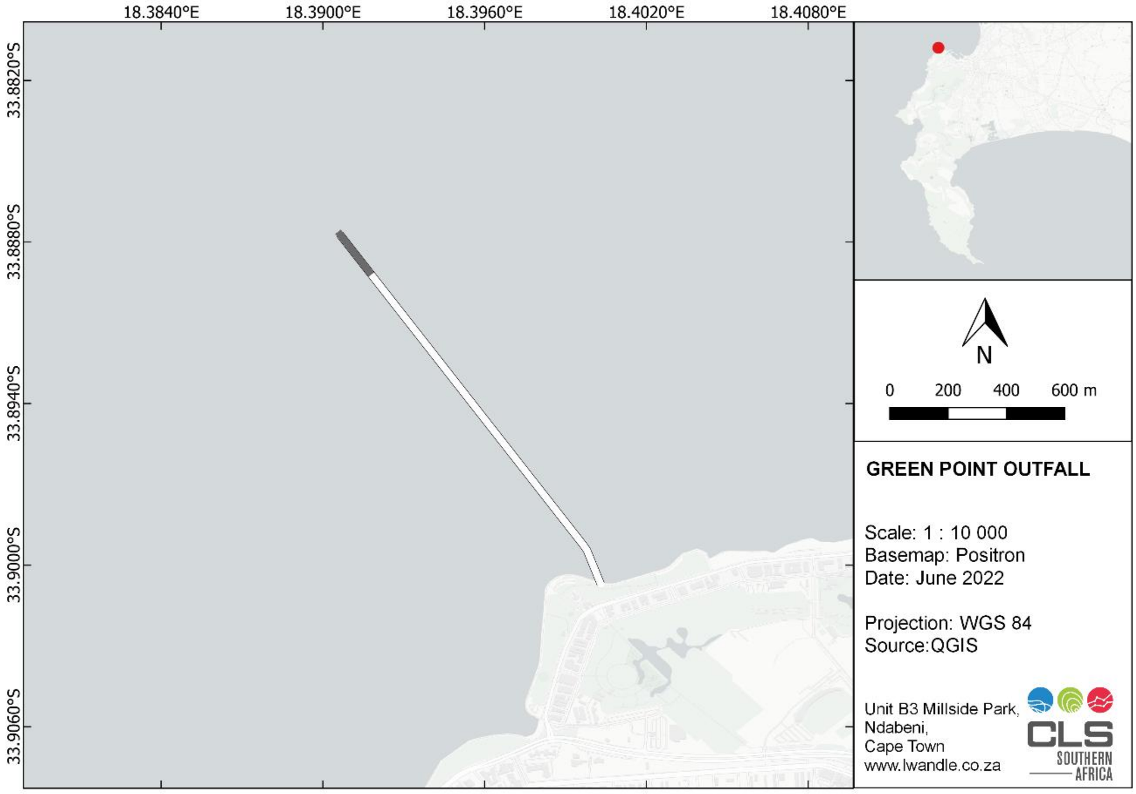

Figure 2.1: Map of the Green Point outfall. The grey section of the outfall indicates the location of the 16 diffusers.

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 Green Point effluent was fully compliant with generally specified limits on pH, ammonia, and orthophosphate, 99% compliant for COD, and 92% for TSS.

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 Green Point 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 89% compliant for pH, 99% for Kjeldahl nitrogen and orthophosphate, 95% for iron, less so for aluminium (74%), but markedly noncompliant for TSS (0.2%), COD (3.3%), and total ammonia nitrogen (0%).

3 Estimates of Required Effluent Dilutions

CSIR (2017) used a mass balance modelling approach to estimate whether effluent discharged through the Green Point outfall 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. This is lower than the 270x for a flow rate of 40 Ml/day and 330x for a flow rate of 29 Ml/day estimated for the outfall by CSIR (1990) and can be considered as conservative. 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 allowable ZID boundary. TSS was an exception for inorganics with a median required dilution of 216x and a maximum of 2 430x. 38% of the samples analysed would require dilutions >200x to meet environmental targets, and 11% would require >500x dilutions. 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 evaluated in section 7.1.

The radius of the allowable spatial extent of the ZID around the Green Point discharge pipe end diffuser bank specified by the CCT (CCT in litt. 2022) is 256 m. This is based on guidance in Anchor (2016) and the Green Point outfall diffuser configuration. This differs from the 75 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 2020) 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 Green Point. 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 were E. coli 1x10^7 cfu/100 ml, enterococci 1.3x10^6 cfu/100 ml, TSS 359 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 shows complex plume behaviour in variable wind conditions in both seasonal periods. Examples from southerly wind conditions in the winter/spring period show a restricted near surface plume aligned with the north-west flowing currents whilst at mid-depth flow remains north-west. Still, the plume spreads laterally as it is carried into Table Bay (Figure 4.1). In north-west winds, the near surface plume flows south-west before turning westwards towards the coastline south-west of the Green Point outfall (Figure 4.2). The modelling indicates that part of the plume travels north-westwards into Table Bay, countering the wind direction. At mid-depth the plume is initially aligned with the wind direction but subsequently flows north-westwards into Table Bay. The surface plume extending into Table Bay may be part of the mid-depth plume surfacing.

The summer/autumn examples (Figure 4.3 & Figure 4.4) show that, in south-easterly winds, the effluent plume is advected into Table Bay with higher *E. coli* concentrations at mid-depth than in the near surface. Under north-westerly wind conditions, no surface plume is predicted to form while it is well developed at mid-depth and travels south-westwards, keeping away from the coastline.

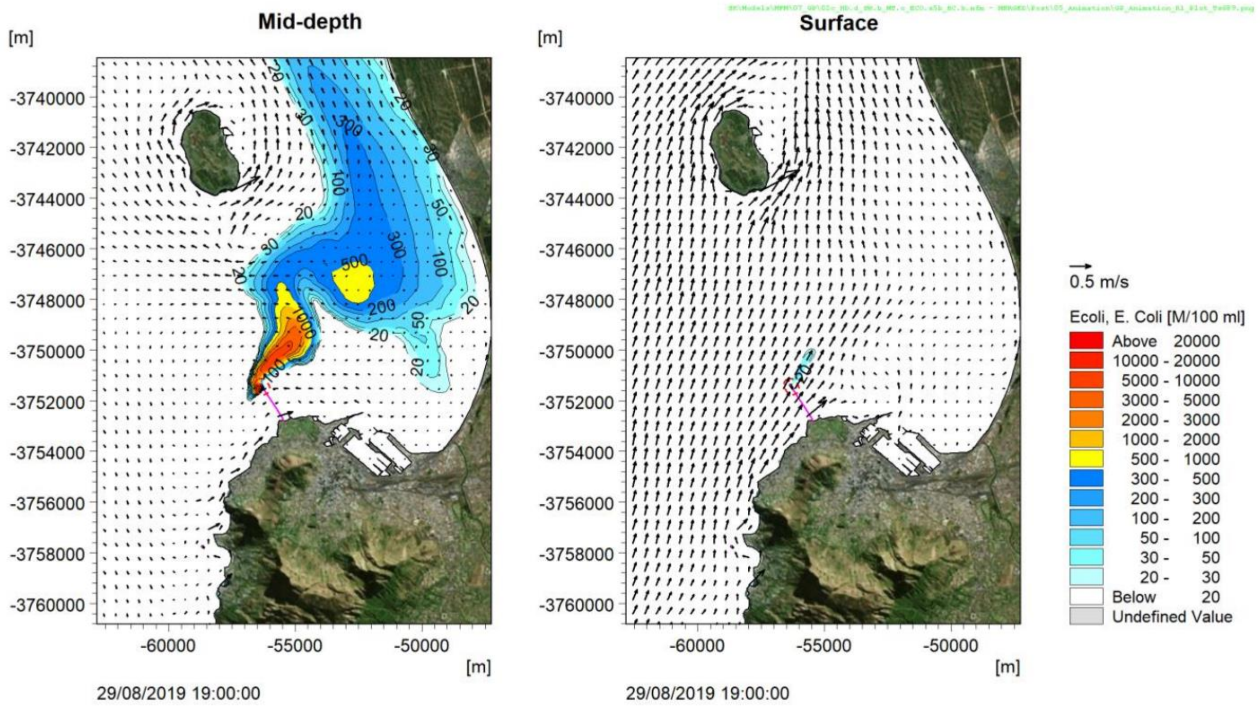

Figure 4.1: Winter/spring: Current vectors and E. coli plume at a moment in time during a southerly wind condition (from PRDW 2020).

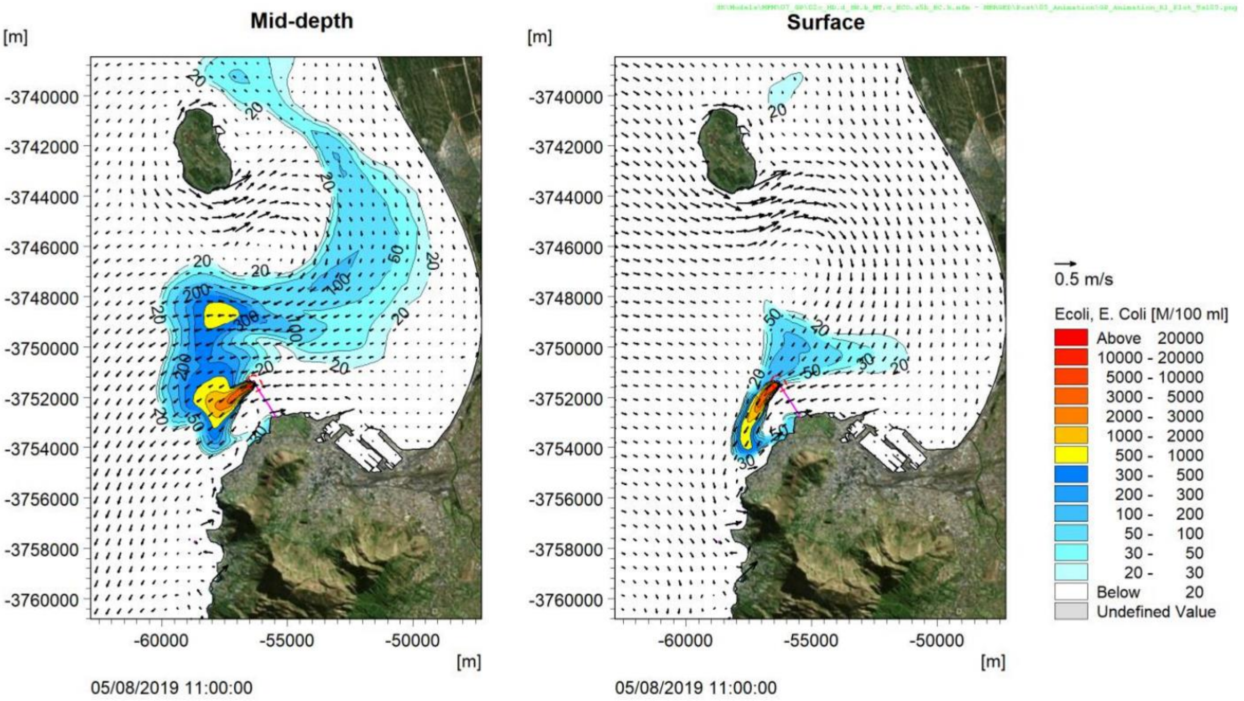

Figure 4.2: Winter/spring: Current vectors and E. coli plume at a moment in time during a north-westerly wind condition (from PRDW 2020).

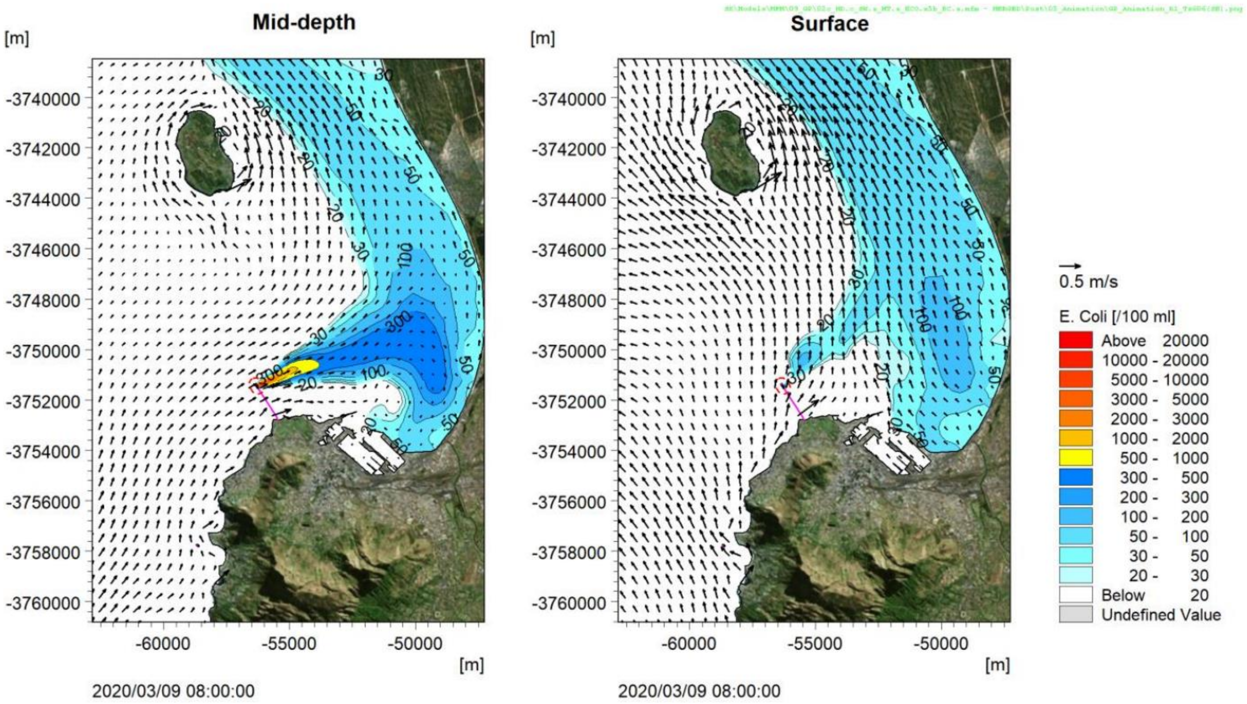

Figure 4.3: Summer/autumn: Current vectors and E. coli plume at a moment in time during a south-easterly wind (from PRDW 2020).

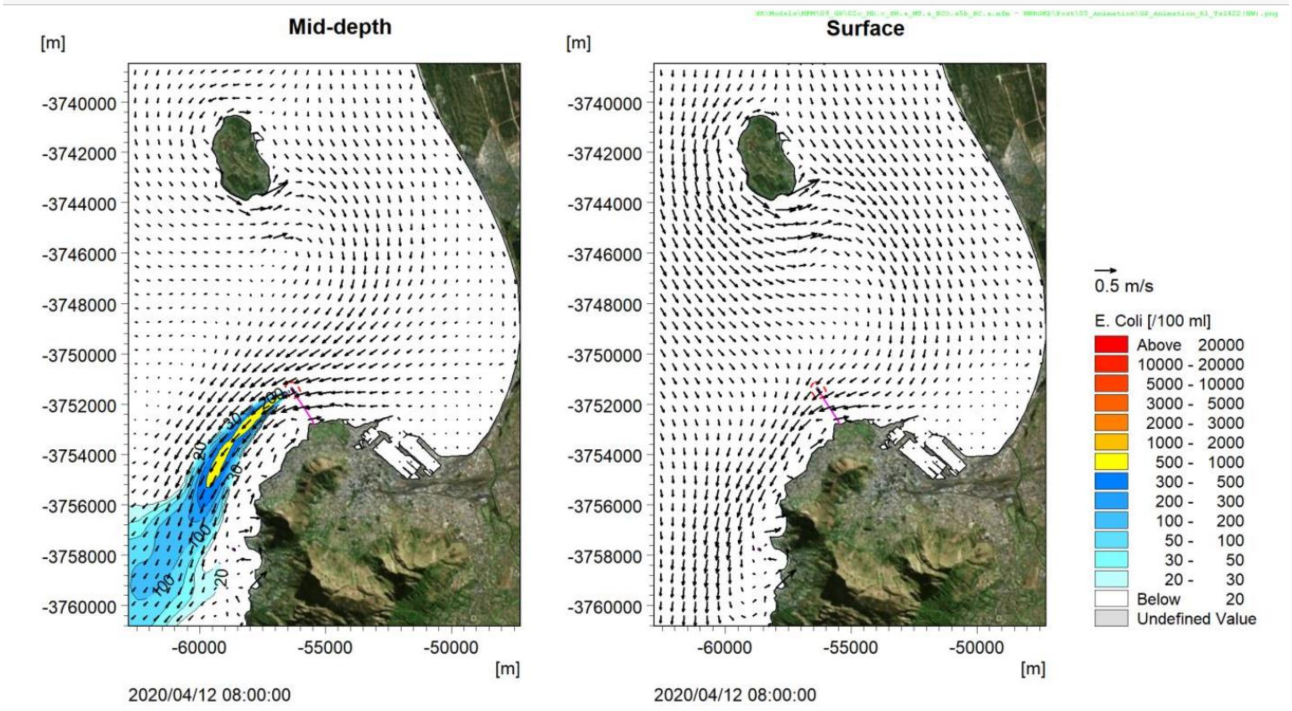

Figure 4.4: Summer/autumn: Current vectors and E. coli plume at a moment in time during a north-westerly wind condition (from PRDW 2020).

4.2 Predicted effluent plume dilutions and water quality guideline compliance

The predicted 5th percentile effluent dilution factor, i.e., that close to the minimum, at the boundary of the allowable ZID, is 528x in winter/spring and 687x in summer/autumn. Plume cross sections (Figure 4.5 & Figure 4.6) show no extension to the seabed and the lowest dilutions are located at mid-depth. Here dilution factors can be <500x. Dilutions >2 000x are predicted to occur within ~700 m of the dilution minima. The two cross sections are similar with minimal differences in plume behaviour in the immediate area of the discharge. These modelling results indicate that required dilutions to meet water quality guidelines for most of the inorganic and organic constituents identified in the effluent including ammonia and COD will be achieved within the Green Point allowable ZID, but that TSS will only meet these 1 400 m from the diffusers in winter/spring and 940 m in summer/autumn. This aligns with assessments by CSIR (2017).

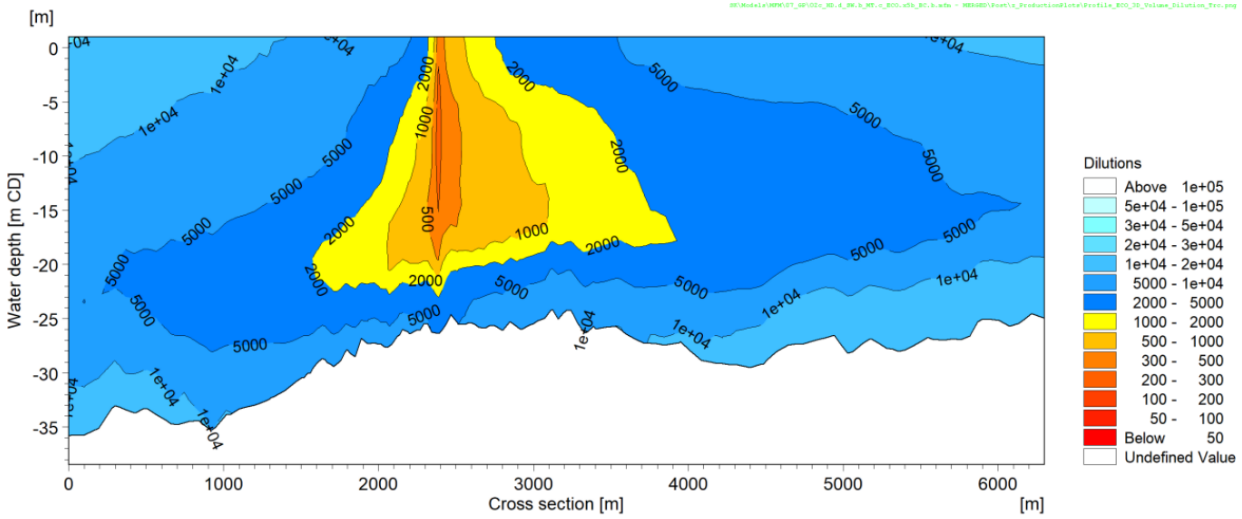

Figure 4.5: Winter/spring: Cross-section of 5th percentile number of dilutions (from PRDW 2020).

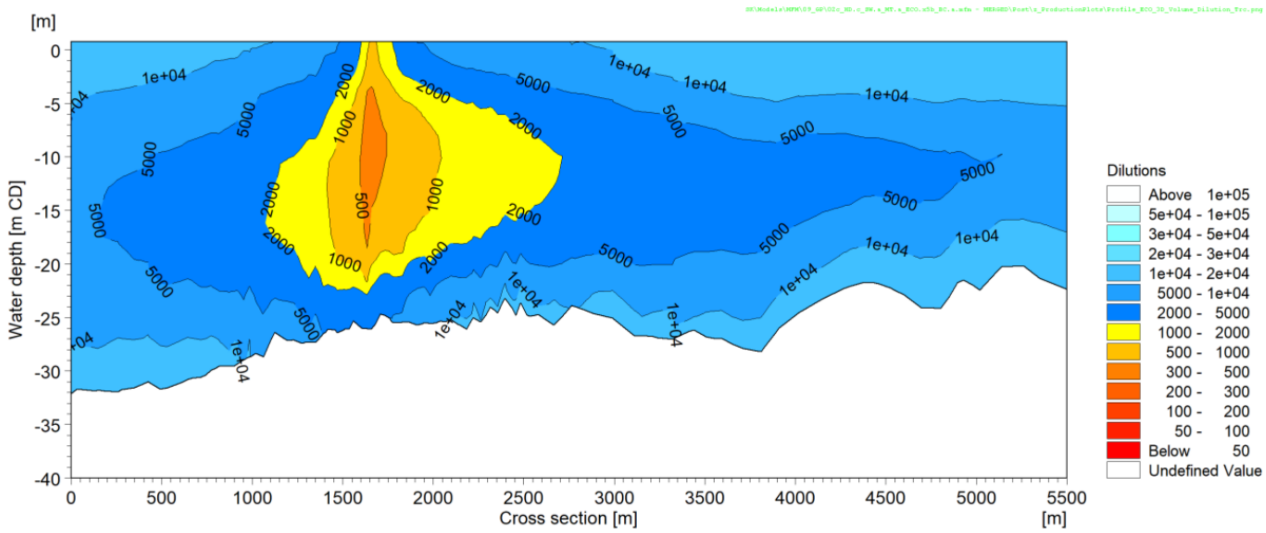

Figure 4.6: Summer/autumn: Cross-section of 5th percentile number of dilutions (from PRDW 2020).

For the faecal indicator bacterium *Enterococcus* predicted daylight hour distributions show that, for both modelled periods, near seabed 90th percentile concentrations above the water quality guideline of 185 cfu/100 ml will be restricted to within the allowable ZID (PRDW 2020, figures 6.12 & 6.28.). In the summer/autumn period the guideline is predicted to be met in the surface layer at the ZID boundary (PRDW 2020, figure 6.30). In the winter/spring period, however, the guideline is predicted to be exceeded with counts in the 185 to 300 cfu/100 ml range extending ~200 m beyond the ZID boundary north-eastwards into Table Bay (PRDW 2020, figure 6.14). Distributions at mid-depth where, as shown above, the discharge plume is concentrated, concentrations >185 cfu/100 ml are predicted to extend 3.2 km north-eastwards into Table Bay and~1.4 km to the south-west in the winter/spring period (PRDW 2020, figure 6.29). The pattern predicted for the summer/autumn period is similar, but the respective distances are 2.3 km and 1.4 km (PRDW 2020, figure 6.29). The 90th percentile plots do not show that high enterococci counts reach the shoreline in either of the two seasons modelled or that there are marked interactions of the discharge plume with the seabed. Winter/spring extracted time series data for nearshore locations at Green Point show that, at the event scale, enterococci counts >185 cfu/100 ml would occur adjacent to the Sea Point Pool on two occasions in the modelled 10-week period (Figure 4.7). In the summer/autumn period, two instances of counts >185 cfu/ml are predicted at the RMS Athens site (Figure 4.8). In both seasonal periods modelled, the water quality guidelines are not predicted to be exceeded in such events as the overall duration of these elevated counts is less than 10% of daylight time.

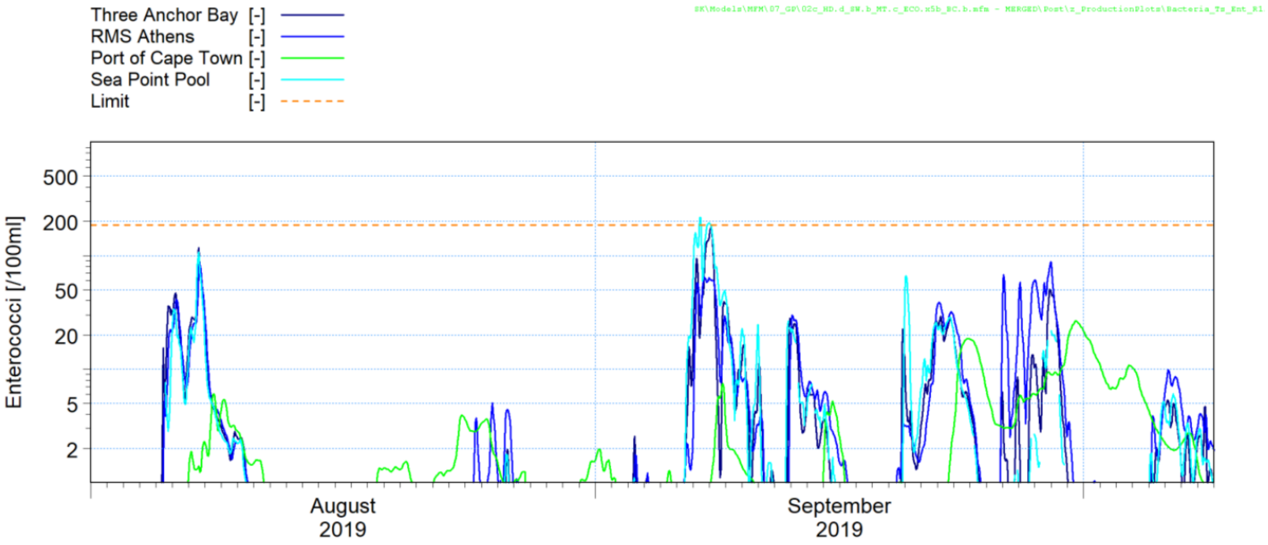

Figure 4.7: Winter/spring: Time series of highest enterococci concentration at any depth at four key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is shown in orange (from PRDW 2020).

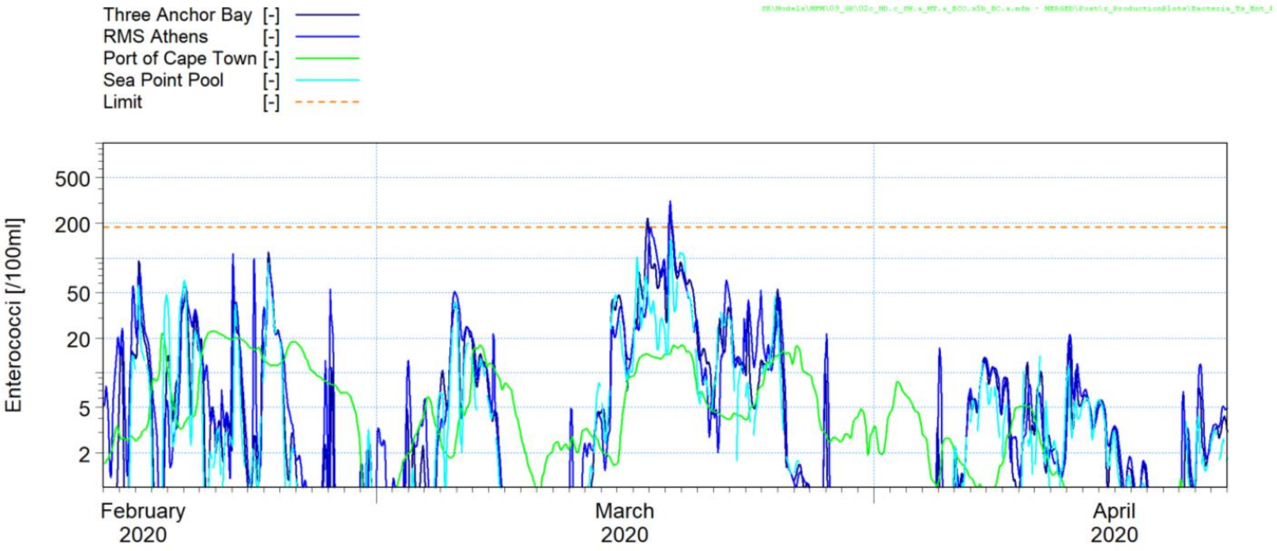

Figure 4.8: Summer/autumn: Time series of highest enterococci concentration at any depth at four key locations. The water quality guideline (185 CFU/100 ml 90th percentile in daylight) is shown in orange (from PRDW 2020).

4.3 Predicted suspended solids transport and deposition

PRDW (2020) modelled the transport and deposition of suspended solids discharged from the Green Point outfall in the winter/spring and summer autumn periods. Table 4.1 shows 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. In winter/spring, moderately higher proportions would be transported out of the model domain and remain suspended. Up to 8% of the discharged mass was predicted to deposit in the Port of Cape Town. The port receives flows from storm water drains and contaminants linked to shipping operations and is an environmentally stressed environment as commercial/industrial ports generally are. The contribution of the Green Point 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 2020).

	Winter/Spring		Summer/Autumn	
Area	**Mass (kg)**	**% Released**	**Mass (kg)**	**% Released**
Port of Cape Town	17 200	3.0%	25 100	8%
Murray's Bay Harbour	24	<0.1%	23.6	<0.1%
Granger Bay	69	<0.1%	107	<0.1%
Hout Bay	1.9	<0.1%	11.8	<0.1%
Offshore (-40m depth)	74 500	12.8%	141 0000	28.1%
Out of model domain	324 000	55.9%	263 000	52.5%
Suspended	164 000	28.2%	71 800	14.3%
Totals	**589 000**	**100.0%**	**500 000**	**100.0%**

4.4 Predicted acute toxicity MATDs

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 Green Point effluent collected at two-month intervals over an eight-month period in 2016. The derived MATDs ranged between 52x and 62x. The predicted 5th percentile dilutions for the allowable ZID boundary (above) exceed these, indicating a low overall toxicity risk to organisms of similar or lower sensitivity than sea urchin gametes from the discharge in the receiving environment.

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 Green Point 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).

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[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.

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.

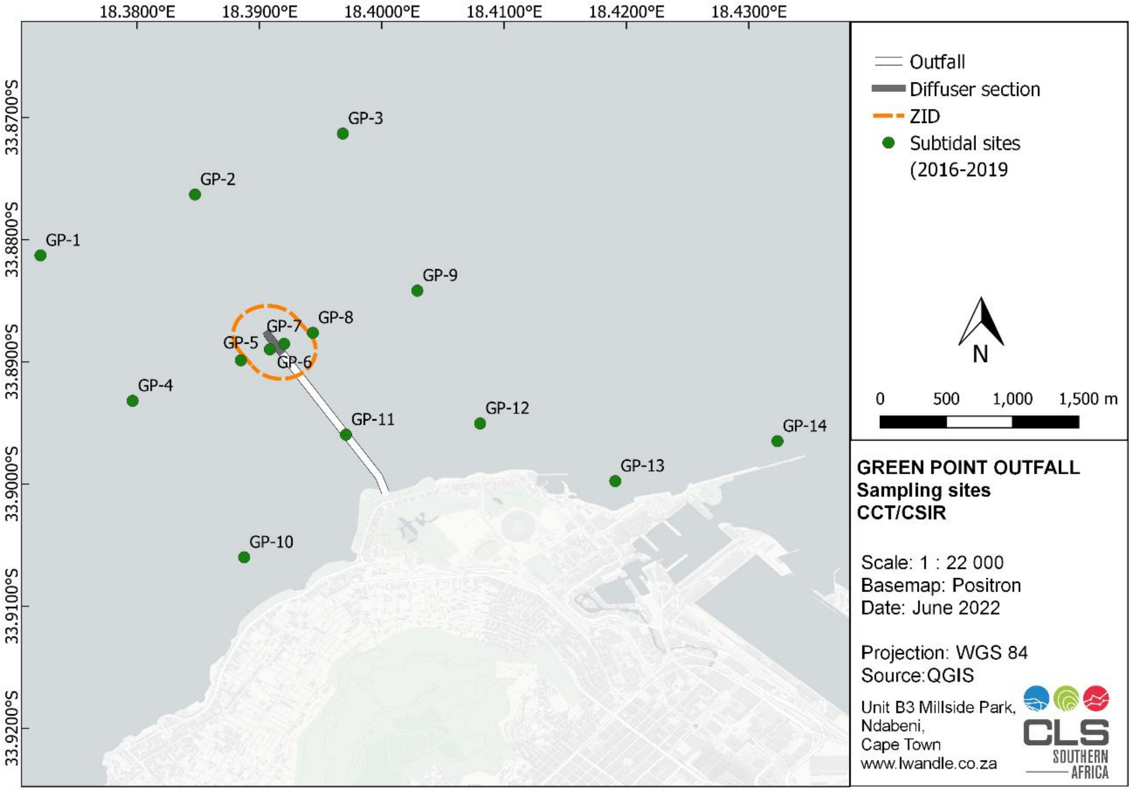

Figure 5.1:Water quality sampling points employed by the CCT for FIB distribution monitoring around the Green Point outfall over the period 2016-2018.

CSIR (2017) show monthly interval distribution plots for enterococci for sea surface samples collected in 2016 (their figures 4.5-4.15). In five of the surveys, counts were below 100 cfu/100 ml but exceeded 500 cfu/100 ml in six surveys. These exceedances occurred mainly at stations GP-6 and GP-7, i.e., within the allowable ZID, extending beyond this on three occasions. In some cases, marked differences in counts between adjacent stations indicated rapid plume dilution or sharp plume boundaries. This is highlighted by CSIR (2017). Geographically, sample stations GP-6 and GP-7 are within the allowable ZID, stations GP- 5 and GP-8 are close to the ZID boundary and stations GP-4 and GP-9 are the south-western and north-eastern ends of the shore parallel transect. Table 5.1 lists the count data for these stations over the entire measurement period (2016-2018) and estimates the 90th and 95th percentile values. The apparent rapid dilution is evident in these data and the 90th percentile values. Station GP-5 is on the ZID's southern edge and appears to be less exposed to plume conditions than to the north of the diffuser bank as reflected in the 90th percentile counts. As expected, samples from within the ZID are non-compliant with the DEA (2012) 90th percentile 185 cfu/100 ml water quality guideline, as is the closely adjacent station (GP-8) immediately north of the ZID.

Northward flow of the discharge plume as indicated by differences in enterococci counts at stations GP- 4 and GP-9 is evident on six occasions. On one of these (16/08/2016) the count exceeded the 185 cfu/100 ml threshold. Southward flow was moderately strongly indicated once (20/06/2016) with a count of 300 cfu/100 ml. In neither case was this sufficient to shift the respective station's water quality rating to non-compliance.

The distribution plots in CSIR (2017) based on the CCT 2016 sample data do show enterococci counts >100 cfu/100 ml at locations other than those adjacent to the outfall diffuser bank, such as GP-9 in May and August and GP-3, GP-4, GP-11, GP-12 and GP-13 in June. The last three stations are part of a ‘screen’ of nearshore stations. The full 3-year data set for these and station GP-10 (Table 5.2) indicates 90th percentile counts well below the water quality guideline and that, according to the 95th percentile values, water quality at three of them would be classified as excellent.

Table 5.1: Enterococci counts (cfu/100 ml) at sample stations within the allowable ZID (GP-6 & GP-7), immediately adjacent sample stations (GP-5 & GP-8) and the two end-members of the longshore transect (GP-4 & GP-9) crossing the outfall diffuser bank 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	GP-4	GP-6	GP-7	GP-5	GP-8	GP-9
09-01-18	1.0	1.0	1.0	1.0	54.0	0.5
13-02-18	0.5	0.5	0.5	0.5	0.5	0.5
10-04-18	0.5	0.5	0.5	0.5	1.0	1.0
15-05-18	0.5	0.5	0.5	0.5	0.5	1.0
21-06-18	37.0	191.0	203.0	13.0	33.0	1.0
26-07-18	0.5	8.0	19.0	1.0	80.0	111.0
16-01-17	0.5	29.0	2.0	0.5	39.0	2.0
13-02-17	9.0	11.0	6.0	1.0	1.0	2.0
13-03-17	0.5	0.5	0.5	1.0	4100.0	2.0
03-04-17	2.0	1.0	0.5	0.5	0.5	1.0
15-05-17	0.5	2.0	0.5	2.0	1.0	0.5
05-06-17	16.0	81.0	125.0	137.0	98.0	105.0
18-07-17	2.0	620.0	2700.0	4.0	2600.0	103.0
28-08-17	0.5	0.5	0.5	17.0	1.0	1.0
18-09-17	5.0	199.0	6.0	9.0	8.0	33.0
30-10-17	0.5	0.5	0.5	0.5	4.0	0.5
13-11-17	1.0	0.5	0.5	0.5	0.5	0.5
05-12-17	0.5	100.0	0.5	1.0	0.5	100.0
25-01-16	2.0	0.5	0.5	0.5	0.5	18.0
29-02-16	0.5	0.5	0.5	0.5	0.5	0.5
04-04-16	3.0	0.5	0.5	1.0	0.5	0.5
12-04-16	0.5	0.5	3.0	0.5	1.0	0.5
23-05-16	0.5	10000.0	36.0	6.0	31.0	106.0
20-06-16	300.0	6400.0	3700.0	690.0	900.0	0.5
11-07-16	58.0	5400.0	4500.0	32.0	22.0	29.0
16-08-16	0.5	10.0	140.0	0.5	380.0	2400.0
13-09-16	1.0	10.0	10.0	1.0	10.0	10.0
25-10-16	0.0	9800.0	0.5	0.5	0.5	0.5
08-11-16	4.0	3400.0	3700.0	0.5	66.0	4.0
08-12-16	0.5	0.5	2.0	0.5	0.5	0.5
90th Percentile	**18.1**	**5500.0**	**2800.0**	**18.5**	**432.0**	**105.1**
95th Percentile	**48.5**	**8270.0**	**3700.0**	**89.7**	**1835.0**	**108.8**

Table 5.2: Enterococci counts (cfu/100 ml) for 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.

Sample Date	Station			
dd/mm/yr	GP-10	GP-11	GP-12	GP-13
09-01-18	0.5	7.0	13.0	12.0
13-02-18	0.5	0.5	0.5	1.0
10-04-18	2.0	41.0	13.0	8.0
15-05-18	0.5	0.5	1.0	0.5
21-06-18	29.0	3.0	2.0	4.0
26-07-18	6.0	32.0	11.0	1.0
16-01-17	2.0	2.0	12.0	2.0
13-02-17	30.0	0.5	3.0	0.5
13-03-17	0.5	0.5	0.5	0.5
03-04-17	0.5	1.0	1.0	6.0
15-05-17	1.0	0.5	2.0	3.0
05-06-17	11.0	124.0	131.0	95.0
18-07-17	2.0	0.5	2.0	4.0
28-08-17	0.5	0.5	2.0	0.5
18-09-17	3.0	6.0	4.0	5.0
30-10-17	14.0	9.0	1.0	12.0
13-11-17	0.5	0.5	5.0	0.5
05-12-17	0.5	0.5	100.0	0.5
25-01-16	3.0	3.0	0.5	0.5
29-02-16	23.0	4.0	0.5	0.5
04-04-16	4.0	0.5	0.5	1.0
12-04-16	6.0	2.0	2.0	8.0
23-05-16	4.0	1.0	0.5	3.0
20-06-16	71.0	250.0	290.0	81.0
11-07-16	55.0	3.0	16.0	4.0
16-08-16	0.5	0.5	1.0	0.5
13-09-16	0.5	0.5	0.5	0.5
25-10-16	0.5	0.5	1.0	1.0
08-11-16	1.0	3.0	3.0	0.5
08-12-16	7.0	5.0	4.0	1.0
90th Percentile	**29.1**	**32.9**	**24.4**	**12.0**
95th Percentile	**43.7**	**86.6**	**117.1**	**49.9**

The CCT sample data are largely in accord with the simulation modelling conducted for the Green Point outfall. Periods, when uniformly low counts were recorded, would have been when the discharge plume was trapped subsurface whilst the axis of elevated counts in the CSIR 2017 plots aligned with the predicted effluent plume axis. This is also evident in the data in some of the cases listed in Table 5.1. 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 perhaps more representative than measured distributions.

As stated above 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 Green Point 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.

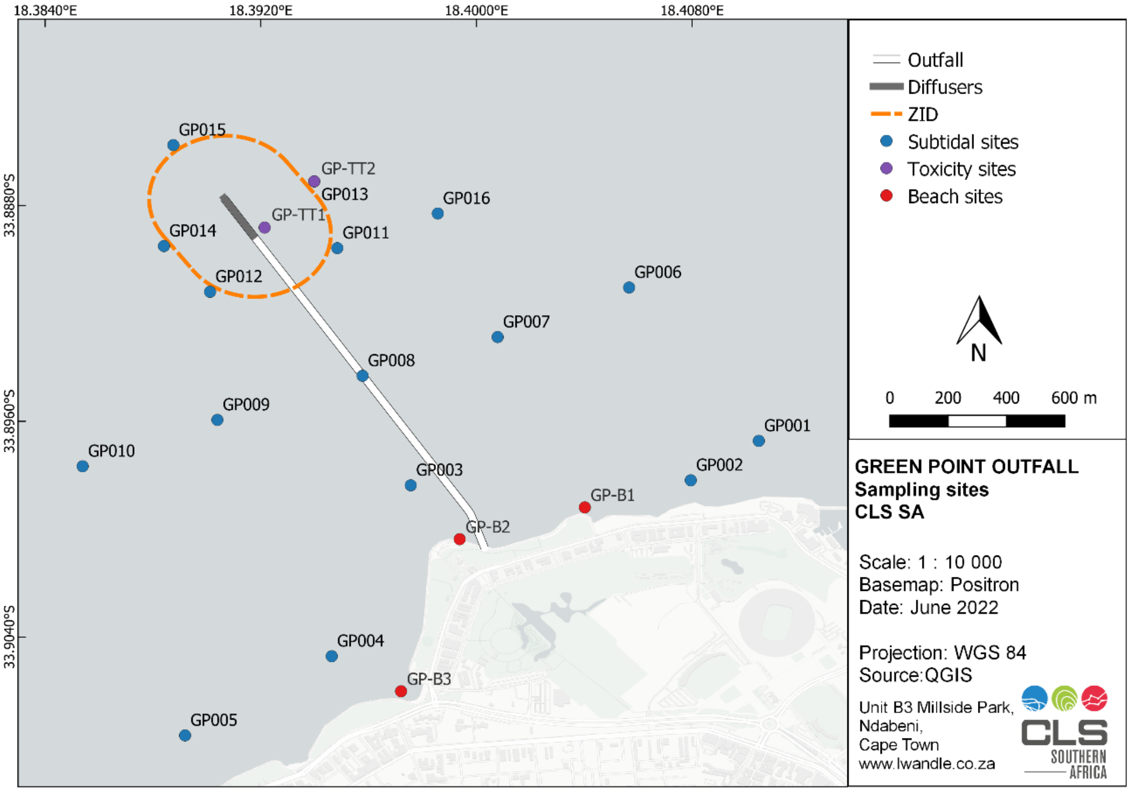

Figure 5.2: Map of the Green Point outfall and the locations of water quality sampling sites. The dashed orange line shows the allowable ZID.

CLS SA distributional plots show minimal differences in surface and mid-depth TSS median concentrations, but elevated levels can occur in bottom waters and towards the shoreline. Orthophosphate and ammonia concentrations are elevated at mid-depth and near the seabed compared to surface values in summer but are more uniform in winter. This can be attributed to summer upwelling. Enterococci distributions are varied with elevated counts at mid-depth and towards the shoreline. All CLS

SA surveys show that 90th percentile values are low in bottom waters. The mapped enterococci distributions are consistent with those modelled. 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, a screen of stations approximately midway from the ZID to the shore, nearshore stations, and beach stations.

Table 5.3: Enterococci count data (cfu/100 ml) obtained in seasonal surveys at the Green Point outfall. The data are partitioned into subsets comprising those adjacent to the allowable ZID boundary stations (GP011-GP015), a screen of stations approximately mid-distant between the discharge pipe end and shoreline (GP006-GP010), stations near the shoreline (GP001—GP005) and three beach sites (GPB-B1, GPB-B2 & GPB-B3). Red text shows counts >185 cfu/100 ml.

Data Set	n samples	90th Percentile	95th Percentile	Maximum Count Recorded
All stations	1731	47.0	141.5	20000
ZID Boundary stations	510	103.1	238.2	10000
ZID Boundary Surface	170	52.7	112.5	660
ZID Boundary Mid Depth	170	291.1	487.5	10000
ZID Boundary Bottom	170	44.3	75.1	218
Screen	510	27.0	53.6	720
Screen Surface	170	26.0	36.5	330
Screen Mid Depth	170	47.2	120.3	720
Screen Bottom	170	22.0	29.1	210
Nearshore	510	18.0	34.6	1100
Nearshore Surface	170	22.0	39.6	1100
Nearshore Mid Depth	170	17.1	36.6	220
Nearshore Bottom	170	15.1	23.6	219
Beaches	99	1182.0	3390.0	20000

The table shows that there is clear evidence that mid-depth enterococci counts in the ZID and Screen data subsets are higher than those in the surface and near the seabed, as predicted by the modelling. In terms of water quality classification according to DEA (2012) guidelines, the following is apparent:

- Over the monitoring period and within the individual seasonal survey durations receiving water quality attains the sufficient status according to the DEA (2012) guidelines (90th percentile of the counts <185 cfu/100 ml),
- Enterococci counts at or adjacent to the ZID boundary fall into the sufficient category except for the mid-depth samples. Mixing within the ZID is only partially efficient in reducing human health risks. However, it is questionable how many recreational users would be exposed to direct contact at mid-depth in the water column,
- The screen of stations meets the excellent status criterion except for the mid-depth set of samples which classify as sufficient,
- The nearshore set of samples classify as excellent,
- Highest counts were 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, and

- There is clear evidence that mid-depth enterococci counts in the ZID and Screen data subsets are higher than those in the surface and near the seabed, as predicted by the modelling. The nearshore subset has marginally higher surface counts, possibly linked to nearshore sources such as stormwater drains.

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 areas outside of the ZID. Such an event is shown in Figure 5.3. Highest counts occurred close to the outfall diffuser bank, with elevated counts distributed across the survey area, but diminished offshore, indicating a more pervasive influence of the outfall than is evident in the tabulated data above. These event scale distributions are also apparent in the modelled plume behaviour indicated, for example, by predicted *E.coli* count distributions in Figure 4.1 to Figure 4.4. These show penetration of the effluent plume into Table Bay in northward flowing currents in both seasons modelled whilst in southward flows the plume is initially transported towards the south-west but shows complex behaviour thereafter as the plume may continue in this direction or reverse and travel into Table Bay. Figure 5.4 & Figure 5.5 show examples of effluent plume dilution factor distributions which, in the main, behave similarly to those illustrated for *E. coli.* Predicted dilution factors within Table Bay are generally >10 000x whilst levels on the shoreline of the western seaboard are predicted to be 2 000x and higher indicating that low enterococci counts can occur. The modelled time series enterococci count data at selected nearshore locations indicate that such events should have short (< 1 day) durations (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 20/6/2016. 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).

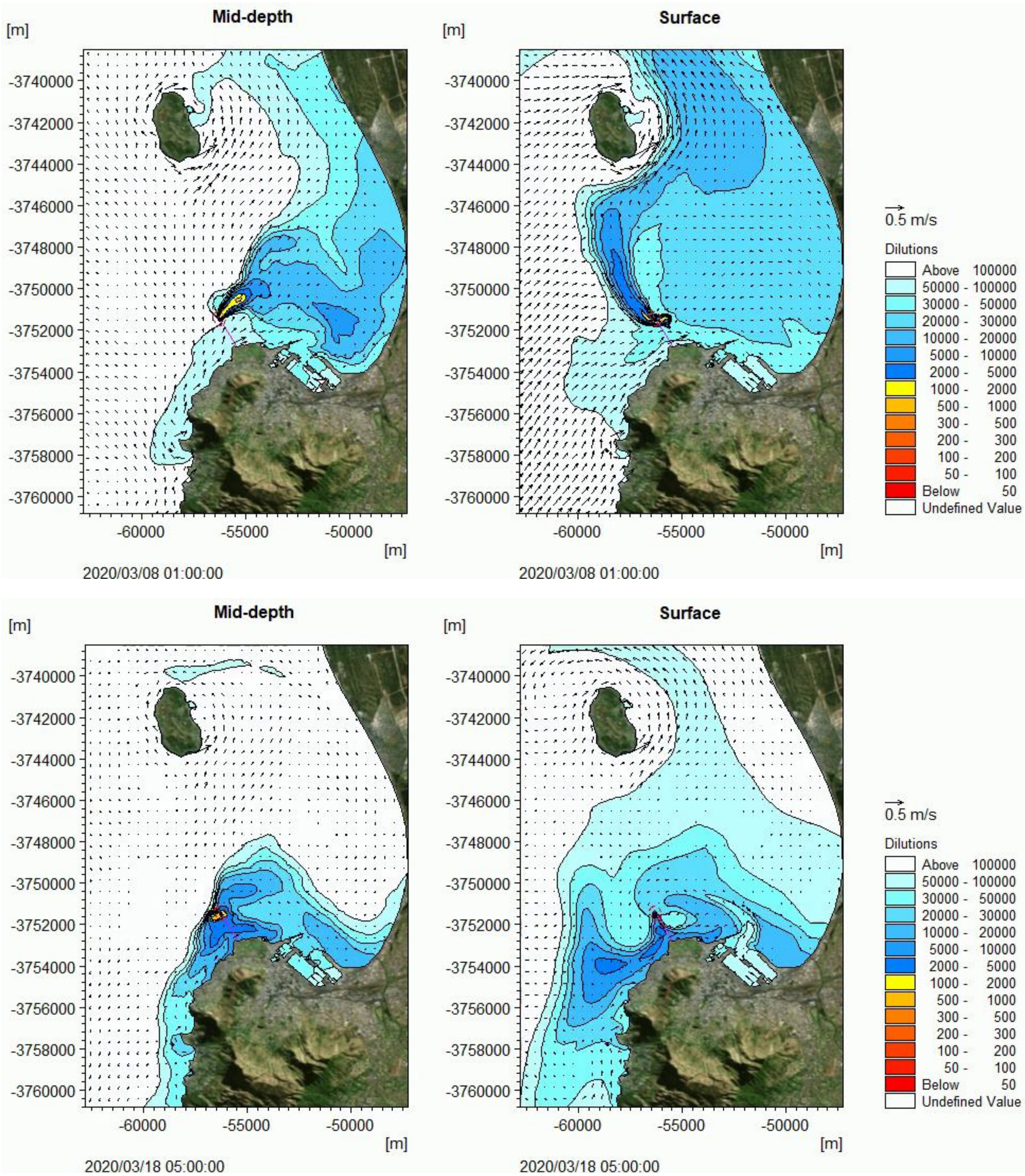

Figure 5.4:Predicted effluent plume dilution factors in the summer/autumn period at an instance in time under north-eastward flowing currents (top panel) and low velocity variable flow directions (bottom panel) (from PRDW 2020 plume animations)

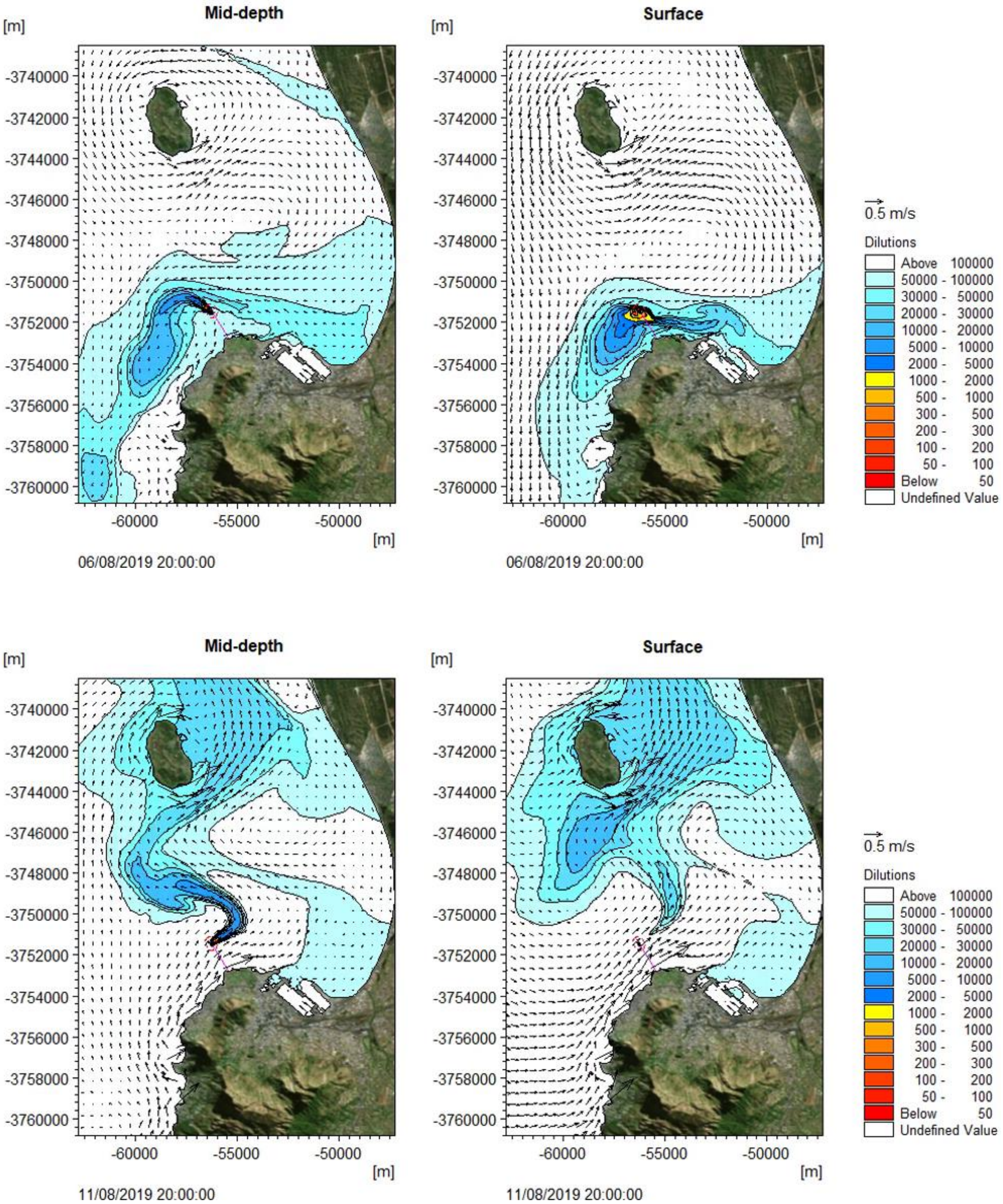

Figure 5.5: Predicted effluent plume dilution factors in the winter/spring period at an instance in time under southward flowing currents (top panel) and northerly flows (bottom panel) (from PRDW 2020 plume animations).

6 Measured Contaminants of Emerging Concern (CECs)

Twenty-one CECs, comprising pharmaceutical and personal care products, have been identified in Green Point pre-discharge effluent samples (CSIR 2017). 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 major source of such chemicals in the coastal ocean is 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 highest total concentrations occurred at sample sites influenced by wastewater treatment works. Thirty compounds were identified in winter and summer surveys at sites adjacent to the Green Point outfall (Mouille Point, Three Anchor Bay, Three Anchor Bay stormwater and Milton Pool). Eighteen compounds were recorded in the winter survey, with 16 showing the highest concentrations in the two Three Anchor Bay sites. The summer survey recorded 30 compounds, 26 of which had highest concentrations at these sites. Highest concentrations were recorded at the Three Anchor Bay stormwater site for 16 of the 18 compounds present in winter and 26 of the 30 compounds present in summer. CSIR (2022) notes that stormwater flows were low during the respective surveys, and the stormwater would be rapidly mixed into the receiving water body accounting for the distributions in concentrations.

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 Green 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 Green Point 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 Green Point effluent inorganic and organic constituents to meet water quality target concentrations (their Table 2.3 in Chapter 2). Required median dilutions were less than 250x 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 (2020) 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. Seventy-six samples were used in the toxicity bioassays, with none yielding an acute toxicity result, supporting the above inference on probable acute toxicity risk.

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 Green Point 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 Green Point 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 at Mouille Point, inshore of the Green Point 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). Body burdens of the organic compounds, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls, display mostly similar trends to trace metal burdens (figures 6.7 & 6.11 in CSIR 2017). These data show that effluent from the Green Point outfall is not influencing contaminant body burdens in mussels to the degree that gradients are established with distance from the outfall.

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. From comparisons of trace metal body burdens in mussels and rock lobster collected in the vicinity of the Green Point outfall CSIR (2017) concluded that there was no demonstrable 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 2.62×10^{10} milli Moles (mM) of ammonia-nitrogen to the sea per year (estimated from data in CSIR, 2017 and PRDW 2020). The Green Point outfall discharges 71% of this at 1.86×10^{10} 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 0.66×10^{13} and 1.51×10^{13} mM N with a mean across 10 upwelling events in the period 1984-1994 of 1.07×10^{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 2.0×10^{14} mM N to the euphotic zone. This is 4-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 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 Green Point outfall, metocean conditions and seabed topography limit its development and consequences.

8 Effects on Sediment Properties

Sediments in Table Bay are mostly sand with very low proportions of silt and mud (Woodborne 1983). Survey results for Table Bay in CSIR (2017) confirm this with all but one of the samples retrieved texturally classifying as sand. A single sample obtained southwest of the Green Point outfall diffuser bank classified as muddy sand. The Table Bay seabed is very rugose, and sediments are sparsely distributed as a thin veneer on rock and in gullies. Exceptions to this are the relatively large sediment areas in ~40 m and ~70 m depths northwest and west of the outfall (Figure 8.1). Sediment texture at both depths was primarily sand with minor proportions of mud in the deeper area areas and gravel (shell material) in the shallower location (Carter 2006).

Sediment total organic content is generally low in coarser sediments with most of the samples analysed by CSIR (2017) containing less than 1% by weight. The muddy sand sample south of the outfall is an exception containing ~7% organic content indicating an apparently isolated location of organic enrichment. The balance of the area sampled by CSIR (2017) was not organically enriched. This is consistent with the modelled fate of suspended sediments discharged through the outfall.

Consistent with the low organic content and mud fraction in the sediments trace metals in sediment samples drawn from Figure 8.1 sites A and B were all lower than the London Convention Annex 1 and 2 special care thresholds indicating minimal contamination of the two sites (Carter 2006). In a very detailed assessment CSIR (2017) detected enrichment in various metals and organic compounds in Table Bay sediments and applied a range of metrics designed to determine toxicity risks to benthic fauna. The main conclusion drawn was that the detected contaminants were unlikely to present such risks. Their review of previous sampling campaigns between 1980 and 2011 show that this was true over this period as well. This multi-decadal cover indicates 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 Green Point outfall.

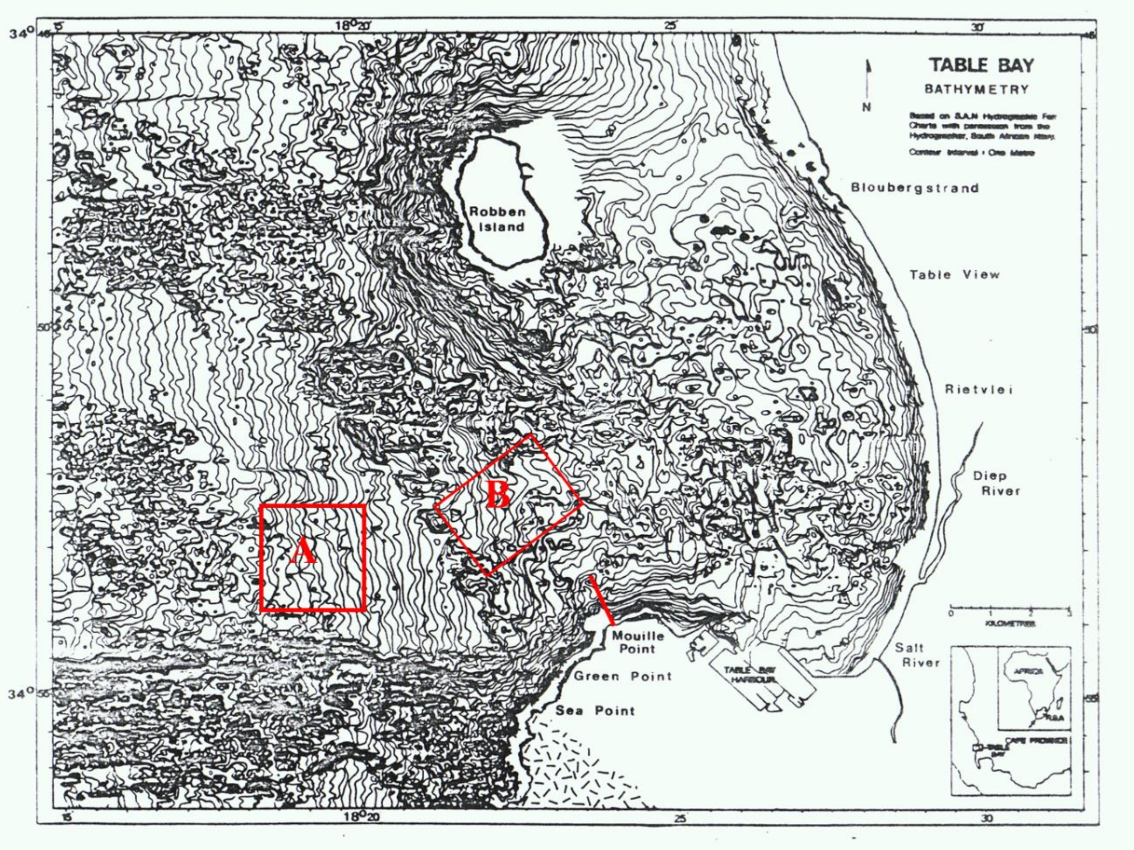

Figure 8.1: 1 m interval bathymetry contours in Table Bay. The approximate location of the Green Point outfall (red) is shown along with sediment sampling areas A in ~70 m depth and B in 40 m depth (modified from Woodborne 1983).

9 Effects on Biodiversity

There are no recent biodiversity surveys in the nearshore shallow subtidal of the Green Point outfall area that can be used to track the effects or not of 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). Further, such effects were not evident in comparisons of results of kelp bed surveys conducted in the late 1970's in the Sea Point and Melkbos areas (Field et al. 1980). These predate the installation of the present Green Point outfall and effluent was being discharged through its predecessor (above) whilst the Melkbos site was and is distant from domestic effluent ocean outfalls (but is 5.7 km south of the Koeberg Nuclear Power Station cooling water discharge that primarily affects water temperatures).

Benthic macrofauna distribution surveys at sites A and B shown in Figure 8.1 were conducted as part of the environmental baseline for offshore dredged sediment disposal in 2006 (Carter 2006). The macrobenthos taxa present were similar to those recorded elsewhere in the region as was the community structure. The sites were different in that although polychaete worms were numerically dominant in both areas, they comprised a smaller proportion of biomass in site A than in site B. In the former molluscs were the largest contributor to biomass followed by rarer but larger taxa such as peanut worms (Sipunculida). At site B the high numerical dominance of polychaetes was mirrored in the biomass distribution with molluscs, crustacea and larger taxa making a smaller contribution. Plots of the distributions of species abundance in x2 geometric classes (Gray and Pearson 1982), the shapes of which show pollution stress, did not indicate such in either of the sites surveyed.

The numeric modelling of the Green Point outfall predicted that a proportion of the particulate matter discharged with the effluent would deposit below the active wave base in >40 m water depth. Distortions of macrobenthos community structure due to such deposition are not evident in the 2006 survey data either at ~40 m or 70 m depths. Accepting that the modelled TSS fate is correct implies that the deposition rate is insufficient to cause such distortions or that the amount depositing is too low to generate such changes.

10 Conclusions

This report summarises surveys on the Green Point 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 Green Point 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 and ammonia nitrogen.
- 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.
- Hydrodynamic modelling predicts that dilutions within the ZID are not totally sufficient to negate the human health risk of the effluent plume. However, the modelling does not show that non-compliance with the enterococci guideline extends to the shoreline. Isolated event scale, enterococci counts >185 cfu/100 ml could occur adjacent to the Sea Point Pool and at the RMS Athens site. Consequently, despite water quality guidelines not being exceeded outside of the ZID the predicted human health risks, although low, are not zero.
- Measured enterococci counts in the receiving environment confirm the modelling results in that, at or adjacent to the ZID boundary, they are guideline compliant except for the mid-depth samples.
- Measured enterococci counts at screens of stations shoreward of the outfall classify as excellent (95th percentile counts <100 cfu/100 ml) apart from mid-depth in the outer screen which is in the sufficient category. 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. Thirty such contaminants have been recorded across one-off winter and summer surveys at shoreline sites at Mouille Point, Three Anchor Bay, Three Anchor Bay stormwater and Milton Pool. 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 organic compounds in mussels and there is no evidence of a link with the effluent discharged through the Green Point 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.
- 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 Green Point outfall.
- Historical surveys on kelp beds at Sea Point and Melkbos Strand do not show effects of the outfall on the kelp bed community structure. Limited surveys on benthic macrofauna distributions in sediment areas within Table Bay where modelling predicts some deposition of discharged inorganic and organic particulate matter do not show evidence of pollution stress.

The overall conclusion from the suite of surveys conducted by CCT and the somewhat sparse supporting information from independent studies is that the Green Point 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 summary 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 occurring in recreational users of the nearshore environments around the Green Point 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) 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 allowable ZID. 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 compromise ~30% of the taxa tested but be protective of 70% (Smit et al. 2008). These include zooplankton, molluscs, crustacea, fish and algae.

TSS also affects the underwater light field, and a subsidiary water quality 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 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 concentration 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 within moderate distances, e.g., 3-5 km of the outfall. 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 (as an additional explanatory variable for PAR attenuation), and 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 Green Point is difficult to access and 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. 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.

11.2.3 Discharged 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 (2020) 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 (Cyrus, 2007). Nitrogen take-up was demonstrated but the source may have been sewage contaminated stormwater flows into the nearshore. *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 Green Point outfall. 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 Milton Pool to immediately south of Granger Bay breakwater. 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 Green Point 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, e.g., stormwater 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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