Cape Town Outfalls Monitoring Programme

Technical report for surveys made in 2015/2016

our future through science






Final Report

June 2017

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

Report Details

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Date: June 2017

For bibliographic purposes this report should be cited as: CSIR (2017) Cape Town Outfalls Monitoring Programme: Surveys made in 2015/2016. CSIR Report CSIR/NRE/ECOS/IR/2017/0035/B.

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General Introduction

1.1. Introduction

Most of the wastewater that is generated daily in households, businesses and industry in the City of Cape Town is treated at 21 inland wastewater treatment works and two oxidation ponds spread across the city. Treated wastewater from these works is discharged into rivers and ultimately into the sea. However, in common with other coastal cities in South Africa and the world the City of Cape Town's liquid waste management strategy includes the discharge of wastewater into the marine environment. Thus, wastewater from households, small businesses and other sources in the Woodstock to Bantry Bay, Camps Bay and Hout Bay areas is discharged in a partially treated form into the marine environment through deepwater outfalls at Green Point, Camps Bay and Hout Bay (Figure 1). The practice of discharging wastewater into the marine environment off Cape Town is not new and in fact started in 1901 when an outfall was constructed at Mouille Point. However, this practice has been the focus of debate since 2014, when photographs showing effluent discharged through the Green Point and Hout Bay outfalls reaching the sea surface were published in the media.

The debate is understandable since wastewater (hereafter generally referred to as effluent) contains biological and chemical material that has the potential to impair the ecological functioning of a marine receiving environment and to endanger the health of humans that recreationally use or extract and consume resources from the receiving environment (*e.g.* fish and shellfish) (*e.g.* Stevens *et al.*, 2003; Nakada *et al.*, 2004; Moon *et al.*, 2008). Since most wastewater works that discharge effluent into a marine environment usually perform preliminary or primary treatment to decrease the load of suspended solids and floatables, there is an inefficient removal of other contaminants and these are introduced to the receiving environment (Chambers *et al.*, 1997; Stevens *et al.*, 2003; Nakada *et al.*, 2004; Horii *et al.*, 2007). Based on estimates of environmental releases, wastewater, whether treated or untreated, is one of the main sources of xenobiotic compounds to aquatic ecosystems (*e.g.* Chambers *et al.*, 1997; Lee *et al.*, 2014a, 2014b, 2015). Nevertheless, the discharge of partially treated effluent to the marine environment is recognised as a practical disposal option provided it is properly controlled (Roberts, 2010), such as by the inclusion of limits and controls in Coastal Waters Discharge Permits that legally authorise the discharge.

Municipal wastewater is a mix of physical, chemical and biological constituents. The composition will vary from one municipality to another and even from one part of a municipality to another depending on the number and type of households, businesses, industry and public establishments discharging wastewater into the sewer reticulation system. Sanitary sewers receive everything that is flushed down toilets or rinsed down drains in bathrooms and kitchens in households, commercial establishments and factories. Raw sewage contains a variety of substances in addition to human waste, including dirt particles, fragments of food, oil and grease, detergents and other cleaning agents, and pharmaceuticals and cosmetics amongst others. Regardless of origin the single largest constituent of raw sewage is freshwater, which usually comprises about 99.5 - 99.9% of the volume. Industrial wastewater may contain a range of constituents depending on processes leading to its generation.

The practice of discharging partially treated wastewater into the marine environment must be viewed in the context of other options for liquid waste management in coastal towns and cities in South Africa and elsewhere in the world. A properly designed marine outfall provides an efficient mechanism for the disposal of wastewater. An immediate dilution in the order of 100:1 can usually be achieved during the first few minutes after discharge for a freshwater dominated wastewater

Figure 1.1. Aerial view of the Cape Town area, showing the positions of the Green Point, Camps Bay and Hout Bay outfalls (denoted by red lines). The Table Mountain National Park Marine Protected Area and Karbonkelberg and Cape of Good Hope Sanctuary ('no take') Zones within the protected area are shown.

into the marine environment, rapidly reducing concentrations of constituents in the effluent. This reduction through dilution is beyond the capability of conventional wastewater treatment works (Roberts, 2010). Wastewater treatment works also produce biosolids (sludge) that must be disposed at landfill sites if it cannot be used as an agricultural fertiliser, reducing their life. The wastewater treatment process is also energy demanding, which itself has environmental implications depending on the electricity generation process and energy demand.

Whether the discharge of effluent to an aquatic ecosystem significantly impairs its ecological functioning depends on its assimilative capacity, that is, its capacity to receive effluent or toxic materials without significant deleterious effects to aquatic life and the health of humans that use or extract resources from that environment. The assimilative capacity is essentially a receiving environments 'pollution diet' - too much pollutant loading combined with inefficient dilution and dispersion and deleterious effects will manifest. Assimilative capacity differs between receiving environments depending on the nature of the effluent and ability of the receiving environment to dilute, disperse and degrade contaminants. Not surprisingly, the voluminous, and off the South African coastline high-energy marine environment has a higher assimilative capacity than small volume sheltered waters, such as estuaries. Of importance is the volume of effluent discharged. Thus, while the absolute concentration of contaminants in effluent might be low and elicit no acute toxicity (*i.e.* toxicity resulting in mortality) their persistent introduction may overwhelm the assimilative capacity of a receiving environment in the long-term and result in chronic toxicity (*e.g.* non-lethal effects, such as reduced reproductive potential and growth of aquatic organisms).

1.2. Outfall Design and Nature of the Effluents

Information on the dimensions of the Green Point, Camps Bay and Hout Bay outfalls is provided in Table 1.1. The wastewater works and outfalls are owned and operated by the City of Cape Town. The discharge of effluent is legally authorised under conditions provided in licence 19/G22E/H/716 for the Green Point outfall, licence 19/G22B/H/B9 for the Camps Bay outfall, and licence 19/G22E/H/653 for the Hout Bay outfall. The licences were issued by the Department of Water Affairs in 2011. However, in compliance with the Integrated Coastal

Management Act, 2008 (Act No. 24 of 2008), the City of Cape Town has applied to the Department of Environmental Affairs for the licences to be replaced by Coastal Waters Discharge Permits. This is because the responsibility for authorising wastewater discharge to the marine environment in South Africa now vests with the Department of Environmental Affairs.

A 60 m long outfall was first constructed at Mouille Point (hereafter Green Point outfall) in 1901. This outfall was replaced by a 550 m long steel outfall in 1931. This was, in turn, replaced by an outfall constructed in 1985 that extended about 1 670 m from the shoreline and discharged effluent through sixteen diffusers about 28 m below the sea surface. The present outfall serves the area from Woodstock to Bantry Bay and was commissioned in 1993 to replace the outfall constructed in 1985, which was severely damaged by storms in the winter of 1989. The present day outfall is 1 676 m long and discharges effluent through 16 diffusers about 28 m below sea level.

The Camps Bay outfall was commissioned in 1977 to replace an outfall constructed in 1927 that was inadequate for its intended purpose (Eagle *et al.*, 1977). It has not been possible to find other information on the original outfall. The present outfall, which is 1 497 m long and discharges effluent through 8 diffusers about 23 m below sea level, serves the Clifton, Camps Bay and Bakoven areas.

The Hout Bay outfall was commissioned in 1993. It replaced the practice of discharging effluent from septic tanks and fish factories into the surf zone at Badtamboer, about 800 m southwest of the harbour. The pump station is situated about 260 m to the south of the Hout Bay harbour. The outfall runs due east from the pump station and is buried shortly after entering the sea. The pipeline doglegs and then runs southwest, parallel to the coastline (MacHutchon, 2012; this study provides excellent multi-beam and side-scan sonar images of the seabed and associated anthropogenic features, including the outfall, in the Hout Bay area). The outfall is buried for most of this section and is only exposed about 80 m northwest of the wreck of the Astor. From this point on it is exposed for 650 m to its terminus. Because the inner part of the outfall is buried only the exposed portion is illustrated in Figure 1 and other figures in this report. Effluent is thus discharged 2 162 m from the (sandy) shoreline, about 39 m below sea level.

The wastewater works for the Green Point and Camps Bay outfalls comprises a pre-treatment works, where sand and grit are removed and the wastewater is screened (3 mm) to remove plastic, paper, rags and other foreign material. The effluent is then discharged to the marine receiving environment. This type of treatment is known as preliminary treatment. The same procedure is followed at the Hout Bay wastewater works except here the wastewater is also macerated. The screened material from all wastewater works is disposed at landfill sites.

1.3. Brief Description of the Marine Receiving Environments

1.3.1. Outfall Locations

The physiography of Table Bay is relatively well understood and has been summarised by Quick and Roberts (1993), Carter (2006) and van Ballegooyen *et al.* (2006), from which most of the information provided below is extracted. Carter (2006) also

Table 1.1. Design dimensions of the Cape Town outfalls and permissible, current and design discharge volumes. HDPE = high density polyethylene.

Outfall	Date Commissioned	Length (m)	Outer Diameter (mm)	Design Capacity (Ml.day^{-1})	Current Discharge (Ml.day^{-1})	Licence Discharge (Ml.day^{-1})	Discharge Depth (m)	Number of Diffusers
Green Point	1993	1 676	800 HDPE	40.0	28.4	27.3	28	16
Camps Bay	1977	1 497	450 HDPE	5.0	2.4	2.3	23	8
Hout Bay	1993	2 162	550 HDPE	9.6	5.7	5.2	39	14 (5 in operation)

provides an excellent discussion on key ecological features and characteristics of the greater Table Bay area.

Table Bay is a large, log-spiral bay, with a water surface area of about 105 km^2 and depth of about 35 m in the centre of the bay (van Ieperen, 1971; cited in Quick and Roberts, 1993). Water depth increases in a westerly direction, reaching about 70 - 80 m at an imaginary line extending between Mouille Point and the western shore of Robben Island. The seabed in Table Bay is covered by thin layers of sand, but there are fairly extensive areas of exposed bed rock (reef) (Woodborne, 1983). The nearshore region between Blouberg and the Port of Cape Town is generally comprised of fine sand, with a tongue of finer (but still sand-dominated) sediment extending from the nearshore seaward to about 25 m depth between Table View and Rietvlei. Smaller pockets of finer-grained sand are found at the entrance to Table Bay and near Robben Island. The remaining areas of Table Bay are covered by medium-grained sand (Woodborne, 1983; CSIR, 1997). The major sources of the sand to Table Bay are seasonal (mainly winter) inputs from the Diep and Salt rivers and local erosion of Malmesbury shales (Quick and Roberts, 1993). There is little appreciable sediment supply due to longshore transport from the south along the Cape Peninsula (MacHutchon, 2012). Sediment is transported in and from Table Bay by wave and storm driven turbulence, with an estimated residence time for surficial sediment of 2 - 3 years (CSIR, 1997). The shoreline of Table Bay comprises 3 km of rocky shore at Blouberg and Mouille Point, approximately 13 km of sandy beach between Blouberg and the Port of Cape Town, and 4 km of artificial shore protection and breakwaters at the Port of Cape Town.

Camps Bay is a relatively small bay, about 850 m wide. The bay is bounded by rocky headlands at Maidens Cove and opposite Camps Bay Drive. The seabed is mix of sand and exposed bed rock (based on a side scan sonar image provided by Wilhelm van Zyl, Council for Geoscience). The area inshore of the outfall diffuser section is comprised mainly of sand, but at, and to the north and south of the diffuser section the cover of exposed bed rock interspersed with pockets of sediment is extensive (see also Eagle *et al*., 1977). The beach at Camps Bay is popular for bathing in summer. The area to the north and south of Camps Bay is comprised of pocket beaches of various sizes situated between rocky headlands and shores.

Hout Bay is situated about 15 km south-southwest of Table Bay. The bay is surrounded by high mountains and provides good shelter for vessels against strong north-westerly winds in winter. The bay is about 2.5 km long and 2 km wide and is open to the sea on the southwest. While the northern shore is sandy, steep rocky cliffs form the eastern and southeastern shoreline. The eastern shore becomes increasingly steep and rocky is it curves around to the open sea. Hout Bay Harbour is situated on the northwestern side of the bay. The sandy shoreline is bisected by the Disa (Hout Bay) River, which has a relatively small catchment and flows weakly during summer. The beach at Hout Bay is popular for bathing in summer, while the world renowned big wave surfing spot of Dungeons is situated a little outside the bay, on its north side. The seabed in and near Hout Bay is characterised by a patchwork of prominent, subdued and scattered reef (mainly on the western margin of the bay and to the northwest of bay entrance), bioclastic gravel (shell hash) and sand (MacHutchon, 2012). Water depth increases gradually from the sandy shoreline, reaching about 38 m just outside of an imaginary line extending between The Sentinel and Chapmans Peak, but being considerably shallower on the western and eastern parts of this imaginary line.

Although the focus in this survey is on the Green Point, Camps Bay and Hout Bay outfalls, there are also outfalls that serve the Chevron facility at Milnerton and Robben Island Museum at Robben Island. The impact of effluent discharge through the Chevron outfall is monitored on a three yearly basis. The monitoring has not provided evidence the discharge is significantly adversely impacting the ecology of the marine receiving environment, at least not in relatively close proximity to the outfall diffuser section (CSIR, 2016a). Although no contemporary information could be found on the impact of effluent discharge through the Robben Island outfall, Prochazka (2003; cited in WSP, 2014) reported little significant impact attributable to effluent discharge through a previous outfall that served the island, although the number of filter feeders, grazers and detritivores near the outfall diffuser section was higher than further away. However, Pulfrich (2014; report included in WSP, 2014) questioned the veracity of the findings based on the study design (short duration after discharge start-up and lack of control sites) and since there appeared to be evidence in 2014 of potential eutrophication impacts, this evident in abundant growth of algae (mainly *Ulva* spp) on the rocky shoreline inshore of the outfall discharge point.

1.3.2. Oceanography

The oceanography of Table Bay is relatively well understood and has been summarised by Quick and Roberts (1993), Carter (2006) and van Ballegooyen *et al.* (2006), from which most of the information below is extracted.

Table Bay is situated in the southern Benguela upwelling system and its circulation and water properties are characteristic of the region. Water movement within the bay is almost exclusively wind-driven, experiencing minor effects from shelf currents further offshore and with waves and swell playing an influential role in the nearshore (van Ieperen, 1971; cited in Quick and Roberts, 1993). Water movement is further influenced by tides, although this is considered minor.

The wind-driven currents differ from summer to winter according to the predominant wind directions. The predominant current direction is to the north (81% in summer and 69% in winter) (van Ieperen, 1971; cited in Quick and Roberts, 1993). Wind from a south-easterly direction results in currents that tend to flow northwards, resulting in an anti-clockwise motion in the bay. Conversely, winds from a north/north-west drive water to the south, producing a slight clockwise motion in the bay. During summer upwelling, cold water (9 - 13^{o}C) intrudes into Table Bay from the Oudekraal upwelling centre, south of Table Bay, resulting in generally shoreward bottom flows. Temperatures can increase rapidly to >20^{o}C during relaxation phases of the upwelling cycle as water flows into Table Bay from the north and northwest (CSIR, 1997). Upwelling and solar heating leads to a highly stratified water column during summer.

During the winter months there are frequent strong north-westerly wind events to the area, causing clockwise water flow within the central part of the bay. Winter seawater temperatures are more uniform than in summer and fall into the narrow range of 14 - 16^{o}C, as there is no upwelling and strong mixing of the water column driven by storms. Typical wind-driven surface current velocities are between 20 - 30 cm.s^{-1} with bottom velocities much reduced to less than 5 cm.s^{-1}. Such velocities would indicate long residence times of water within the bay. van Ieperen (1971; cited in Quick and Roberts, 1993) estimated the residence time of water in Table Bay to vary from 15 to more than 190 hrs, with an average of approximately 4 days (96 hrs). This particularly applies to the bottom waters where van Ieperen (1971; cited in Quick and Roberts, 1993) noted that currents were undetectable in 80% of the measurements made over an annual cycle. Quick and Roberts (1993) were of the opinion that the flushing of Table Bay is relatively poor and needs to be taken into account when using the bay to assimilate anthropogenic waste, particularly as there is a poor flushing of bottom waters. However, the CSIR (1990), after assessing current data provided by Atkins (1970) and van Ieperen (1970), concluded that onshore currents at a distance of about 1 600 m offshore (about the distance at which the Green Point outfall diffuser section is situated) occurred only 5% of the time compared to about 25% of the time at a distance of about 690 m offshore. There was a strong seasonal difference in the direction of current flow, these occurring about 39% of the time based on the travel of drogues released about 690 m from the shoreline in winter, but about 10% of the time in summer. There was sharp decrease in the proportion of onshore currents with distance offshore, at 4 and 6% for summer and winter respectively. The CSIR (1990) concluded that because easterly longshore currents into Table Bay occur more frequently than south-westerly currents towards Sea Point combined with the infrequent onshore currents made Green Point an attractive site for a marine outfall. The CSIR (1990) also concluded that effluent was likely to rarely reach the shoreline.

The salinity of Table Bay was investigated by van Ieperen (1971, cited in Quick and Roberts, 1993).

Salinity ranged between 34.7 and 35.3, with very little difference across the bay. Two rivers, the Diep and Salt, flow into Table Bay, with lower salinity near the mouths of these rivers.

Currents in Hout Bay are governed by the dominant meteorological conditions for a particular period. In summer, with predominant southeast winds, a northerly flow dominates, with the opposite true in winter when northwesterly winds dominate. The CSIR (1986) recorded current speeds at two positions in Hout Bay that varied between 3 - 50 cm.s^{-1}, with speeds predominantly in the range 10 - 20 cm.s^{-1}. The dominant current directions are northwest toward Badtamboer for 40% of the time, south for 30% of the time, southwest (offshore) for 10% of the time, and northeast (into the bay) for 20% of the time.

Atkins (1965; cited in Harris, 1978) tracked currents in the Camps Bay area using surface floats. Float trajectories were complex, with little apparent correlation with wind. None of the float trajectories in a figure provided in Harris (1978) taken from Atkins (1965) appear to reach the shoreline apart from one (at Maidens Cove), but numerous floats were transported into and then from the bay.

1.3.3. Beneficial Uses

The marine environment in Table Bay and along the western (Atlantic) side of the Cape Peninsula has many beneficial uses that in some way or other could be impacted or influenced by effluent discharge through the Green Point, Camps Bay and Hout Bay outfalls. These include bathing, surfing, sailing, recreational and commercial fishing and shellfish harvesting, tourism (land and sea-based), and marine protected areas amongst others. It is beyond the scope of this report to describe in detail where these beneficial uses take place save to state that much of the peninsula is a high use area.

The whole of Table Bay is a declared rock lobster sanctuary, where commercial and recreational fisheries are not permitted. The Table Mountain National Park has an associated multiuse Marine Protected Area. The northern boundary of the Marine Protected Area extends 14 km west of Mouille Point and then south to Cape Point (Figure 1.1). Commercial and recreational fishing and shellfish harvesting are permitted within the boundaries of the Marine Protected Area, but there are several 'no take' sanctuaries where any form of fishing or shellfish harvesting is prohibited. Two ‘no take’ sanctuaries are situated on the western side of Cape Peninsula, namely the Karbonkelberg and Cape of Good Hope Sanctuary Zones (Figure 1.1). Robben Island in Table Bay is a provincial nature reserve but has no formal status as a Marine Protected Area.

The Cape Town outfalls study area provides habitat for a large variety of marine fauna and flora and it is beyond the scope of this report to discuss these in detail. Of importance, however, are seabirds and west coast rock lobsters (*Jasus lalandii*). It is estimated that in 2005, more than 60% of the global population of African Penguins (*Spheniscus demersus*) were foraging in continental shelf waters in and adjacent to Table Bay, these birds coming from the breeding sites at Dassen and Robben Islands (Crawford, 2006). Robben Island is also an important breeding site for Bank Cormorants (*Phalacrocorax neglectus*), which are endemic to the Benguela Upwelling System. It supports the third largest breeding colony in existence. Both African Penguins and Bank Cormorants have undergone severe declines in population size and are classified as Endangered under International Union for the Conservation of Nature criteria (BirdLife International, 2016, 2017).

West coast rock lobsters have been subjected to intense fish pressure to the extent that the population is widely considered to be severely overfished.

1.4. Outfall Design and Factors that Influence Effluent Dilution and Dispersion in the Marine Environment

In 2014, photographs showing effluent reaching the sea surface near the Green Point and Hout Bay outfall diffuser sections were widely published in the social and printed media. These and subsequent photographs and videos of effluent reaching the sea surface near the Green Point and Camps Bay outfall diffuser sections have been accompanied by extensive public debate and comment on the practice of discharging preliminary treated effluent into the marine environment off the Atlantic seaboard of Cape Town. The concern is understandable, even if some comments and claims are, in the opinion of the scientists that prepared this report, uninformed.

The examination of satellite images provided in Google Earth shows that effluent discharged through the Green Point outfall reaches the sea surface fairly frequently, and that effluent discharged through the Camps Bay and Hout Bay outfalls also reaches the sea surface, but less frequently. This said, recent maintenance of the Green Point outfall diffuser section (including partially blocked diffusers) may have resulted in effluent discharged through the Green Point outfall reaching the surface less frequently than was previously the case (personal communication with Werner Rossle, City of Cape Town). Considering the debate around effluent reaching the sea surface it is worthwhile providing considering outfall design and factors that influence the dilution and dispersion of effluent in the marine environment.

Outfalls are not open ended pipes. Rather, effluent is discharged through a series of ports (diffusers) on the so-called diffuser section of an outfall, the end of which is capped. The diffuser section is the last part of an outfall and may have dimensions of a few to hundreds of meters depending on the number of diffusers. The number of diffusers is dictated by the need to disperse and dilute the effluent in the relevant receiving environment, and nature of the effluent. For example, there are 16 diffusers on the Green Point outfall and 14 on the Hout Bay outfall. However, nine diffusers on the Hout Bay outfall are 'blanked off' to ensure effluent is discharged at an appropriate pressure based on the present discharge volume. Effluent is discharged through the diffusers at a fairly high pressure, generated either by gravity flow or mechanical pumping. The diffusers are designed to create a turbulent jet of effluent that serves to intensely mix the effluent with the receiving water, to promote the dilution of effluent constituents. More significant mixing occurs when the buoyant effluent ascends through the water column. The buoyancy is a consequence of the effluent being comprised predominantly (99.5 - 99.9%) of freshwater, which is less dense than seawater. During mixing the effluent is progressively diluted with the seawater, becoming denser and thereby losing momentum and buoyancy. The diluted effluent will either reach the sea surface or stop rising at some depth below the surface when it reaches neutral buoyancy, forming a plume that is then dispersed by currents. There is thus a zone of intense mixing around the diffuser section of an outfall, within which concentrations of effluent constituents are usually allowed to exceed locally accepted values for natural waters. This is variously referred to as the zone of initial dilution, nearfield mixing zone, or regulatory mixing zone, but will generally be referred to in this report as the zone of initial dilution. Typically, about 90% of effluent dilution occurs in the nearfield. Effluent is dispersed passively in the farfield, with a rate of dilution far lower than in the nearfield.

Effluent is more likely to reach the sea surface if diffusers are blocked, currents are weak, the water column is weakly or not thermally stratified, and the effluent is discharged at a relatively shallow depth. Thermal stratification refers to a marked change in temperature through the water column, often over a few meters, with water above the thermocline being warmer than that below. Because temperature influences water density, rising effluent may not be able to 'penetrate' the thermocline and become trapped beneath the thermocline depth. In this situation dilution is less pronounced than if there is no thermocline. If currents are fairly strong then effluent is diluted and dispersed below the sea surface.

Strictly speaking, the vertical distance from the diffusers to the centreline of the effluent plume when it reaches neutral buoyancy or the sea surface is called the height-of-rise, and the dilution achieved at the completion of this process is called initial dilution. It is generally agreed the zone of initial dilution should have a maximum size that is agreed by regulators and stakeholders depending on the nature of the effluent and the receiving environment. In some countries a limit to the size of the zone of initial dilution is set. For example, in Scotland the size is normally set at 100 m from the centre of the 'boil', or from the nearest diffuser in the event of a multi-diffuser setup (SEPA, 2013). A similar size is used in the State of Queensland in Australia (DEHP, 2016). In South Africa, the historical rule of thumb approach was to consider the zone of initial dilution as twice the average depth of the diffuser section of an outfall. Thus, the zone of initial dilution for the Green Point outfall could be taken as 56 m and that for the Camps Bay and Hout Bay outfalls as 56 and 78 m respectively. The Department of Environmental Affairs (Anchor, 2016) has provided draft criteria for defining the spatial extent of the mixing zone for an outfall, and at which margin water quality must be compliant with water quality targets. The criteria state that the mixing zone may not extend more than 300 m in any direction from the diffuser of a single diffuser outfall. In the event an outfall has more than one diffuser, the combined mixing zone for each diffuser may not exceed the total area encompassed by a circle of 300 m radius. Thus, if there are two diffusers then the mixing zone extends 150 m from each diffuser, and so on. If this approach is followed for the Green Point outfall, which has 16 diffusers, the mixing zone extends 75 m from each diffuser. In the case of the Camps Bay outfall, which has eight diffusers, the permissible mixing zone extends 106 m from each diffuser, while the mixing zone for the Hout Bay outfall extends 134 m from each of the 5 operational diffusers.

The minimum amount of dilution until effluent reaches neutral buoyancy is known as the minimum initial dilution. It is a theoretical value that is usually estimated through numerical modelling or by measuring the dilution of a tracer dye discharged along with the effluent under calm (essentially stagnant) conditions, that is, in the more-or-less absence of current flow (worst case condition). Through numerical modelling the CSIR (1990) estimated the minimum initial dilution for the Green Point outfall damaged by storms in 1989. The outfall was of a similar length and diffuser configuration to the present outfall. The minimum initial dilution was estimated as 280 for an effluent flow rate of 336 $l.s^{-1}$ and 220 and 170 for flow rates of 463 and 984 $l.s^{-1}$ respectively. However, the minimum initial dilution increased to 330, 270 and 180 at these flow rates respectively for a new outfall diffuser section design recommended by the CSIR (1990). The CSIR (1990) also estimated the proportion of time the effluent was predicted to reach the sea surface, at about 19, 25, and 55% of the time for effluent flow rates of 336, 463 and 984 $l.s^{-1}$. This estimate differed only minimally to predictions for the damaged outfall. The CSIR (1990) also estimated secondary dilution in the farfield to determine if faecal indicator bacteria were likely to reach the shoreline. At the highest effluent flow rate (984 $l.s^{-1}$) the number of dilutions directly onshore of the outfall and at Sea Point and Milnerton exceeded 6 000, 14 000 and 500 000 respectively for 99% of the time (these increase markedly at lower effluent flow rates). It was further estimated that faecal coliform colony forming unit counts directly onshore of the outfall would be <910 - 1600 for 99% of the time, and <25 - 31 for 90% of the time depending on three effluent flow rate scenarios discussed above. Effluent was not predicted to reach the shoreline 90% of the time.

Toms and Botes (1986) estimated a minimum initial dilution through numerical modelling for the Camps Bay outfall at 300, but empirical measurements using a tracer dye provided dilutions of 680 - 880. However, Toms and Botes (1986) discussed challenges in establishing the minimum initial dilution for the outfall, including that at the time the effluent flow was not sufficient for continuous pumping. Rather, effluent was pumped (discharged) in five minute cycles, resulting in irregular dye discharge.

Botes and Kapp (1995) estimated mean, median and 95th percentile dilutions of effluent for the Hout Bay outfall as 8 000, 6 890 and 4 043 respectively under near stagnant conditions (current speed = 0.02 $m.s^{-1}$). However, the mean, median and 95th percentile dilution for effluent that was trapped below a weak thermocline at the time was lower, at 640, 460 and 120 respectively. Because of the limited amount of measurements made Botes and Kapp (1995) considered the minimum initial dilution as 120, but were of the opinion this was too low and unlikely to be realistic (*i.e.* would probably be somewhat higher).

The initial dilution of buoyant effluent discharged at depths >20 m is usually about 200 times under calm conditions and >1 000 times in current flows >0.2 $m.s^{-1}$ (DWAF, 2004). Minimum initial dilutions of 200 can thus theoretically be expected for the

Green Point, Camps Bay and Hout Bay outfalls provided the water column is not strongly stratified.

Based on the concept of a zone of initial dilution (or mixing zone) there is an area around an outfall wherein water quality can reasonably be expected to be compromised on a regular basis. Although the concept is widely applied and effluent discharge licences or permits usually make allowance for a mixing zone, mixing zones are designated to manage the discharge of toxicants that do not bioaccumulate and whose impacts are primarily related to their concentration. The use of a mixing zone is not appropriate for managing the discharge of nutrients or bioaccumulatory and particulate substances. With respect to nutrients, stimulation of microalgal (*e.g.* phytoplankton) growth may occur a considerable distance from an outfall and be mediated by the biological characteristics of the receiving environment as a whole. For an effluent that contains compounds that biomagnify in the food web, gradual dilution might not necessarily keep concentrations of these compounds below acceptable levels even if they meet acute toxicity targets at the margin of the zone of initial dilution. For sedentary benthic organisms (*e.g.* worms) that are acutely sensitive to effluent constituents the mixing zone may also become a 'sacrificial' zone (*e.g.* CSIR, 2016).

1.5. Purpose of this Report

To ensure the integrity of a marine receiving environment is not unacceptably compromised the Department of Environmental Affairs issues Coastal Waters Discharge Permits in terms of the Integrated Coastal Management Act, 2008 (Act No. 24 of 2008). The permits stipulate the conditions under which the discharge is legally authorised. As stated previously, this competency was previously vested in the Department of Water Affairs (now the Department of Water and Sanitation), and the City of Cape Town has the required licenses from this authority. As also stated previously, the City of Cape Town has applied to the Department of Environmental Affairs for Coastal Waters Discharge Permits for the Green Point, Camps Bay and Hout Bay outfalls, but these have not yet been issued and this will in part depend on the findings of this survey. Effluent discharge is thus continuing in terms of the conditions set out in the existing licenses issued by the Department of Water Affairs. A condition of the licenses and a condition that will inevitably be included in Coastal Waters Discharge Permits (should these be issued) is that the City of Cape Town must implement and report on the findings of an environmental monitoring programme that has the objective of assessing the impact of the discharge on the ecology of the receiving marine environment. In compliance with this condition the City of Cape Town appointed the CSIR to monitor the impact of effluent discharge through the Green Point, Camps Bay and Hout Bay outfalls on the marine receiving environments. This report presents the findings of surveys made in 2015/2016. A purpose of this report is to demonstrate compliance with the condition of authorisation for effluent discharge in terms of environmental impact monitoring and reporting. The report serves the equally important roles of providing managers of the Green Point, Camps Bay and Hout Bay wastewater works with strategic information for managing the discharges and of informing the public on the status (or health) of the marine receiving environments.

1.6. Structure of this Report

The 2015/2016 survey of the Cape Town outfalls monitoring programme was comprised of several components. This report is organised so that the findings of each component are provided in a separate chapter, with relevant information (*e.g.* Materials and Methods, Results and Discussion) contained therein. The chapters are:

Chapter 1: General Introduction
Chapter 2: Effluent Characterisation,
Chapter 3: Effluent Toxicity
Chapter 4: Water Quality
Chapter 5: Sediment Quality
Chapter 6: Concentrations and Human Health Risks Posed by Chemicals in the Tissue of Black Mussels and West Coast Rock Lobsters
Chapter 7: Conclusions

The Literature Cited and a Glossary of Terms and Acronyms is provided, while most raw data are included as appendices to the report (raw data for some chapters are too voluminous to include).