

Chapter 2

Effluent Characterisation

2.1. Introduction

Outfall monitoring programmes usually focus on the effluent receiving environment since this is where ecological impacts and human health risks posed by the discharge may manifest. However, information on the physical and chemical characteristics of an effluent provides important information for estimating ecological and human health risks posed by its discharge into a receiving environment, for identifying chemicals that should be targeted for analysis in various environmental media in the receiving environment (*e.g.* water, sediment) based on their propensity to remain dissolved in water or to accumulate in sediment or biological tissue and their known toxicity, and for managing the discharge (*e.g.* by altering treatment, volume of discharge etc.). Effluent characterisation thus focusses principally on identifying chemicals that may be cause for concern because they are (consistently) present at elevated concentrations in effluent, are known to pose ecological and/or human health risks at elevated concentrations in aquatic ecosystems, and are resistant to physical and biological degradation and thus readily accumulate in sediment and/or the tissue of aquatic organisms and in this way may be biomagnified through the food web. Characterising an effluent also provides information on whether its physical and chemical properties are compliant with limits prescribed in licenses or permits that legally authorise the discharge.

If concentrations of constituents in an effluent are integrated with the theoretical (modelled) or known (verified) minimum initial dilution for an outfall through which the effluent is discharged this permits an estimate of their concentration after initial dilution in the receiving environment through the use of simple mass balance modelling. Although the composition of effluent is taken into account during the outfall design process, mass balance modelling allows for the continual assessment of the potential for water quality impairment in the

receiving environment related to changes in an effluents composition with time and/or due to chemicals that may not have been considered in the design process.

This chapter discusses the findings of the physical and chemical analysis of effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2015 and 2016 and includes a discussion on the estimated number of dilutions required to reduce concentrations of effluent constituents to targets for ecosystem protection in the marine receiving environments.

2.2. Materials and Methods

2.2.1. Fieldwork

Final effluent (*i.e.* to be discharged) was collected from the Green Point, Camps Bay and Hout Bay wastewater works by the Scientific Services Branch of the City of Cape Town daily. For this study the findings of analyses on effluent collected between 1 March 2015 and 30 September 2016 are discussed. The results are considered to reliably reflect the temporal variation in the physical and chemical characteristics of effluent from each wastewater works.

At approximately two month intervals over an eight month period in 2016 additional effluent was collected and analysed for organic chemicals and pharmaceutical compounds that are not routinely analysed for by the Scientific Services Branch of the City of Cape Town (or other effluent dischargers in South Africa). The suite of organic chemicals and pharmaceutical compounds analysed represents chemicals often detected in effluent in other parts of the world. The results of these analyses probably do not reliably reflect the temporal variation in organic chemical and pharmaceutical compound concentrations considering only four samples were analysed, but the analyses were performed to develop an understanding on the prevalence and concentrations of these chemicals in the effluents

and to identify chemicals for analysis in sediment, mussels and rock lobsters collected in the marine receiving environments.

The effluent samples were held on ice until return to the laboratory, where they were refrigerated at 4°C until analysis or transfer to CSIR laboratories. Samples were transferred to CSIR laboratories and where relevant from there to international laboratories on ice.

2.2.2. Laboratory Analyses

The Scientific Services Branch of the City of Cape Town analysed the effluent for a suite of physical and chemical indicators at daily, weekly or monthly intervals. Some samples were analysed at CSIR laboratories in Stellenbosch and Durban and by the Eurofins/Omegam laboratory in the Netherlands. The Scientific Services Branch and CSIR laboratories are accredited by the South African National Accreditation System while the Eurofins/Omegam laboratory is accredited by the Dutch Accreditation Council. The effluent was analysed using procedures and instruments too numerous and voluminous to describe here but are available on request unless of a proprietary nature. Samples destined for pharmaceutical compound analysis for one survey were damaged in transit. Note the term pharmaceutical compound, as used in this report, includes what would ordinarily be considered pharmaceuticals (medicines), plus anti-bacterial compounds and compounds found in personal care products amongst others.

2.3. Results and Discussion

2.3.1. Physical and Chemical Properties of Effluent

A time series of the values/concentrations of various physical and chemical constituents analysed in effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016 is provided in Figures 2.1 - 2.5. The degree to which values/concentrations of various effluent constituents comply with limits (Table 1) included in licenses that legally authorise effluent discharge through each outfall into the marine environment is discussed below. The licenses do not, however, provide guidance on whether constituents in all

samples analysed should be compliant with the limits or if there is latitude (e.g. 95th percentile of samples should be compliant) to accommodate anomalous events or upset conditions. It should be noted in this context that some jurisdictions use a monthly average to determine compliance in the event an effluent constituent is measured in more than one effluent sample collected within a month, but an in or out of compliance approach if a single sample is analysed. Some jurisdictions also prescribe different approaches for assessing compliance depending on whether grab and composite effluent samples are analysed. The approach followed in this study was to consider in or out of compliance regardless of the number of effluent samples analysed in the absence of guidance from the Department of Environmental Affairs for determining compliance.

The conductivity of effluent from the Green Point wastewater works was, on average, higher and more variable than that for effluent from the Camps Bay and Hout Bay wastewater works (Figure 2.1). The conductivity of effluent from the Camps Bay wastewater works was the least variable and, on average, the lowest. Licenses authorising effluent discharge through the outfalls do not include a limit for conductivity.

The pH of effluent from the Green Point wastewater works was less variable and, on average, slightly lower than that for effluent from the Camps Bay and Hout Bay wastewater works (Figure 2.1). A condition of the licenses authorising effluent discharge through the outfalls is that the pH of the effluent should fall within the range 5.5 - 9.5 (Table 2.1). The effluent from each wastewater works was 100% compliant with this condition.

The total suspended solids concentration in effluent from each wastewater works varied considerably over time and was periodically high to extremely high in Hout Bay effluent (Figure 2.1). This said, an extremely high concentration (taken here as >15 000 mg.l⁻¹) was evident in only four samples collected from the Hout Bay wastewater works over a two week period in May 2015. The source of the high suspended solids concentrations is uncertain. A condition of the licenses authorising effluent discharge through the outfalls is that the

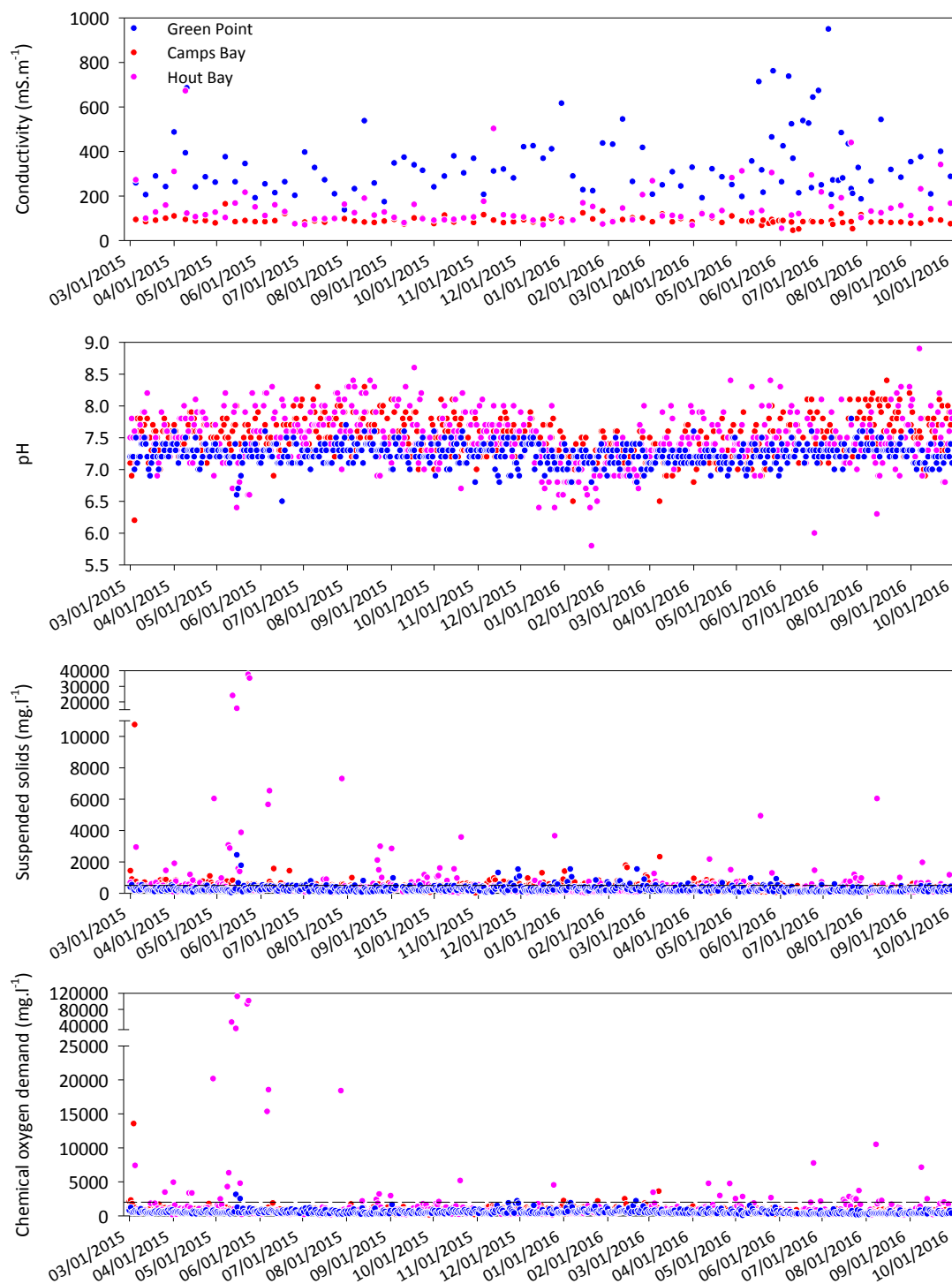


Figure 2.1. Time series of value/concentration of various physical and chemical constituents in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. The horizontal dashed lines in the total suspended solids and chemical oxygen demand plots represent limits specified in licenses authorising the discharges.

total suspended solids concentration should not exceed 500 mg.l⁻¹ (Table 2.1). Effluent from the Green Point, Camps Bay and Hout Bay wastewater works was 92, 78 and 80% compliant with this condition respectively.

The chemical oxygen demand of all effluents was moderate to high, but occasionally extremely high

(Figure 2.1). However, an extremely high chemical oxygen demand (taken here as >10 000 mg.l⁻¹) was relevant to a single effluent sample collected from the Camps Bay wastewater works in March 2015 and nine effluent samples collected over an extended period from the Hout Bay wastewater works. Four of the latter samples are the same as those with an extremely high total suspended solids

concentration. For each effluent the correlation between the chemical oxygen demand and total suspended solids concentration was strong to very strong, probably implying that the chemical oxygen demand was linked to the breakdown of suspended organic matter. A condition of the licenses authorising effluent discharge through the outfalls is that the chemical oxygen demand should not exceed 2000 mg.l⁻¹ (Figure 2.1). Effluent from the Green Point, Camps Bay and Hout Bay wastewater works was 99, 99 and 91% compliant with this condition respectively.

Nutrient concentrations were broadly comparable amongst the effluents, but at least one nutrient was periodically present at a high to very high concentration in each effluent (Figure 2.2). As expected the contribution of nitrate + nitrite to the total nitrogen concentration was typically trivial. The orthophosphate concentration was typically moderate, but occasionally very high in Hout Bay effluent (Figure 2.2). Very high ammonia (taken here as >400 mg.l⁻¹) and orthophosphate (taken here as >60 mg.l⁻¹) concentrations were generally evident in Hout Bay wastewater works effluent samples that concurrently had a high chemical oxygen demand and total suspended solids concentration, implying a link between these constituents. A condition of the licenses authorising effluent discharge through the outfalls is that the total kjeldahl nitrogen, ammonia and orthophosphate concentration should not exceed 30, 60 and 20 mg.l⁻¹ respectively (Figure 2.1). The total kjeldahl nitrogen limit is, however, illogical as it is lower than the ammonia concentration (which comprises part of total nitrogen). Compliance with the total kjeldahl nitrogen limit was, therefore, not considered. Effluent from the Green Point wastewater works was 100% compliant with ammonia and orthophosphate limits. Effluent from the Camps Bay wastewater works was 88% compliant

with the ammonia limit and 100% compliant with the orthophosphate limit. Effluent from the Hout Bay wastewater works was 79% compliant with the ammonia limit and 96% compliant with the orthophosphate limit.

Chloride, sodium and magnesium concentrations were more variable and, on average, higher in Green Point compared to Camps Bay and Hout Bay effluent (Figure 2.3). Licenses authorising effluent discharge through the outfalls do not include limits for anions and cations.

The concentration of most metals was broadly comparable amongst the effluents, although some metals (e.g. copper, zinc) were occasionally at a substantially higher concentration in Camps Bay compared to Green Point and Hout Bay effluents (Figure 2.4). The copper and zinc concentration was, on average, slightly higher in Green Point and Camps Bay effluent than in Hout Bay effluent. Licenses authorising effluent discharge through the outfalls do not include limits for metals.

Between 36 - 50% of organic chemicals analysed in effluent from the Green Point, Camps Bay and Hout Bay wastewater works were at a concentration that exceeded the method detection limit, but usually more frequently in Green Point effluent (Figure 2.5). Some classes of organic chemical were never detected, including organochlorine pesticides and polychlorinated biphenyls whose use is banned or highly restricted under conditions of the Stockholm Convention on Persistent Organic Pollutants (to which South Africa is a signatory). Contemporary use pesticides were very infrequently detected while polycyclic aromatic hydrocarbons, volatile halogenated hydrocarbons, chlorobenzenes and chlorophenols were infrequently detected. The classes of organic chemical most often detected were volatile organic hydrocarbons, phenols and

Table 2.1. Limits for various effluent constituents included in licenses authorising the discharge of effluent through the Green Point, Camps Bay and Hout Bay outfalls.

Constituent	Limit
pH	5.5 - 9.5
Suspended solids	500 mg.l ⁻¹
Ammonia (unionised and ionised)	30 mg.l ⁻¹
Total kjeldahl nitrogen	60 mg.l ⁻¹
Chemical oxygen demand	2000 mg.l ⁻¹
Orthophosphate	20 mg.l ⁻¹

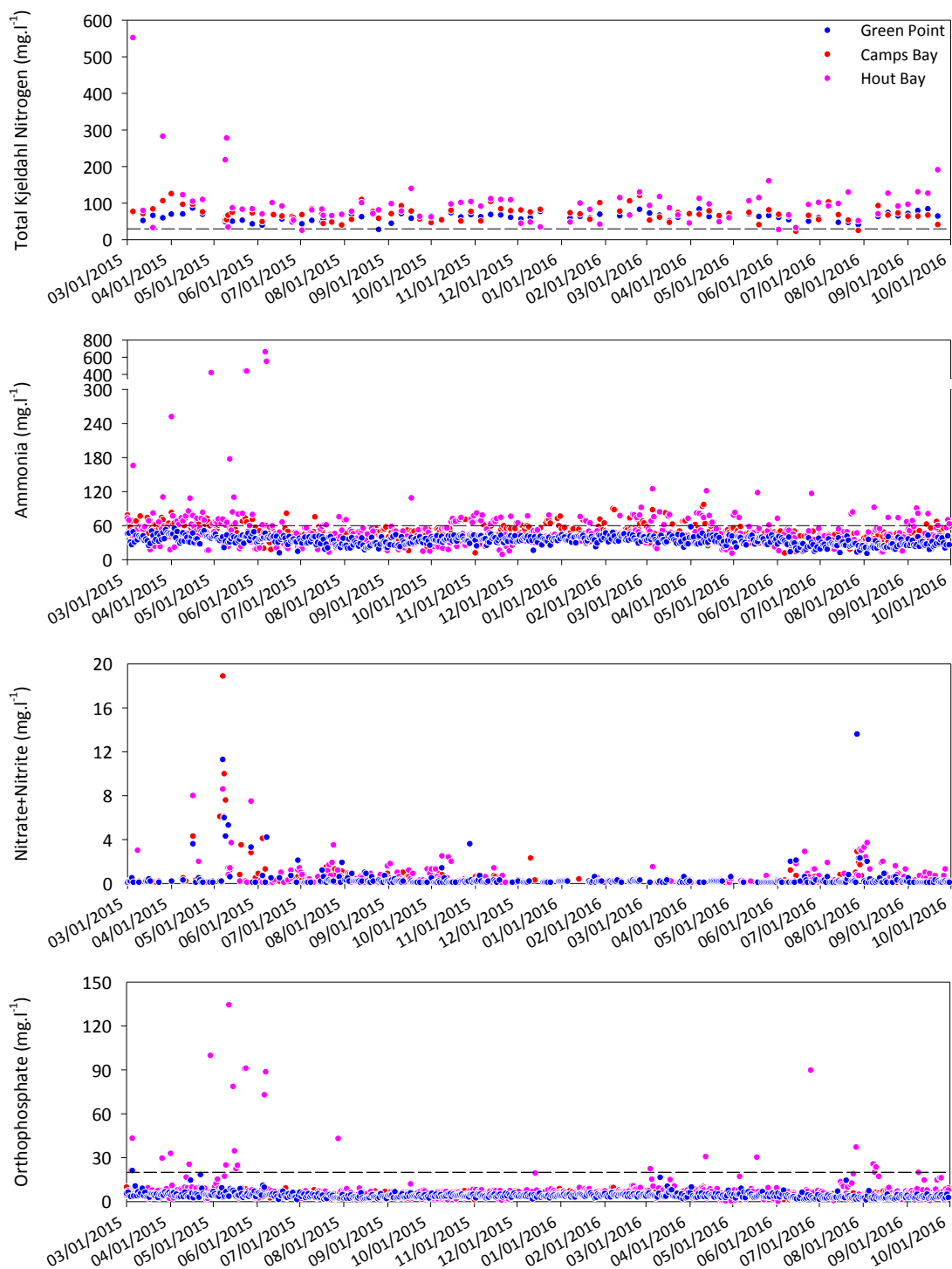


Figure 2.2. Time series of nutrient concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. The horizontal dashed lines in the total kjeldahl nitrogen, ammonia and orthophosphate plots represent limits specified in licenses authorising the discharges.

total petroleum hydrocarbons. The effluents generally had similar signatures (fingerprints) in terms of the suite of organic chemicals detected. The concentrations of organic chemicals in Green Point and Camps Bay effluent were broadly comparable and generally slightly higher than in Hout Bay effluent. Notable exceptions were the markedly higher average concentration of tetrachloroethene (a solvent widely used in cleaning and

degreasing products) and 1,2- and 1,4-dichlorobenzene (used in fumigants for mould and mildew control, and in toilet [including urinal] air fresheners) in Green Point effluent, and the higher average concentration of total petroleum hydrocarbons in Camps Bay effluent (particularly carbon range C21-C30; these chemicals have many industrial and household applications).

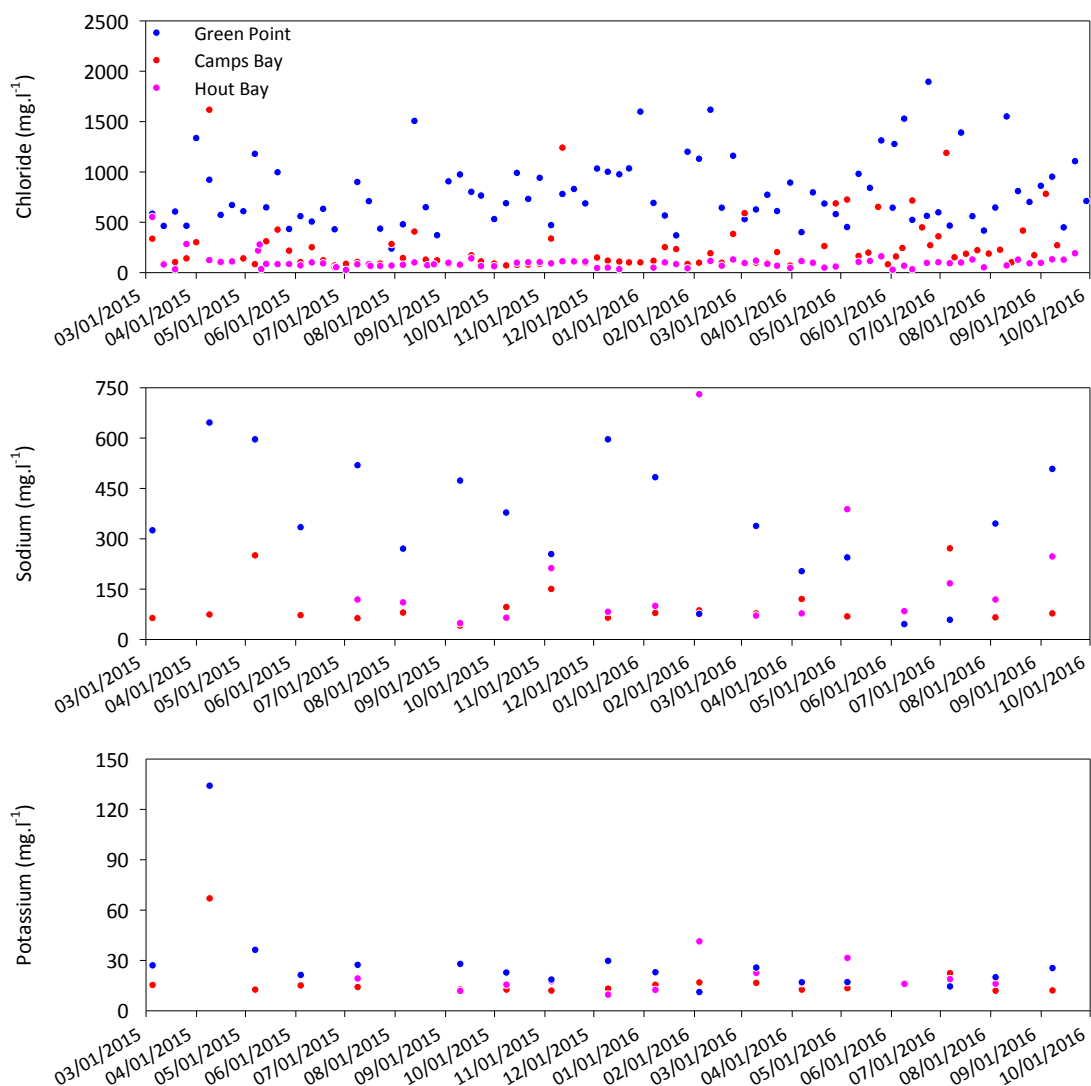


Figure 2.3. Time series of anion and cation concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016.

The frequent detection of volatile organic hydrocarbons, phenols and total petroleum hydrocarbons in the Green Point, Camps Bay and Hout Bay effluents reflects their wide use in society, including in household products. They are, for example, found in petrol and petroleum based products, paints, varnishes, household cleaning, spot removal and disinfectant products, and in personal care products such as perfumes and deodorants. As stated previously, a few pesticides were detected in the effluents, probably reflecting their use in household pesticide sprays. Some are also found in personal care products. For example, permethrin is used in formulations to treat scabies and lice.

Licenses authorising effluent discharge through the outfalls do not include limits for organic chemicals.

The Department of Environmental Affairs has formulated limits for constituents in effluent discharged into offshore (General Limit) and nearshore (Special Limit) marine environments that might become relevant in the issuing of Coastal Waters Discharge Permits (Anchor, 2016). The Special Limit is intended for effluents discharged into nearshore waters, which are defined as the zone extending seawards of Chart Datum to a point where the seabed is greater than 10 m below Chart Datum or 500 m offshore, whichever is greater). Notwithstanding uncertainties on some General and Special Limits, and that Special Limits would not apply to the Green Point, Camps Bay and Hout Bay outfalls considering the distances these effluents are discharged offshore, the limits are used here to assess the degree to which the effluents would be compliant were they included in

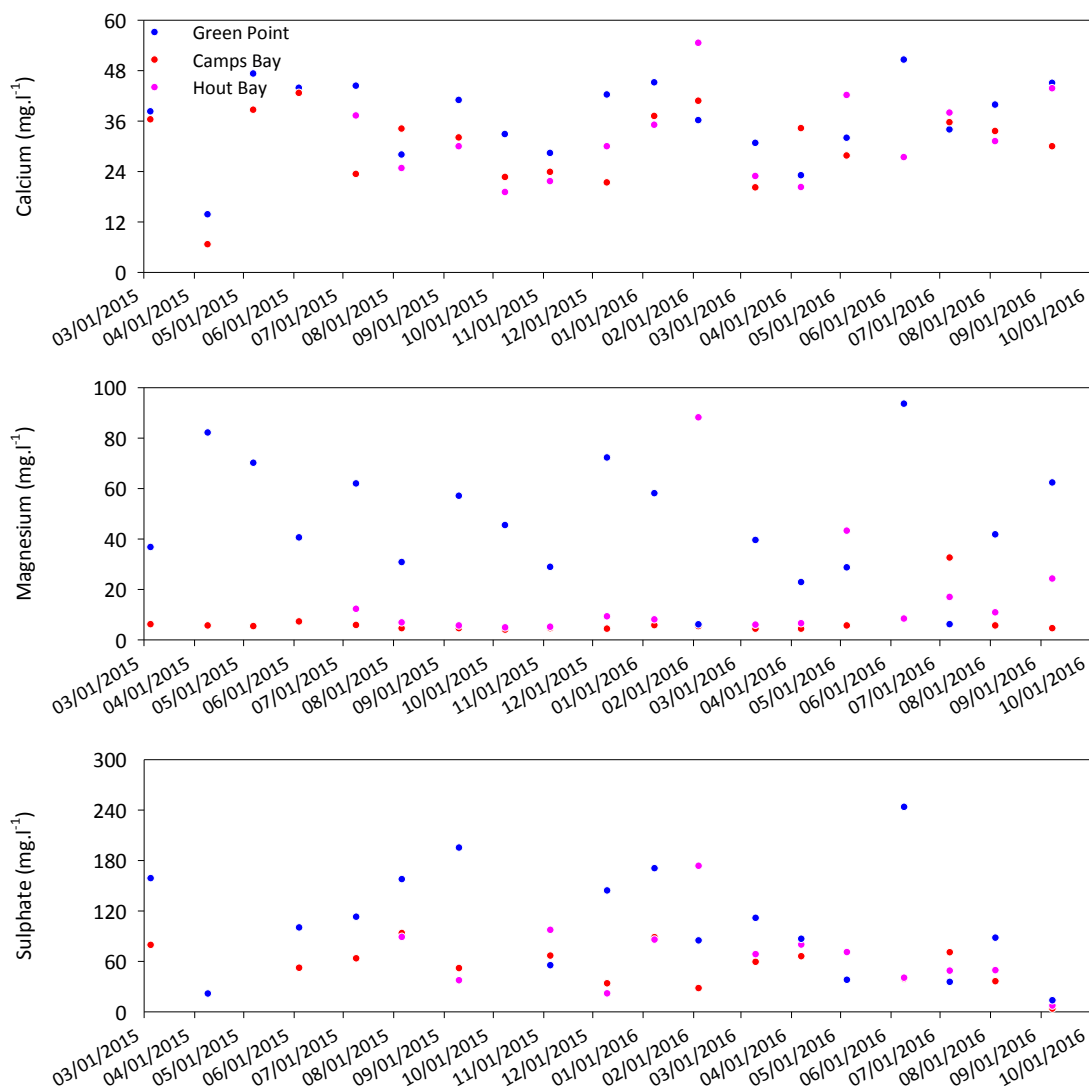


Figure 2.3 continued. Time series of anion and cation concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016.

Coastal Waters Discharge Permits for these wastewater works (Table 2.2).

Effluent from each wastewater works analysed between 1 March 2015 and 30 September 2016 would, to varying degrees, be non-compliant with General Limits for pH, total suspended solids, chemical oxygen demand, total kjeldahl nitrogen, ammonia, orthophosphate, boron, aluminium and iron (Table 2.2). In fact, a very low proportion to none of the effluent samples would be compliant for total suspended solids, chemical oxygen demand and ammonia. For some constituents (*e.g.* total suspended solids) this reflects the fact that their concentration in Green Point, Camps Bay and Hout Bay effluents is relatively high. For other constituents (*e.g.* ammonia) the limits will never be met in preliminary treated wastewater (*e.g.* von

Sperling, 2007).

Pharmaceutical and personal care products are a class of so-called 'emerging contaminants' that comprise numerous prescription and over the counter medicines, cosmetics, shampoos and soaps amongst others. Of the 49 compounds analysed, 21 were detected in Green Point effluent, 23 in Camps Bay effluent, and 21 in Hout Bay effluent (Figure 2.6). A similar suite of compounds was usually detected in each effluent and often in a comparable order in terms of their concentration. Thus, 19 compounds were common to all effluents, one was common to two effluents, and five were unique to an effluent. Thirteen compounds were always detected in Green Point and Camps Bay effluent and ten in Hout Bay effluent, while 11 were always detected in all effluents. Paracetamol (pain

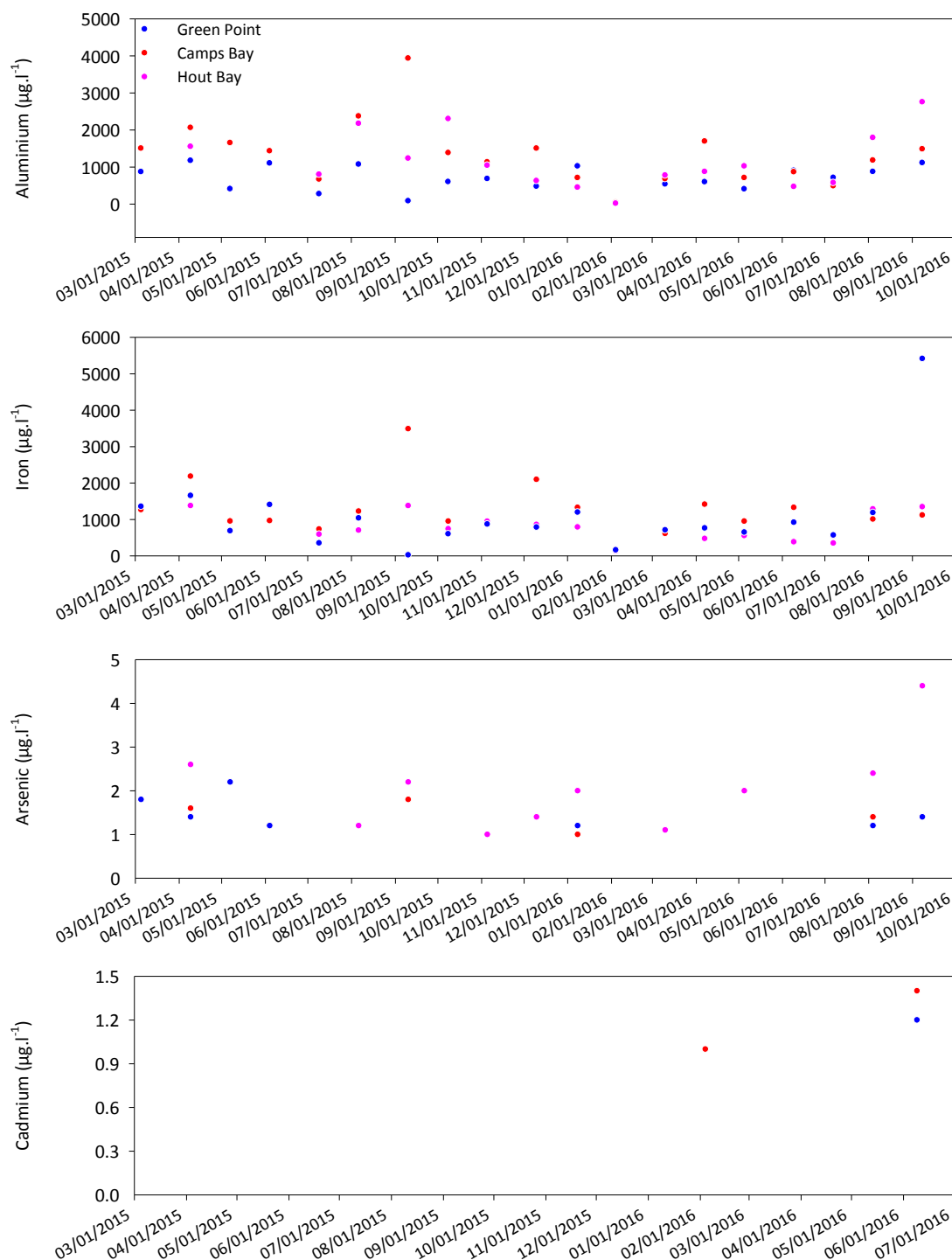


Figure 2.4. Time series of metal concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Missing data points reflect that the metal was at a concentration below the method detection limit.

reliever and fever reducer) was by some way at the highest concentration in each effluent. Other compounds at a relatively high concentration were naproxen (pain and inflammation reliever), bezafibrate (lipid lowering agent), carbamazepine (anti-convulsive used to treat epilepsy and attention deficit hyperactivity disorder), diclofenac (used to treat mild pain), irbesartan (used to treat

hypertension), mebendazole (used to treat parasitic worm infestations), and triclocarban (antibacterial agent in hand lotions and soaps). The presence of pharmaceutical compounds in the effluents should come as no surprise considering their societal use and that many are excreted from our bodies relatively unchanged (Martindale, 2011). They are also common in effluent in other parts of

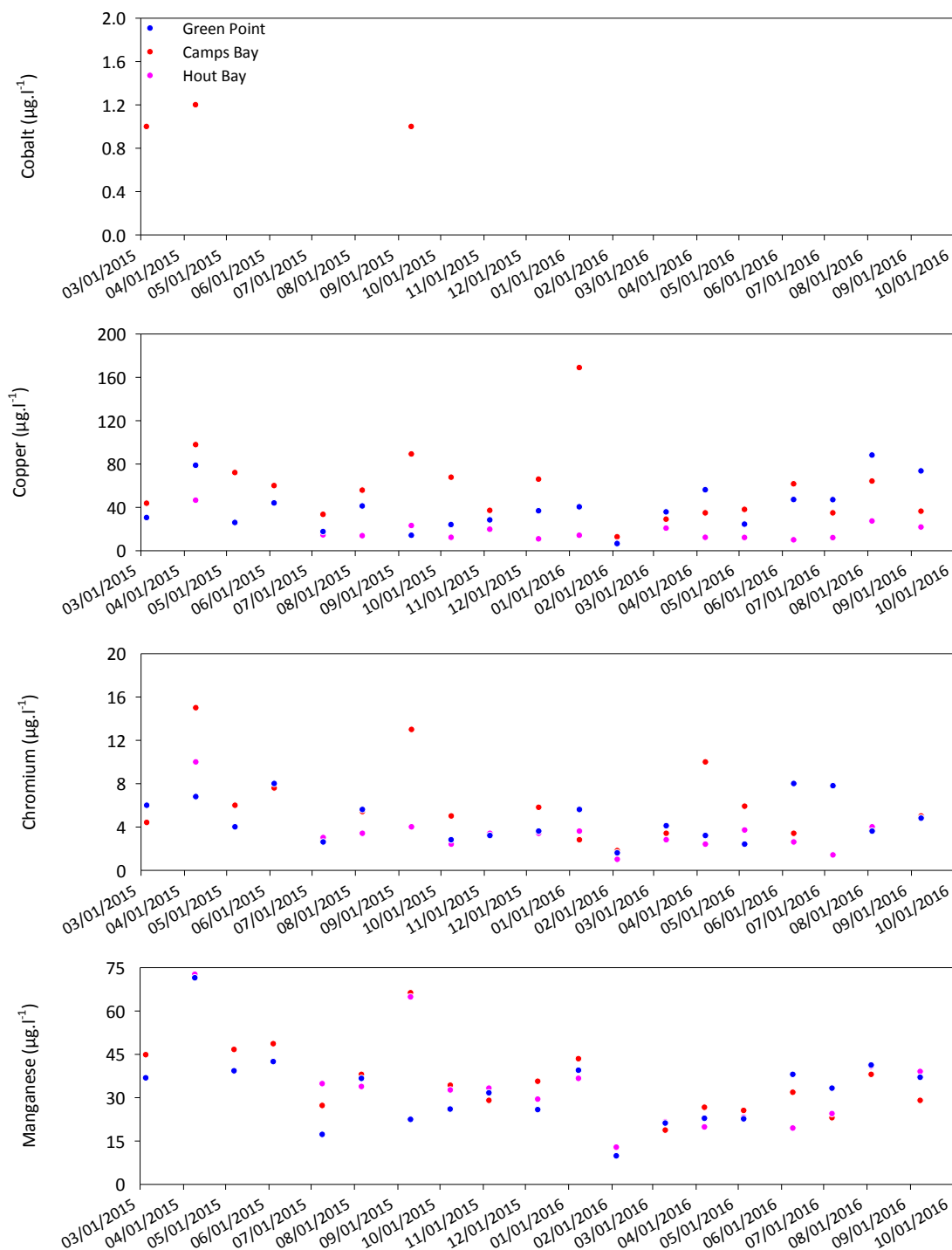


Figure 2.4 continued. Time series of metal concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Missing data points reflect that the metal was at a concentration below the method detection limit.

the world at comparable or higher concentrations (e.g. Metcalfe *et al.*, 2003; Servos *et al.*, 2005; Fick *et al.*, 2011; Vidal-Dorsch *et al.*, 2012; Loos *et al.*, 2013; Kostich *et al.*, 2014). It should also come as no surprise that pharmaceutical compounds have been widely detected in coastal (and other aquatic) ecosystems, with the main source ascribed to effluent discharge (e.g. Singh *et al.*, 2010; Kosma *et al.*, 2014; Nodler *et al.*, 2014; Birch *et al.*, 2015;

Arpin-Pont *et al.*, 2016).

There is little published information on the physical and chemical characteristics of effluent discharged into the marine environment in other parts of South Africa against which comparisons can be made. Figures 2.7 and 2.8 compare concentrations of various chemicals in Green Point, Camps Bay and Hout Bay effluent to concentrations in final effluent

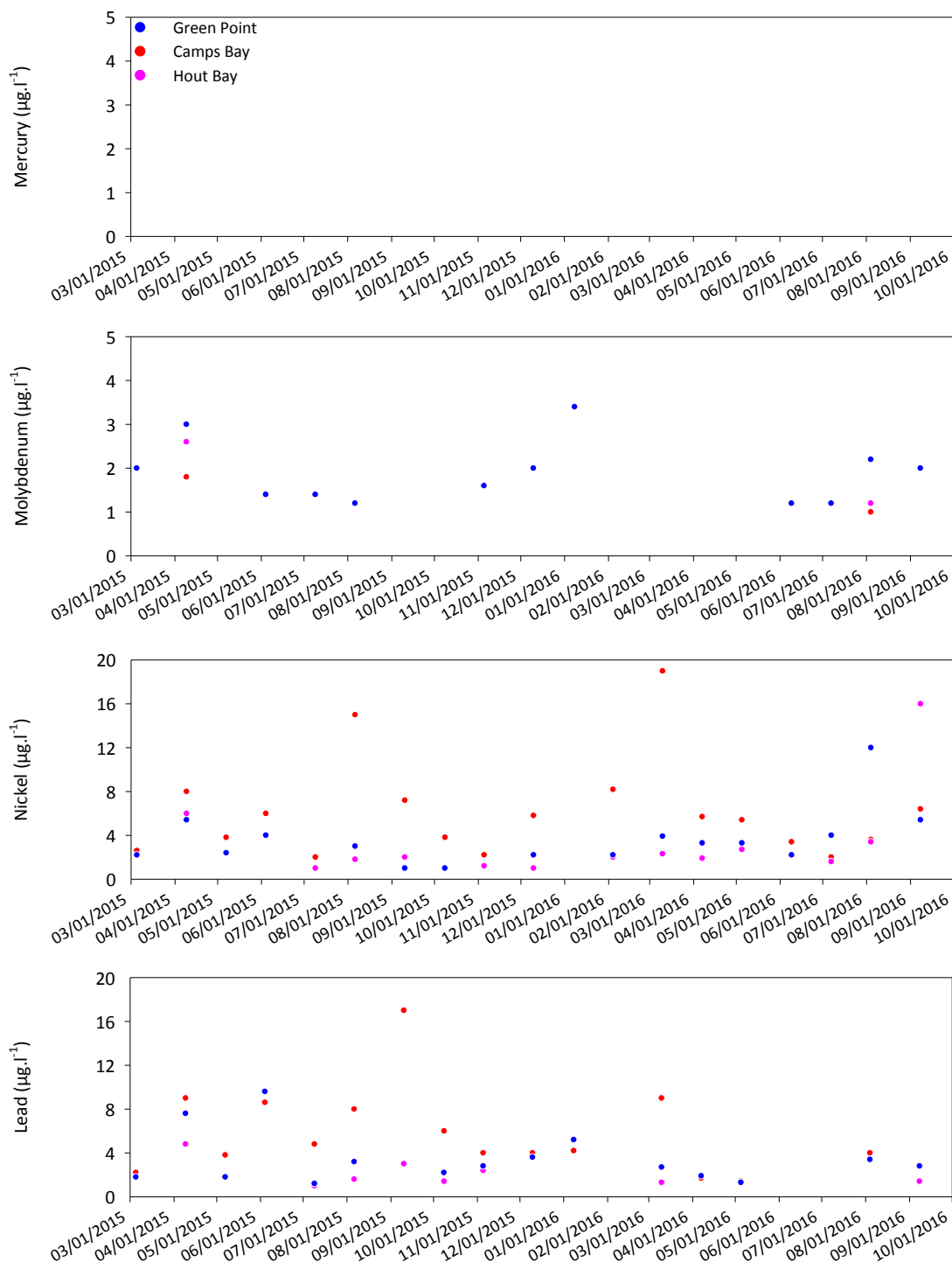


Figure 2.4 continued. Time series of metal concentrations in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Missing data points reflect that the metal was at a concentration below the method detection limit.

from the Central and Southern Works wastewater works in Durban (CSIR, 2013 and unpublished data). These effluents are also discharged to the marine environment through deepwater outfalls. Effluent discharged through the Central Works outfall has a predominantly domestic component but with a contribution from small businesses, restaurants, fast food outlets and so on. Effluent discharged

through the Southern Works outfall also has a significant domestic component but the contribution from light and heavy industry is greater than that for the Central Works outfall. Both works treat the wastewater to a primary level before discharge.

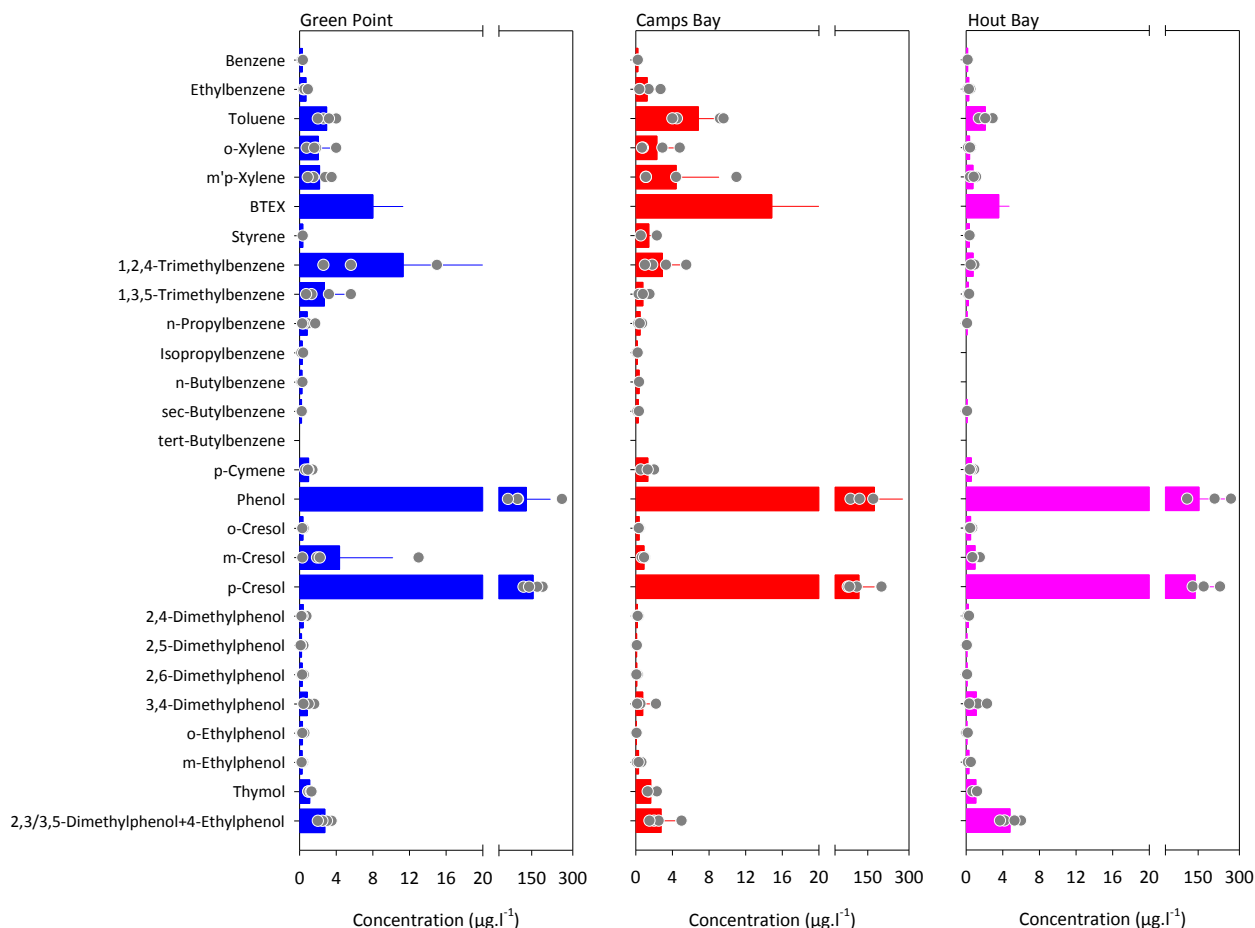


Figure 2.5. Concentrations (mean $\pm$ standard deviation) of various organic chemicals in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical was at a concentration below the method detection limit.

The average concentration of most metals was broadly comparable between the effluents, albeit tending to be higher in Southern Works effluent (e.g. chromium, nickel; Figure 2.7). The average copper concentration was, however, higher in Green Point and Camps Bay effluent than in Central Works and Southern Works effluent, the latter having concentrations comparable to that for Hout Bay effluent. The average zinc concentration for Green Point, Camps Bay and Hout Bay effluent was considerably higher than for Central Works effluent, but lower than for Southern Works effluent. The reason for the high copper and zinc concentrations in Green Point, Camps Bay and/or Hout Bay effluent is uncertain, yet interesting as concentrations of these metals would outwardly be expected to be comparable to concentrations in Central Works effluent and lower than in Southern Works effluent considering the wastewater origin.

The difference for organic chemicals was more

pronounced, these chemicals usually detected more often and at a higher average concentration in Central Works and particularly Southern Works effluent compared to Green Point, Camps Bay and Hout Bay effluent (Figure 2.8). For example, benzene, toluene, ethylbenzene and xylene were detected more often and at a considerably higher concentration in Central Works and particularly Southern Works effluent, as were most polycyclic aromatic hydrocarbon isomers. There were exceptions, with some chemicals detected as often and at as high or a higher concentration than in Central Works and Southern Works effluent. These include trichloromethane (chloroform; used as a precursor to the production of Teflon, as a solvent for fats, included in refrigerants, waxes, resins, cleansing agents and fire extinguishers) and dichlorobenzenes (used in fumigants for the control of moths, mould and mildew, and in toilet air fresheners [including urinals]).

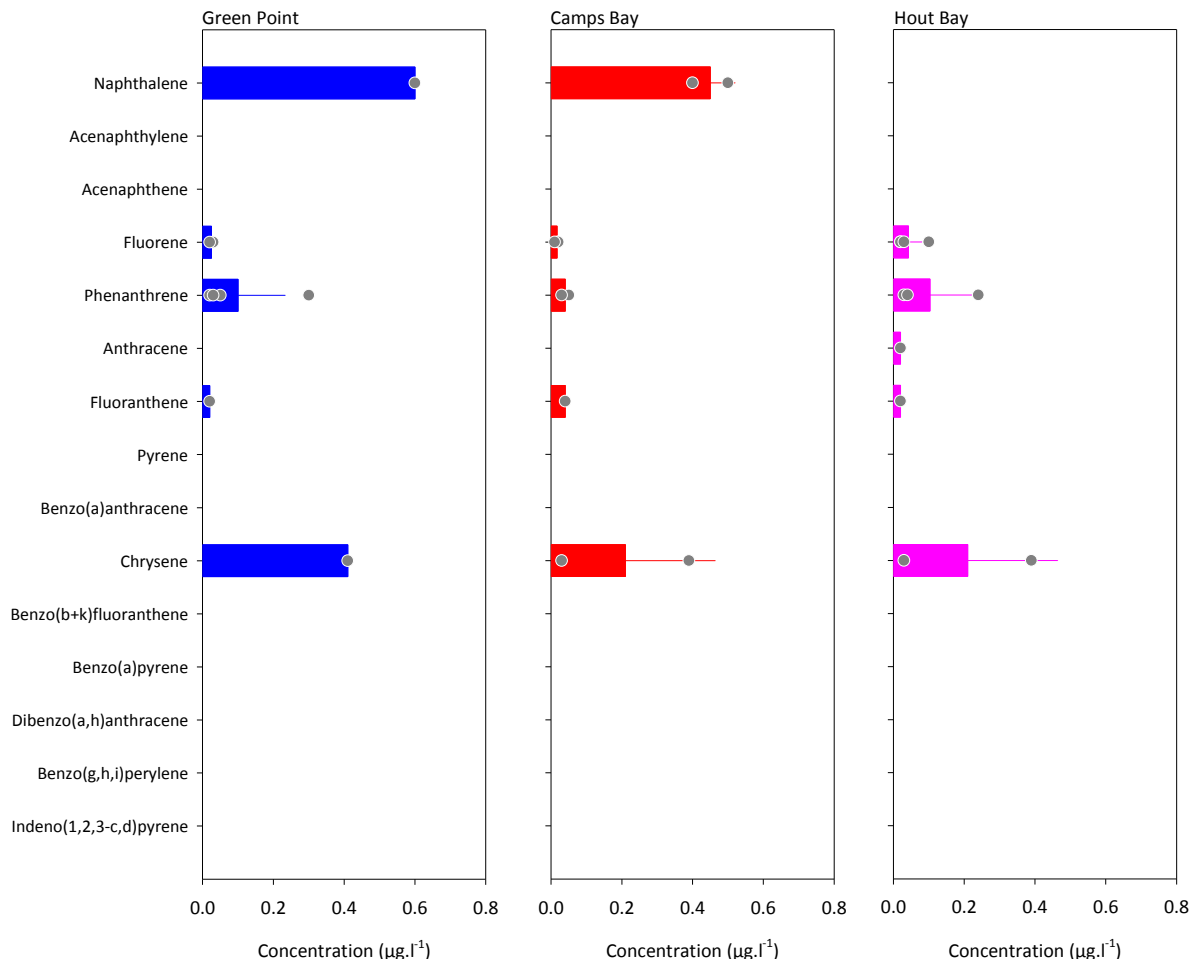


Figure 2.5 continued. Concentrations (mean $\pm$ standard deviation) of various organic chemicals in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical was at a concentration below the method detection limit.

2.3.2. Estimate of Chemical Concentrations in Marine Receiving Environments after Initial Dilution

As stated above, the concentration of effluent constituents after initial dilution in a marine receiving environment can be estimated through simple mass balance modelling. If the minimum initial dilution for an outfall is known this is a conservative (protective) estimate since the average initial dilution will inevitably be higher than the minimum initial dilution. This is because the marine environment is rarely stagnant.

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 as 220 and 170 at flow rates of 463 and 984 l.s⁻¹ respectively.

However, the estimated 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 (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 respectively. These estimates differed 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, and if so whether this would pose a human health risk. 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 increased markedly at lower effluent flow rates). It was estimated that faecal coliform colony forming unit

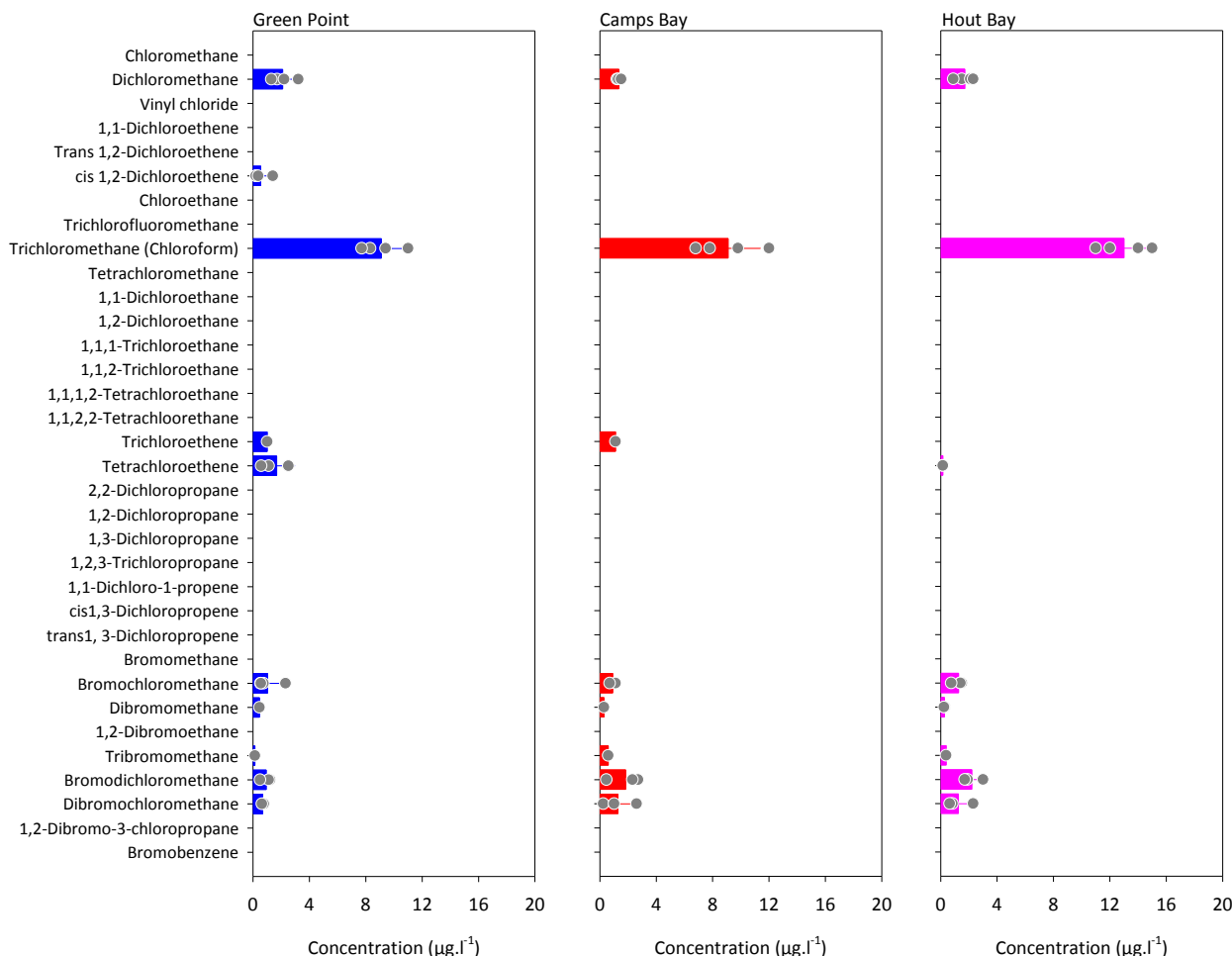


Figure 2.5 continued. Concentrations (mean $\pm$ standard deviation) of various organic chemicals in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical was at a concentration below the method detection limit.

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 the effluent flow rate scenarios discussed above. Effluent was not predicted to reach the shoreline 90% of the time.

Based on predictions, Toms and Botes (1986) estimated the initial dilution for the Camps Bay outfall at 300 under near stagnant conditions. However, empirical measurements of the concentration of a tracer dye released with effluent into the marine receiving environment provided dilutions of 680 - 880, about 2.3 - 2.9 times greater than the prediction. Toms and Botes (1986) discussed challenges in establishing the initial dilution based on empirical measurements of the concentration of a tracer dye in the marine receiving environment, including that the effluent was pumped in cycles (about 5 minutes on and 5 minutes off) rather than continuously at that time.

This resulted in pulses of tracer dye in the marine receiving environment, which differed in intensity (concentration).

Botes and Kapp (1995) estimated the mean, median and 95th percentile initial dilution of effluent discharged through the Hout Bay outfall at 8 000, 6 890 and 4 043 respectively under near stagnant conditions (current speed of 0.02 m.s^{-1}) based on empirical measurements of the concentration of a tracer dye released with effluent into the marine receiving environment. However, some effluent was trapped below the thermocline and the mean, median and 95th percentile dilution at this point was estimated as 640, 460 and 120 respectively. Because of the limited amount of measurements made Botes and Kapp (1995) considered the initial dilution to be 120, but were of the opinion this was an anomalous measurement that was unlikely to be realistic and that the initial

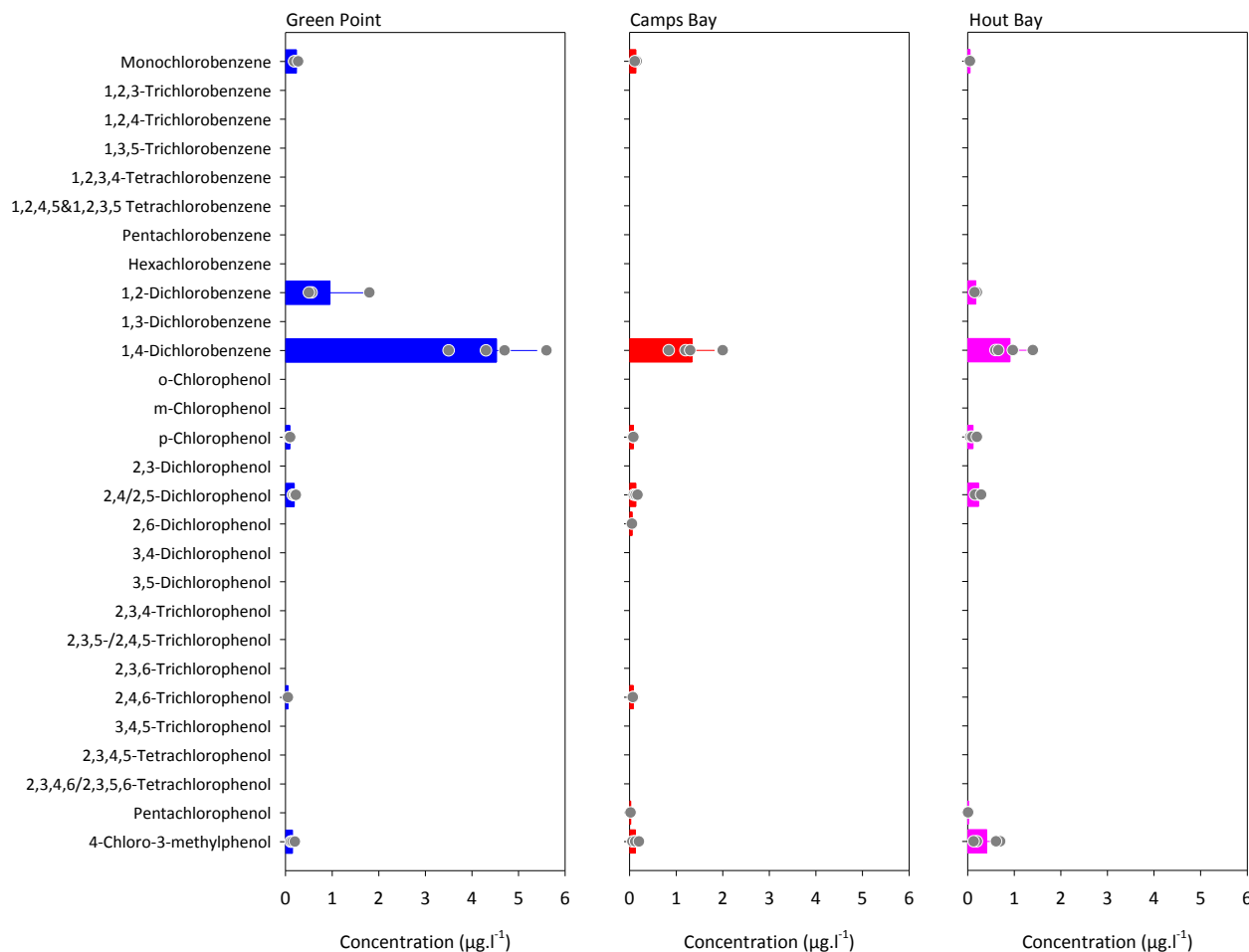


Figure 2.5 continued. Concentrations (mean ± standard deviation) of various organic chemicals in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical/compound was at a concentration below the method detection limit.

dilution would be higher.

Since there is uncertainty on the minimum initial dilution for the Green Point, Camps Bay and Hout Bay outfalls the approach followed in this study was to use a mass balance model to estimate the required dilutions for effluent constituents to meet targets for ecosystem protection, and to then compare this to an assumed minimum initial dilution of 200. A minimum initial dilution of 200 was used as the point for comparison since this is usually achieved for a buoyant effluent discharged at a depth >20 m under calm conditions (DWAF, 2004). This is lower than the minimum initial dilution estimated by the CSIR (1990) for the Green Point outfall and by Toms and Botes (1986) for the Camps Bay outfall, but higher than that estimated for the Hout Bay outfall by Botes and Kapp (1995), although as discussed above the latter investigators were of the minimum initial dilution for the latter outfall was likely to be higher than the estimate.

Using a minimum initial dilution of 200 is thus a conservative (protective) approach.

The mass balance model used for this study requires information on three variables, namely the concentration of a constituent in the effluent of interest, and background and target (guideline) concentrations for the constituent in the marine receiving environment, as follows:

$$D = (C_{\text{eff}} - C_b) / (C_t - C_b)$$

Where,

- D = required dilution to meet target,
- C_{eff} = concentration of constituent in effluent,
- C_b = background concentration of constituent in marine receiving environment,
- C_t = target for constituent in marine receiving environment.

The target concentration for the marine receiving

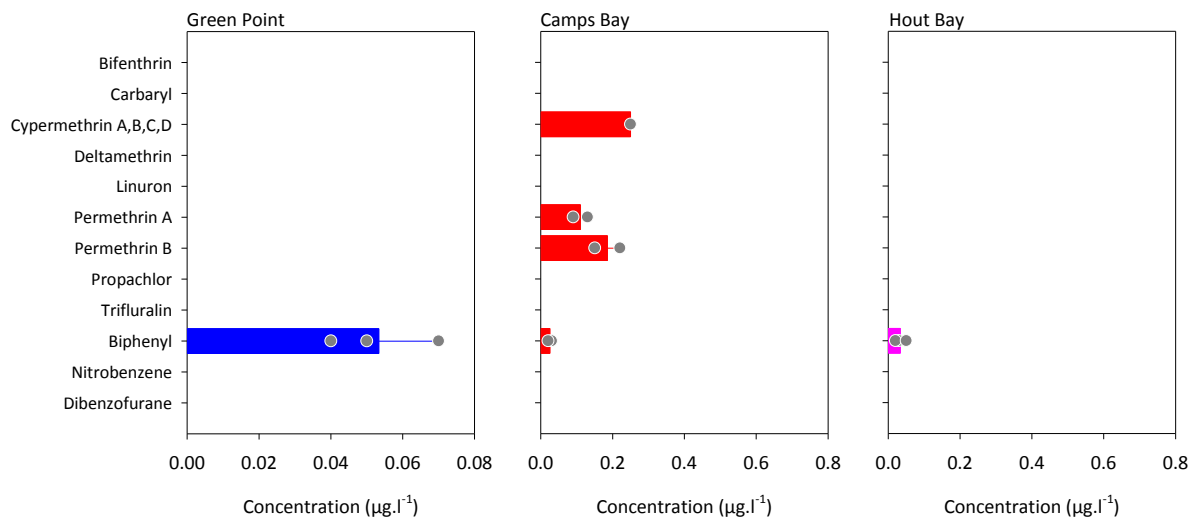


Figure 2.5 continued. Concentrations (mean $\pm$ standard deviation) of various organic chemicals analysed in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical was at a concentration below the method detection limit.

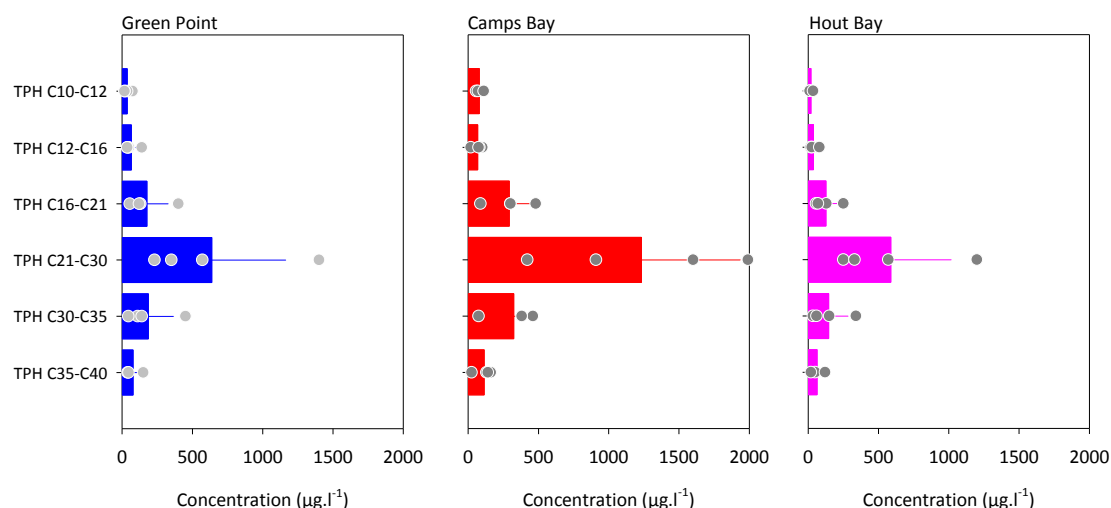


Figure 2.5 continued. Concentrations (mean $\pm$ standard deviation) of various organic chemicals in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in the samples analysed. Missing data reflect that the chemical was at a concentration below the method detection limit.

environments was, where possible, taken from the South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995). These guidelines do not provide targets for organic chemicals. For these chemicals targets for ecosystem and human health protection for marine ecosystems in the State of California in the USA (California Ocean Plan¹) were used since of the various water quality guidelines considered the California Ocean Plan provides targets for the largest proportion of chemicals analysed for this survey. Furthermore, conditions in the marine environment along the west coast of South Africa are considered to be similar to those in

California (upwelling, for example, is an oceanographic phenomenon that characterises both coastlines).

Where an effluent constituent concentration was below the method detection limit this was replaced with a surrogate concentration equal to the detection limit rather than the conventional approach of using a surrogate concentration of one-half the detection limit. This is a more conservative approach as the estimated required dilutions will be higher than if the conventional approach to handling of non-detects is followed.

¹ http://www.waterboards.ca.gov/water_issues/programs/ocean/

Table 2.2. Compliance of effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016 with limits under consideration by the Department of Environmental Affairs for possible inclusion in Coastal Waters Discharge Permits. Cells shaded pink denote <100% compliance.

Parameter	Unit	General Limit	Special Limit	Green Point		Camps Bay		Hout Bay	
				Compliance (%) General Limit	Compliance (%) Special Limit	Compliance (%) General Limit	Compliance (%) Special Limit	Compliance (%) General Limit	Compliance (%) Special Limit
pH		7.1-8.3	7.3-8.2	88.9	47.9	93.8	78.0	86.8	68.9
Total Suspended Solids	mg.l ⁻¹	50	10	0.2	0.0	1.4	0.2	1.1	0.0
Chemical oxygen demand	mg.l ⁻¹	250	75	3.3	0.2	5.7	0.0	9.2	0.0
Total kjeldahl nitrogen as N	mg.l ⁻¹	100	10	98.8	0.0	90.0	0.0	64.1	0.0
Ammonia as N	mg.l ⁻¹	10	3	0.0	0.0	0.0	0.0	0.2	0.0
Nitrate as N	mg.l ⁻¹	15	1.5	100.0	80.0	100.0	93.8	100.0	100.0
Nitrite as N	mg.l ⁻¹	15	1	100.0	100.0	100.0	100.0	100.0	100.0
Orthophosphate as P	mg.l ⁻¹	10	1	98.6	0.0	99.7	0.0	90.9	1.6
Boron as B	mg.l ⁻¹	1	0.5	100.0	93.3	100.0	91.7	100.0	100.0
Aluminium as Al	mg.l ⁻¹	1	1	73.7	73.7	36.8	36.8	50.0	50.0
Iron as Fe	mg.l ⁻¹	3	0.3	94.7	10.5	94.7	5.3	100.0	6.3
Arsenic as As	mg.l ⁻¹	0.2	0.1	100.0	100.0	100.0	100.0	100.0	100.0
Cadmium as Cd	mg.l ⁻¹	0.2	0.1	100.0	100.0	100.0	100.0	100.0	100.0
Cobalt as Co	µg.l ⁻¹	1	1	100.0	100.0	100.0	100.0	100.0	100.0
Copper as Cu	mg.l ⁻¹	3	1	100.0	100.0	100.0	100.0	100.0	100.0
Chromium as total Cr	mg.l ⁻¹	2	1	100.0	100.0	100.0	100.0	100.0	100.0
Manganese as Mn	mg.l ⁻¹	2	0.1	100.0	100.0	100.0	100.0	100.0	100.0
Nickel as N	mg.l ⁻¹	5	1	100.0	100.0	100.0	100.0	100.0	100.0
Lead as Pb	mg.l ⁻¹	4.4	0.1	100.0	100.0	100.0	100.0	100.0	100.0
Selenium as Se	mg.l ⁻¹	0.05	0.02	100.0	100.0	100.0	100.0	100.0	100.0
Vanadium as V	mg.l ⁻¹	100	10	100.0	100.0	100.0	100.0	100.0	100.0
Zinc as Zn	mg.l ⁻¹	15	2	100.0	100.0	100.0	100.0	100.0	100.0
Polychlorinated biphenyls	µg.l ⁻¹	0.03	0.03	100.0	100.0	100.0	100.0	100.0	100.0
Phenols	mg.l ⁻¹	0.5	0.1	100.0	100.0	100.0	100.0	100.0	100.0
Pesticides (Dieldrin, Endrin, DDT)	µg.l ⁻¹	0.001	0.002	100.0	100.0	100.0	100.0	100.0	100.0

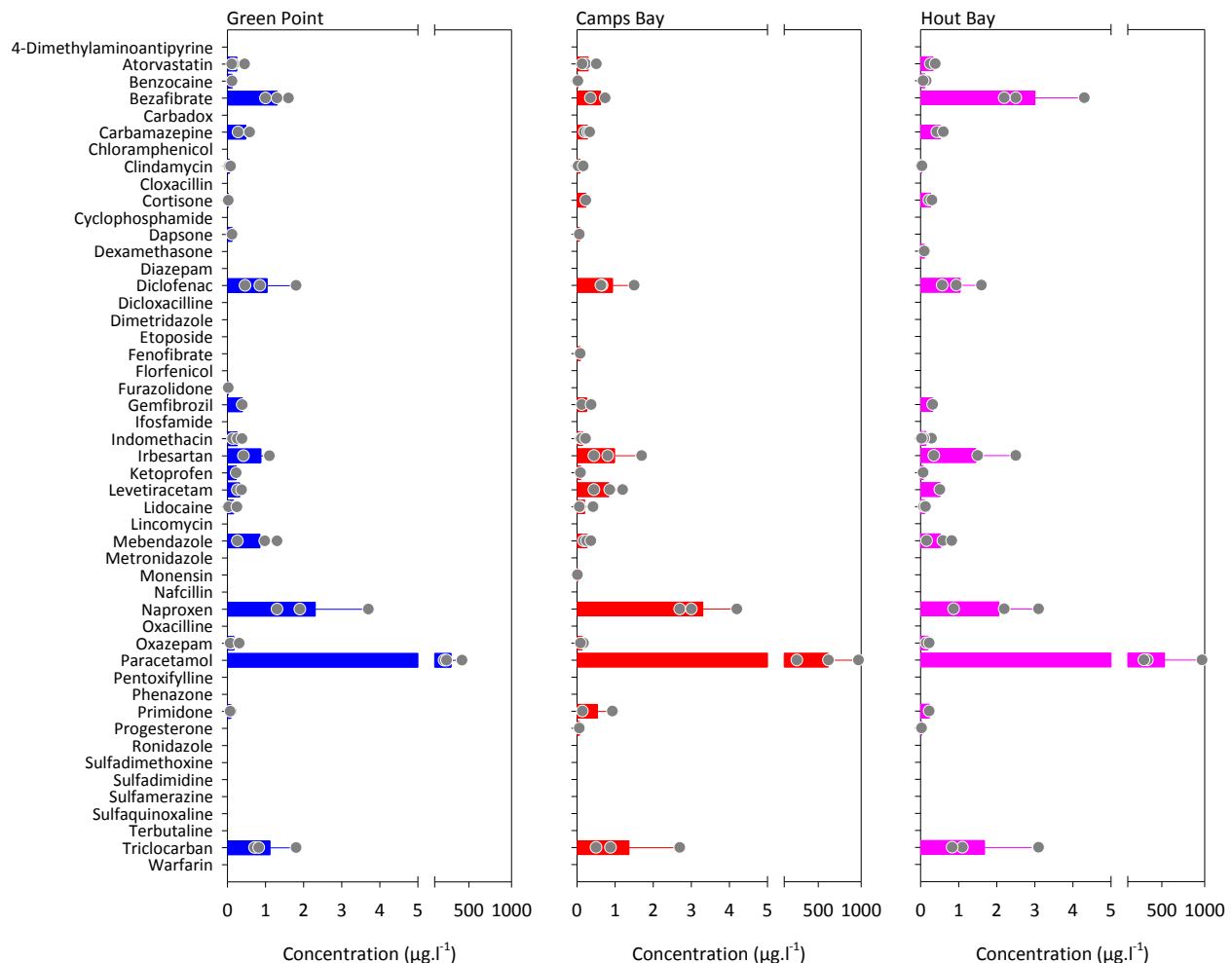


Figure 2.6. Concentrations (mean $\pm$ standard deviation) of pharmaceutical compounds in three effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016. Solid symbols represent concentrations in different samples analysed. Missing data reflect that the compound was at a concentration below the method detection limit.

The South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995) provide a total suspended solids target of 10% above the ambient concentration. No total suspended solids concentration data suitable for defining a background concentration for the marine environment off Cape Town could be found in the scientific literature. PRDW (2016) considered a total suspended solids concentration of 5.9 mg.l^{-1} to reflect the background for the marine environment off Koeberg. In light of the uncertainty on the background total suspended solids concentration for the Green Point, Camps Bay and Hout Bay marine receiving environments the concentration was assumed to be 10 mg.l^{-1} , to provide a target of 11 mg.l^{-1} . The total suspended solids concentration in the Green Point, Camps Bay and Hout Bay marine receiving environments undoubtedly falls below 10 mg.l^{-1} at times, but the duration of such events is unknown. This conclusion is based on a high degree

of shoreline water clarity evident in some satellite images provided in Google Earth. By the same token the concentration can be expected to periodically exceed 10 mg.l^{-1} . Thus, a large (but unquantified) volume of suspended material is introduced into the marine environment off Cape Town by diffuse sources, such as river and stormwater runoff during periods of high rainfall. Storms that generate large waves at sea will also influence the suspended solids concentration. Examples of the influence of these sources on suspended solids concentrations (and turbidity) in the marine environment off Cape Town can be found in satellite images provided in Google Earth. In these instances a larger number of dilutions will be required for the total suspended solids concentration in effluent to meet the target in the marine receiving environments.

The required dilution to reduce the lowest, median

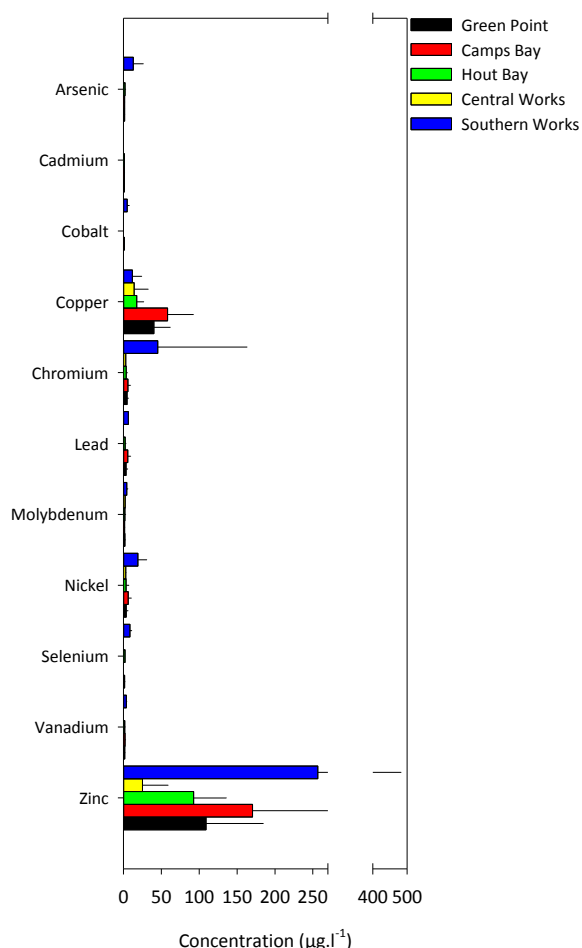


Figure 2.7. Comparison of metal concentrations (mean $\pm$ standard deviation) in effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016 to concentrations analysed in twelve effluent samples collected from the Central and Southern Works wastewater works in Durban between June 2013 and November 2016.

and highest total suspended solids concentration in Green Point, Camps Bay and Hout Bay effluents to 11 mg.l^{-1} in the marine receiving environments are provided in Table 2.2. It is important to note the required dilutions increase considerably if the target is taken as 6.49 mg.l^{-1} (*i.e.* assuming a background concentration of 5.9 mg.l^{-1} as defined by PRDW (2016) for the Koeberg area), such that the median concentration in the effluents would require almost twice the number of dilutions as those provided in Table 2.2. It is possible to calculate a compliance limit for a constituent in effluent by integrating the estimated minimum initial dilution for an outfall and background and target concentrations for the constituent in the marine receiving environment (so-called water quality based effluent limit). For example, if the

minimum initial dilution for the Green Point, Camps Bay and Hout Bay outfalls is taken as 200 and background and target concentrations for total suspended solids in the marine receiving environments as 10 and 11 mg.l^{-1} respectively, the limit to ensure compliance after minimum initial dilution of the effluent is 210 mg.l^{-1} . The total suspended solids concentration in about 53, 75 and 62% of effluent samples from the Green Point, Camps Bay and Hout Bay wastewater works respectively exceed this limit. The water quality based effluent limit is lower if the minimum initial dilution is lower (*e.g.* limit is 110 mg.l^{-1} if minimum initial dilution is taken as 100) or the background concentration is lower (*e.g.* limit is 124 mg.l^{-1} if background concentration is taken as 5.9 mg.l^{-1}). A water quality based effluent limit of 210 mg.l^{-1} is less than half the limit (500 mg.l^{-1}) provided in licenses authorising effluent discharge through the outfalls.

The background concentration for ammonia in the marine receiving environments was taken as 0.227 mg.l^{-1} . This corresponds to the 80th percentile of ammonia concentrations analysed by the CSIR in 209 seawater samples collected at the surface, middle and bottom of the water column at 45 sites in Table Bay in two surveys in 1980 and one survey in 1982 (CSIR, 1982, 1985). The use of the 80th percentile rather than the highest concentration is consistent with the approach recommended by ANZECC/ARMCANZ (2000) and BCLME (2006). The samples were, however, collected when the outfall was operating and the 80th percentile may overestimate the background concentration. PRDW (2016) provided a background concentration for ammonia along the southwest coast of South Africa of 0.015 mg.l^{-1} . This is far lower than the concentration used for this study.

The required dilution to reduce the lowest, median and highest ammonia concentrations measured in Green Point, Camps Bay and Hout Bay effluents to the target in the marine receiving environments is provided in Table 2.2. The ammonia concentration in none of the effluent samples from the Green Point wastewater works required >200 dilutions compared to about 2 and 10% of samples from the Camps Bay and Hout Bay wastewater works respectively. These proportions remain unchanged

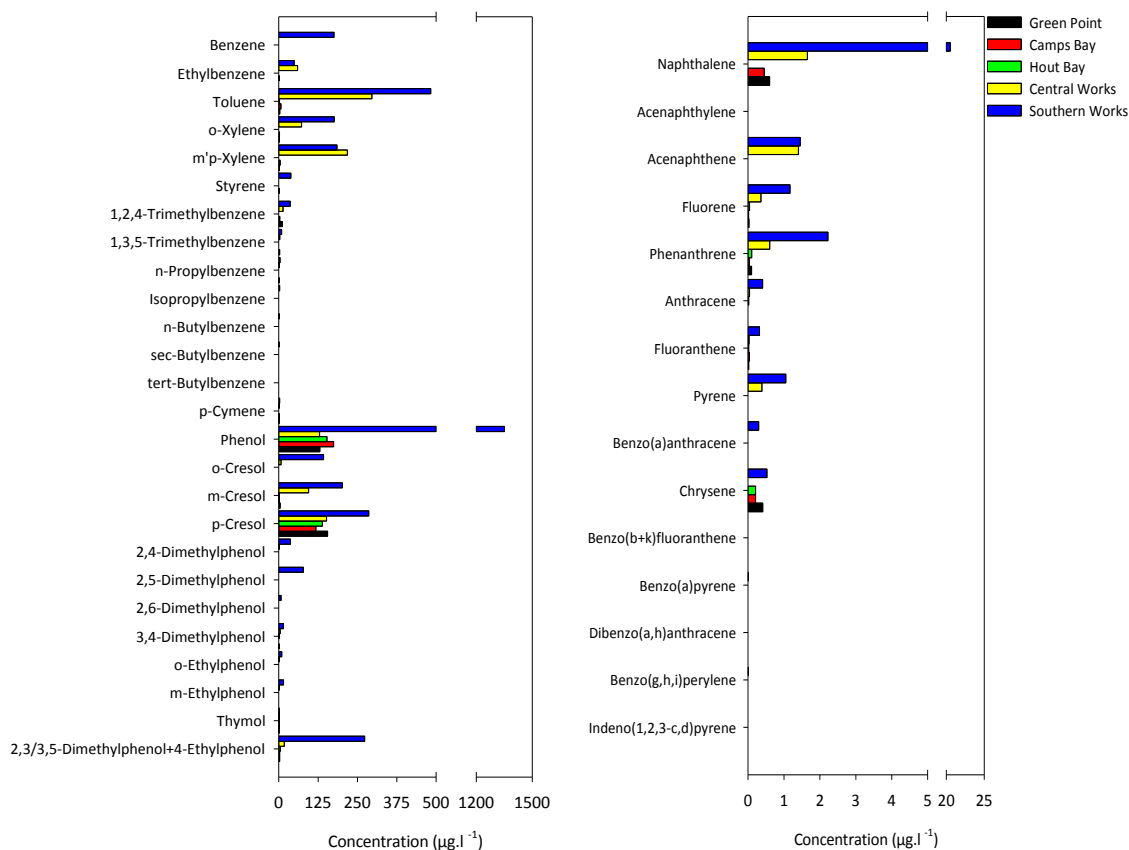


Figure 2.8. Comparison of organic chemical concentrations (mean) in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016 to concentrations analysed in twelve effluent samples collected from the Central and Southern Works wastewater works in Durban between June 2013 and November 2016.

if the background concentration is taken as 0.015 mg.l^{-1} (as per PRDW, 2016), due to a small proportion of high concentrations in some of the effluent samples. Using the water quality based effluent limit approach discussed above, at a minimum initial dilution of 200 the effluent limit for ammonia is 60 mg.l^{-1} . This is identical to the limit in licenses authorising effluent discharge through the outfalls. The ammonia concentration in 0, 2.2 and 10% of effluent samples from the Green Point, Camps Bay and Hout Bay wastewater works respectively exceeded this limit.

The background concentration for metals in the marine receiving environments were taken as the 80th percentile of concentrations analysed in 209 seawater samples collected at the surface, middle and bottom of the water column at 45 sites in Table Bay in two surveys in 1980 and one survey in 1982 (CSIR, 1982, 1985). The latter studies did not analyse concentrations of arsenic or chromium. Concentrations of these metals were estimated as 3 and 0.6 µg.l^{-1} respectively (see references in DWAF, 1995). The arsenic concentration is at the upper

end of the range for arsenic in clean, open-ocean waters (range $0.5 - 3 \text{ µg.l}^{-1}$, mean = 1.7 µg.l^{-1}) (Andreae, 1979). A dilution ≤ 3.9 was sufficient to reduce arsenic, cadmium, chromium, nickel and lead concentrations in effluent from the Green Point, Camps Bay and Hout Bay wastewater works to their targets (Table 2.3). Copper and zinc required more dilutions, but never more than 37.4 dilutions (and in fact usually much lower, as evident in the median required dilutions in Table 2.3).

A dilution of <10.7 was theoretically sufficient to reduce the concentration of all organic chemicals in Green Point, Camps Bay and Hout Bay effluents to targets provided in the California Ocean Plan apart from polycyclic aromatic hydrocarbons and polychlorinated biphenyls, which required far more dilutions (Table 2.4). However, this reflects the fact that targets for these chemicals in the California Ocean Plan are far below the method detection limits achieved in this study. To place the California Ocean Plan target for polychlorinated biphenyls ($0.000019 \text{ µg.l}^{-1}$) into perspective the United States Environmental Protection Agency recommended a

national marine water quality criterion for Due to the limited amount of experimental data on

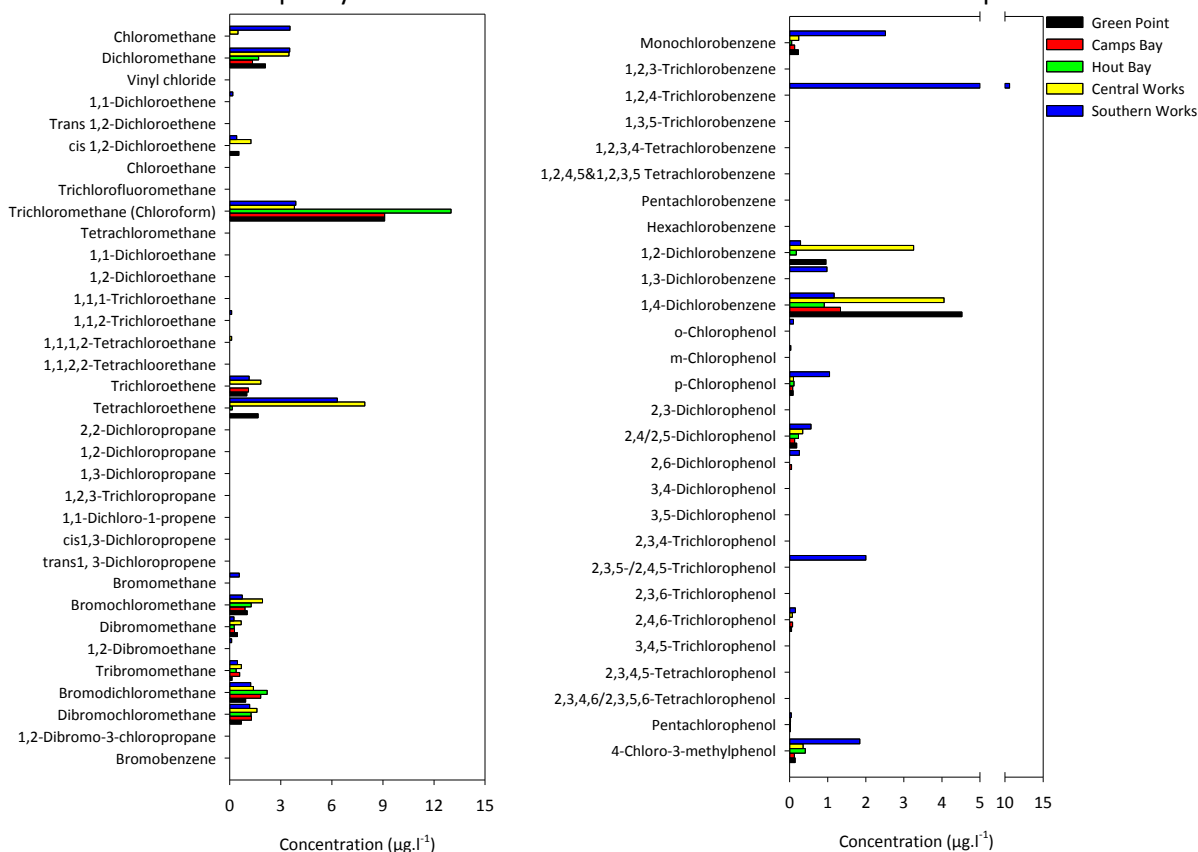


Figure 2.8 continued. Comparison of organic chemical concentrations (mean) in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016 to concentrations analysed in twelve effluent samples collected from the Central and Southern Works wastewater works in Durban between June 2013 and November 2016.

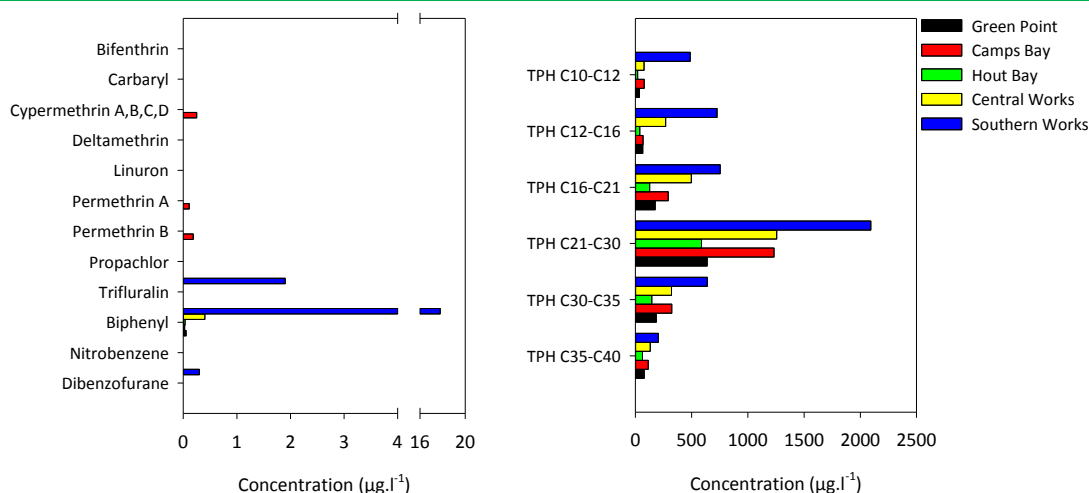


Figure 2.8 continued. Comparison of organic chemical concentrations (mean) in four effluent samples collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2016 to concentrations analysed in twelve effluent samples collected from the Central and Southern Works wastewater works in Durban between June 2013 and November 2016.

polychlorinated biphenyls in seawater in the United States of $0.03 \mu\text{g.l}^{-1}$. If the latter concentration is used as the target then polychlorinated biphenyls in each effluent were estimated to require ≤ 2.33 dilutions (the concentration in each effluent was below the method detection limit).

the toxicity of pharmaceutical compounds to marine organisms, hazard and risk assessment for these chemicals is difficult or impossible. There are, for example, no marine water quality guidelines for pharmaceutical compounds. Predicted no effect concentrations provided by Bergmann *et al.* (2011)

were thus used as the target for estimating the required dilutions. Theoretically, ≤ 3.6 dilutions were required to reduce pharmaceutical compound concentrations in Green Point, Camps Bay and Hout Bay effluents to the target apart from paracetamol, which required up to 42, 97 and 97 dilutions for the effluents respectively (Table 2.5).

The background concentration of various ions in 'typical' seawater is 19 353 mg.l⁻¹ for chloride, 10 760 mg.l⁻¹ for sodium, 2 712 mg.l⁻¹ for sulphate, 1 292 mg.l⁻¹ for magnesium, 412 mg.l⁻¹ for calcium, and 399 mg.l⁻¹ for potassium. These far exceed concentrations in effluent from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. In other words, the discharge of effluent will in fact dilute these constituents in seawater rather than themselves requiring dilution to meet targets.

A major impact associated with the discharge of partially treated effluent arises when organic matter in the effluent, such as carbohydrates, fats and proteins in human metabolic waste, food and other biodegradable waste matter is broken down in the receiving environment. While bacteria naturally present in a receiving environment are able to degrade this matter they use dissolved oxygen in the process. This may result in a depression in dissolved oxygen concentration. Since the initial dilution process is rapid the biochemical oxygen demand of effluent is usually not immediately important. However, the immediate oxygen demand, which represents the oxygen demand of reduced substances that are usually rapidly oxidised (*e.g.* oxidation of sulphide to sulphate) is not necessarily negligible. To estimate the immediate oxygen demand for Green Point, Camps Bay and Hout Bay effluents the dissolved oxygen concentration in the marine receiving environments after initial dilution was estimated as:

$$DO_f = DO_a + ([DO_e - IDOD - DO_a]/S_a)$$

Where,

- DO_f = Final dissolved oxygen concentration of the receiving water at the plume trapping depth (in mg.l⁻¹),
- S_a = Initial dilution,

- IDOD = Immediate dissolved oxygen demand (in mg.l⁻¹),
- DO_e = Dissolved oxygen concentration of the effluent (in mg.l⁻¹),
- DO_a = Ambient dissolved oxygen concentration immediately up-current of the diffuser, averaged from the diffuser port depth to the plume trapping depth (in mg.l⁻¹).

According to the USEPA (1994) the dissolved oxygen concentration of effluent at the point of discharge is usually 0 mg.l⁻¹ and the immediate oxygen demand of effluent ranges between 0 - 10 mg.l⁻¹. The effluent dissolved oxygen concentration and immediate oxygen demand were thus assumed to be 0 and 10 mg.l⁻¹ respectively, providing a worst case scenario. The ambient dissolved oxygen concentration was assumed to be 7 mg.l⁻¹, a conservative assumption as some investigators (*e.g.* Toms, 1985) have assumed a background dissolved oxygen concentration in the study area of about 8 mg.l⁻¹. Based on these concentrations the dissolved oxygen concentration after initial dilution in the marine receiving environments is estimated at 5.3 mg.l⁻¹ and 6.9 mg.l⁻¹ at an initial dilution of 10 and 200 respectively. These concentrations exceed the South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995) target of 5 mg.l⁻¹ that should be met 95% of the time, and at ≥ 17 dilutions also the target of 6 mg.l⁻¹ that should be met 99% of the time for the south and east coasts of South Africa. However, the guideline relevant to the Western Cape is that the dissolved oxygen concentration should not fall below 10% of the established natural variation. Reworking the above formula the percent depression of dissolved oxygen due to the oxygen demand of effluent constituents is estimated to range between 17.6% for an assumed initial dilution of 10 and 1.0% for an assumed minimum initial dilution of 200. The percent depression is <10% for dilutions >19. It is, therefore, unlikely the dissolved oxygen target will not be met at the margin of the zone of initial dilution for each outfall.

After initial dilution dissolved oxygen is consumed by biochemical oxygen demand in the farfield. The biological oxygen demand analysed after a 5 day effluent incubation period is required to estimate farfield dissolved oxygen depletion. To estimate if

dissolved oxygen depression due to biochemical oxygen demand in the farfield is likely to reduce the dissolved oxygen concentration to below the water quality target the following formula was used:

$$DO_{\text{target}} \leq DO_f - 1.46 \times ((BOD_a + [BOD_e - BOD_a])/S_a)$$

Where,

- DO_f = Dissolved oxygen concentration at the completion of initial dilution (in mg.l^{-1}),
- BOD_a = Ambient biochemical oxygen demand concentration immediately up-current of the diffuser, averaged from the diffuser port depth to the plume trapping depth (in mg.l^{-1}),
- BOD_e = Effluent biochemical oxygen demand concentration (in mg.l^{-1}),
- S_a = Initial dilution,
- DO_{target} = Dissolved oxygen concentration target in marine receiving environment (10% variation from ambient) (in mg.l^{-1}).

The ambient biochemical oxygen demand was taken as 0 mg.l^{-1} . The City of Cape Town does not measure the biological oxygen demand of effluent. The biochemical oxygen demand was thus estimated by multiplying the chemical oxygen demand for each effluent sample collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016 by a factor of 0.46 and then adding a value of five. This is based on the relationship between chemical oxygen demand and biochemical oxygen demand established for raw sewage by Sérgio *et al.* (2004). Taking the ambient dissolved oxygen concentration for the marine receiving environments as 7 mg.l^{-1} , the target dissolved oxygen concentration is 6.3 mg.l^{-1} (*i.e.* 10% depression relative to natural variation). According to the USEPA (1994), if the above inequality is true then effluent discharge alone is unlikely to result in the depression of the dissolved oxygen concentration to below the target in the farfield and no analysis of farfield biochemical oxygen demand is required. For Green Point effluent the median and maximum biochemical oxygen demand exertion on dissolved oxygen concentration beyond the zone of initial dilution at an initial dilution of 200 is 5.3 and 6.7 mg.l^{-1} , but the minimum is 0 mg.l^{-1} . For Camps Bay effluent the median and maximum biochemical oxygen demand

exertion on dissolved oxygen concentration at an initial dilution of 200 is 4.4 and 6.4 mg.l^{-1} , but the minimum is 0 mg.l^{-1} . For Hout Bay effluent the median and maximum biochemical oxygen demand exertion on dissolved oxygen concentration at an initial dilution of 200 is 4.8 and 6.6 mg.l^{-1} , but the minimum is 0 mg.l^{-1} . The farfield biochemical oxygen demand exertion thus does not exceed the dissolved oxygen target for a large proportion of effluent samples. The dissolved oxygen concentration in the farfield may thus be depressed below the target as a result of effluent discharge. This requires further evaluation to determine if this is true as it is not possible to estimate the farfield dissolved oxygen concentration depression as a result of biochemical oxygen demand without information on several variables for each outfall (*e.g.* farfield dilution rate, seawater temperature).

As stated above, the theoretical minimum initial dilution for the Green Point, Camps Bay and Hout Bay outfalls is uncertain. The minimum initial dilution was thus assumed to be 200 since this is common for effluent discharged in the marine environment at depths $>20 \text{ m}$ under calm conditions (DWAF, 2004). However, even if the minimum initial dilution for each outfall is taken as 20, then metal, organic chemical and pharmaceutical compound concentrations in virtually all effluent samples from each wastewater works are unlikely to have exceeded water quality targets beyond the zone of initial dilution in the marine receiving environments. Copper and zinc in some effluent samples required up to 37.4 and 27.7 dilutions respectively, while the paracetamol concentration in Camps Bay and Hout Bay effluent required up to 97 dilutions.

The situation is different for ammonia and total suspended solids. The concentration of these constituents in a fairly large to large proportion of effluent samples depending on the wastewater works required >200 dilutions to meet their targets (Table 2.3). If a minimum initial dilution of 200 is realistic this suggests a chance, even if only periodic, that concentrations of these constituents will exceed the target at the margin of the zone of initial dilution for the Camps Bay and Hout Bay outfalls. Even at a considerably higher number of dilutions there is a possibility the concentration of

these constituents might not meet targets. For example, the total suspended solids concentration in 7.7, 21.3 and 19.5% of effluent samples from the Green Point, Camps Bay and Hout wastewater works respectively required >500 dilutions to meet the target. There is anecdotal evidence that water quality beyond the zone of initial dilution for the Green Point outfall is often, and for the Hout Bay and Camps Bay outfalls is at least periodically not compliant with the target for total suspended solids prescribed in the South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995). This conclusion is based on the visibility of effluent reaching the sea surface in satellite images provided in Google Earth at distances beyond (up to 2.2 km for the Green Point outfall) what can reasonably be considered to encompass the spatial extent of the zone of initial dilution. The visibility is likely a consequence of suspended particulate organic matter in the effluent.

The mass balance modelling discussed above suggests non-compliances are likely to be limited to total suspended solids and ammonia, with few other constituents (or at least those measured) likely to exceed targets beyond the zone of initial dilution. The dissolved oxygen concentration in the farfield may be depressed below the target as a result of the biochemical oxygen demand associated with the decomposition of particulate organic matter in the effluent, but this is less certain than the situation for suspended solids and ammonia.

The Department of Environmental Affairs (Anchor, 2016) is considering criteria for defining the spatial extent of the mixing zone around the diffuser section of an outfall, at the margin of which water quality should be compliant with water quality targets. The criteria state that the mixing zone may not extend more than 300 m in any direction from an outfall with a single diffuser. In the event an outfall has more than one diffuser the combined mixing zone for the diffusers may not exceed the area encompassed by a circle of 300 m radius. Thus, if there are two diffusers the mixing zone may extend 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 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. As discussed above, effluent is visible at the sea surface in satellite images provided in Google Earth at a distance beyond 75 m of the Green Point outfall diffuser section, but infrequently at distances beyond 106 m and 134 m of the Camps Bay and Hout Bay outfall diffuser sections respectively. However, photographs² on some internet sites provide evidence the effluent plume periodically extends beyond the above distances for the Camps Bay and Hout Bay outfalls.

Contaminants are undoubtedly adsorbed onto particulate organic matter in effluent discharged through the Green Point, Camps Bay and Hout Bay outfalls. This may provide a route of entry for certain contaminants into the food web in the marine receiving environments when these particles settle on the seabed, since many marine organisms will use this matter as a food/energy source.

It is important to note the use of mass balance modelling to estimate potential ecological impacts of effluent discharged through an outfall into a marine receiving environment is not without limitations. A zone of initial dilution/mixing zone is designated to manage the discharge of soluble, non-bioaccumulatory toxicants whose impacts are primarily related to their concentration (toxicity). Mass balance modelling cannot be used to manage for non-linear processes such as eutrophication associated with nutrient concentrations in effluent, nor to estimate the ecological impact of chemicals with a high bioaccumulation and biomagnification potential. A marine organism might, for example, be exposed to a chemical in effluent that is at a concentration that consistently meets its water quality target after initial dilution and not suffer acute toxicity (mortality), but because the chemical has a high bioaccumulation and biomagnification potential may through its lifetime accumulate the chemical to a high concentration in its tissue, with potential chronic implications for itself and/or higher trophic levels in the food web.

² e.g. <http://campsbayratepayers.blogspot.co.za/2016/12/sewage-pumped-in-atlantic-ocean-now.html>

Table 2.3. Minimum, median and maximum concentrations for various constituents in effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Background and target concentrations, and the minimum, median and maximum dilutions required to reduce effluent constituent to the target are provided. Ranges of required dilutions are provided for certain effluent constituents. Shaded cells denote a required dilution >200.

Effluent constituent	Effluent source	Effluent Concentration			Background concentration	Target concentration	Required dilutions			% Effluent samples in required dilution range				
		Minimum	Median	Maximum			Minimum	Median	Maximum	>100	>200	>300	>400	>500
Total suspended solids (mg.l ⁻¹)	GP	44.0	226.0	2440.0	10	11	34.0	216.0	2430.0	90.6	53.0	33.8	18.6	7.7
	CB	10.0	344.0	10750.0	10	11	0.0	334.0	10740.0	90.9	75.3	57.7	37.5	21.3
	HB	16.0	268.0	37600.0	10	11	6.0	258.0	37590.0	84.7	61.6	43.4	30.3	19.5
Ammonia (mg.l ⁻¹)	GP	11.0	34.0	57.8	0.227	0.6	28.9	90.6	154.5	35.9	0.0	0.0	0.0	0.0
	CB	11.7	43.7	97.2	0.227	0.6	30.8	116.6	260.2	67.4	2.2	0.0	0.0	0.0
	HB	9.1	41.3	661.6	0.227	0.6	23.8	110.2	1774.5	61.8	9.8	2.1	1.4	1.1
Arsenic (µg.l ⁻¹)	GP	1.2	1.4	2.2	2.00	12.0	0.0	0.0	0.0					
	CB	1.0	1.4	1.8	2.00	12.0	0.0	0.0	0.0					
	HB	1.0	2.0	4.4	2.00	12.0	0.0	0.0	0.2					
Cadmium (µg.l ⁻¹)	GP	1.2	1.2	1.2	0.05	0.4	3.3	3.3	3.3					
	CB	1.0	1.2	1.4	0.05	0.4	2.7	3.3	3.9					
	HB	1.2	1.2	1.2	0.05	0.4	3.3	3.3	3.3					
Copper (µg.l ⁻¹)	GP	6.6	36.8	88.2	0.49	5.0	1.4	8.1	19.4					
	CB	12.8	55.8	169.0	0.49	5.0	2.7	12.3	37.4					
	HB	7.2	14.0	46.6	0.49	5.0	1.5	3.0	10.2					
Chromium (µg.l ⁻¹)	GP	1.6	4.1	8.0	0.60	8.0	0.1	0.5	1.0					
	CB	1.8	5.0	15.0	0.60	8.0	0.2	0.6	1.9					
	HB	1.0	3.4	10.0	0.60	8.0	0.1	0.4	1.3					
Nickel (µg.l ⁻¹)	GP	1.0	3.2	12.0	0.44	25.0	0.0	0.1	0.5					
	CB	2.0	5.6	19.0	0.44	25.0	0.1	0.2	0.8					
	HB	1.0	2.0	16.0	0.44	25.0	0.0	0.1	0.6					
Lead (µg.l ⁻¹)	GP	1.2	2.8	9.6	2.06	12.0	0.0	0.1	0.8					
	CB	1.4	4.1	17.0	2.06	12.0	0.0	0.2	1.5					
	HB	1.0	1.6	4.8	2.06	12.0	0.0	0.0	0.3					
Zinc (µg.l ⁻¹)	GP	26.2	95.6	376.0	2.29	25.0	1.1	4.1	16.5					
	CB	57.4	135.0	631.0	2.29	25.0	2.4	5.8	27.7					
	HB	32.6	83.4	198.0	2.29	25.0	1.3	3.6	8.6					

Table 2.4. Minimum, median and maximum concentrations ($\mu\text{g.l}^{-1}$) for various organic chemicals in effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Background and target concentrations ($\mu\text{g.l}^{-1}$), and the minimum, median and maximum dilutions required to reduce effluent constituent to the target are provided.

Effluent constituent	Effluent source	Effluent concentration			Background concentration	Target concentration	Required dilutions		
		Minimum	Median	Maximum			Minimum	Median	Maximum
Benzene	Green Point	0.1	0.165	0.36	0	5.9	0.02	0.03	0.06
	Camps Bay	0.1	0.155	0.22	0	5.9	0.02	0.03	0.04
	Hout Bay	0.1	0.1	0.18	0	5.9	0.02	0.02	0.03
Ethylbenzene	Green Point	0.38	0.715	0.92	0	4100	0.00	0.00	0.00
	Camps Bay	0.38	0.915	2.7	0	4100	0.00	0.00	0.00
	Hout Bay	0.18	0.255	0.48	0	4100	0.00	0.00	0.00
Toluene	Green Point	2.0	2.9	4	0	85000	0.00	0.00	0.00
	Camps Bay	4.0	6.85	9.6	0	85000	0.00	0.00	0.00
	Hout Bay	1.4	2.05	2.9	0	85000	0.00	0.00	0.00
Fluoranthene	Green Point	0.02	0.02	0.2	0	15	0.00	0.00	0.01
	Camps Bay	0.02	0.03	0.2	0	15	0.00	0.00	0.01
	Hout Bay	0.02	0.02	0.2	0	15	0.00	0.00	0.01
Polycyclic aromatic hydrocarbons (total)	Green Point	1.12	1.255	11.51	0	0.0088	127.27	142.61	1307.95
	Camps Bay	1.12	1.215	11.39	0	0.0088	127.27	138.07	1294.32
	Hout Bay	1.13	1.16	11.43	0	0.0088	128.41	131.82	1298.86
Polychlorinated biphenyls (total)	Green Point	0.07	0.07	0.07	0	0.000019	3684.21	3684.21	3684.21
	Camps Bay	0.07	0.07	0.07	0	0.000019	3684.21	3684.21	3684.21
	Hout Bay	0.07	0.07	0.07	0	0.000019	3684.21	3684.21	3684.21
Dichloromethane	Green Point	1.3	1.95	3.2	0	450	0.00	0.00	0.01
	Camps Bay	0.2	1.25	1.5	0	450	0.00	0.00	0.00
	Hout Bay	0.89	1.8	2.3	0	450	0.00	0.00	0.01
Vinyl chloride	Green Point	0.2	0.2	0.2	0	36	0.01	0.01	0.01
	Camps Bay	0.2	0.2	0.2	0	36	0.01	0.01	0.01
	Hout Bay	0.2	0.2	0.2	0	36	0.01	0.01	0.01
Phenolic compounds (non-chlorinated)	Green Point	63	99	260	0	30	2.10	3.30	8.67
	Camps Bay	87	145	320	0	30	2.90	4.83	10.67
	Hout Bay	22	160	270	0	30	0.73	5.33	9.00
Phenolic compounds (chlorinated)	Green Point	0.71	0.78	4.22	0	1	0.71	0.78	4.22
	Camps Bay	0.649	0.71	4.27	0	1	0.65	0.71	4.27
	Hout Bay	0.76	1.145	4.8	0	1	0.76	1.15	4.80
1,2-Dichloroethane	Green Point	0.1	0.1	0.1	0	28	0.00	0.00	0.00
	Camps Bay	0.1	0.1	0.1	0	28	0.00	0.00	0.00
	Hout Bay	0.1	0.1	0.1	0	28	0.00	0.00	0.00

Effluent constituent	Effluent source	Effluent concentration			Background concentration	Target concentration	Required dilutions		
		Minimum	Median	Maximum			Minimum	Median	Maximum
1,1,1-Trichloroethane	Green Point	0.1	0.1	0.1	0	540000	0.00	0.00	0.00
	Camps Bay	0.1	0.1	0.1	0	540000	0.00	0.00	0.00
	Hout Bay	0.1	0.1	0.1	0	540000	0.00	0.00	0.00
1,1,2-Trichloroethane	Green Point	0.1	0.1	0.1	0	9.4	0.01	0.01	0.01
	Camps Bay	0.1	0.1	0.1	0	9.4	0.01	0.01	0.01
	Hout Bay	0.1	0.1	0.1	0	9.4	0.01	0.01	0.01
1,1,2,2-Tetrachloroethane	Green Point	0.1	0.1	0.1	0	2.3	0.04	0.04	0.04
	Camps Bay	0.1	0.1	0.1	0	2.3	0.04	0.04	0.04
	Hout Bay	0.1	0.1	0.1	0	2.3	0.04	0.04	0.04
1,3-Dichloropropene	Green Point	0.2	0.2	0.2	0	8.9	0.02	0.02	0.02
	Camps Bay	0.2	0.2	0.2	0	8.9	0.02	0.02	0.02
	Hout Bay	0.2	0.2	0.2	0	8.9	0.02	0.02	0.02
Dibromochloromethane	Green Point	0.1	0.36	0.76	0	6.2	0.02	0.06	0.12
	Camps Bay	0.1	0.615	2.6	0	6.2	0.02	0.10	0.42
	Hout Bay	0.1	0.73	2.3	0	6.2	0.02	0.12	0.37
Chlorobenzenes	Green Point	4.57	6.14	6.69	0	570	0.01	0.01	0.01
	Camps Bay	1.38	1.84	2.6	0	570	0.00	0.00	0.00
	Hout Bay	1.14	1.38	2.041	0	570	0.00	0.00	0.00
1,4-Dichlorobenzene	Green Point	3.5	4.5	5.6	0	18	0.19	0.25	0.31
	Camps Bay	0.84	1.25	2	0	18	0.05	0.07	0.11
	Hout Bay	0.6	0.815	1.4	0	18	0.03	0.05	0.08
Dichlorobenzenes (total)	Green Point	0.2	0.63	1.9	0	5100	0.00	0.00	0.00
	Camps Bay	0.2	0.2	0.2	0	5100	0.00	0.00	0.00
	Hout Bay	0.2	0.225	0.3	0	5100	0.00	0.00	0.00
2,4,6-Trichlorophenol	Green Point	0.05	0.05	0.5	0	0.29	0.17	0.17	1.72
	Camps Bay	0.05	0.075	0.5	0	0.29	0.17	0.26	1.72
	Hout Bay	0.05	0.05	0.5	0	0.29	0.17	0.17	1.72
Nitrobenzene	Green Point	0.3	0.3	0.3	0	4.9	0.06	0.06	0.06
	Camps Bay	0.3	0.3	0.3	0	4.9	0.06	0.06	0.06
	Hout Bay	0.3	0.3	0.3	0	4.9	0.06	0.06	0.06

Table 2.5. Minimum, median and maximum concentrations ($\mu\text{g.l}^{-1}$) for various organic chemicals in effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works between 1 March 2015 and 30 September 2016. Background and target concentrations ($\mu\text{g.l}^{-1}$), and the minimum, median and maximum dilutions required to reduce effluent constituent to the target are provided.

Effluent constituent	Effluent source	Effluent concentration			Background concentration	Target concentration	Required dilutions		
		Minimum	Median	Maximum			Minimum	Median	Maximum
Atorvastatin	Green Point	0.11	0.16	0.45	0	3.4	0.03	0.05	0.13
	Camps Bay	0.13	0.22	0.51	0	3.4	0.04	0.06	0.15
	Hout Bay	0.26	0.39	2	0	3.4	0.08	0.11	0.59
Bezafibrate	Green Point	1	1.3	1.6	0	1.2	0.83	1.08	1.33
	Camps Bay	0.35	0.74	0.76	0	1.2	0.29	0.62	0.63
	Hout Bay	2.2	2.5	4.3	0	1.2	1.83	2.08	3.58
Carbamazepine	Green Point	0.28	0.58	0.58	0	2.5	0.11	0.23	0.23
	Camps Bay	0.19	0.28	0.33	0	2.5	0.08	0.11	0.13
	Hout Bay	0.43	0.52	0.6	0	2.5	0.17	0.21	0.24
Clindamycin	Green Point	0.03	0.04	0.08	0	4.0	0.01	0.01	0.02
	Camps Bay	0.03	0.03	0.16	0	4.0	0.01	0.01	0.04
	Hout Bay	0.02	0.02	0.04	0	4.0	0.01	0.01	0.01
Cyclophosphamide	Green Point	0.01	0.01	0.01	0	19700.0	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.01	0	19700.0	0.00	0.00	0.00
	Hout Bay	0.01	0.01	0.01	0	19700.0	0.00	0.00	0.00
Diazepam	Green Point	0.01	0.01	0.01	0	2.7	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.01	0	2.7	0.00	0.00	0.00
	Hout Bay	0.01	0.01	0.01	0	2.7	0.00	0.00	0.00
Diclofenac	Green Point	0.46	0.85	1.8	0	10.0	0.05	0.09	0.18
	Camps Bay	0.63	0.66	1.5	0	10.0	0.06	0.07	0.15
	Hout Bay	0.57	0.94	1.6	0	10.0	0.06	0.09	0.16
Phenazone	Green Point	0.01	0.05	0.05	0	20.0	0.00	0.00	0.00
	Camps Bay	0.01	0.03	0.1	0	20.0	0.00	0.00	0.01
	Hout Bay	0.01	0.02	0.05	0	20.0	0.00	0.00	0.00
Fenofibrate	Green Point	0.01	0.03	0.05	0	1.6	0.01	0.02	0.03
	Camps Bay	0.03	0.08	0.09	0	1.6	0.02	0.05	0.06
	Hout Bay	0.01	0.01	0.03	0	1.6	0.01	0.01	0.02
Florfenicol	Green Point	0.03	0.05	0.05	0	1.3	0.02	0.04	0.04
	Camps Bay	0.01	0.03	0.05	0	1.3	0.01	0.02	0.04
	Hout Bay	0.01	0.05	0.05	0	1.3	0.01	0.04	0.04
Furazolidone	Green Point	0.01	0.02	0.02	0	1.3	0.01	0.02	0.02
	Camps Bay	0.01	0.01	0.05	0	1.3	0.01	0.01	0.04
	Hout Bay	0.01	0.01	0.02	0	1.3	0.01	0.01	0.02

Effluent constituent	Effluent source	Effluent concentration			Background concentration	Target concentration	Required dilutions		
		Minimum	Median	Maximum			Minimum	Median	Maximum
Gemfibrozil	Green Point	0.01	0.1	0.39	0	3.8	0.00	0.03	0.10
	Camps Bay	0.05	0.12	0.37	0	3.8	0.01	0.03	0.10
	Hout Bay	0.01	0.01	0.32	0	3.8	0.00	0.00	0.09
Ifosfamide	Green Point	0.01	0.01	0.01	0	2000.0	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.01	0	2000.0	0.00	0.00	0.00
	Hout Bay	0.01	0.01	0.01	0	2000.0	0.00	0.00	0.00
Indomethacin	Green Point	0.13	0.26	0.38	0	0.2	0.56	1.12	1.64
	Camps Bay	0.09	0.11	0.22	0	0.2	0.39	0.47	0.95
	Hout Bay	0.03	0.09	0.29	0	0.2	0.13	0.39	1.25
Ketoprofen	Green Point	0.05	0.1	0.23	0	3.1	0.02	0.03	0.07
	Camps Bay	0.05	0.05	0.09	0	3.1	0.02	0.02	0.03
	Hout Bay	0.05	0.05	0.07	0	3.1	0.02	0.02	0.02
Lidocaine	Green Point	0.03	0.19	0.25	0	21.2	0.00	0.01	0.01
	Camps Bay	0.06	0.09	0.42	0	21.2	0.00	0.00	0.02
	Hout Bay	0.05	0.08	0.13	0	21.2	0.00	0.00	0.01
Lincomycin	Green Point	0.01	0.01	0.01	0	0.1	0.14	0.14	0.14
	Camps Bay	0.01	0.01	0.01	0	0.1	0.14	0.14	0.14
	Hout Bay	0.01	0.01	0.01	0	0.1	0.14	0.14	0.14
Metronidazole	Green Point	0.01	0.01	0.01	0	36.0	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.01	0	36.0	0.00	0.00	0.00
	Hout Bay	0.01	0.01	0.01	0	36.0	0.00	0.00	0.00
Monensin	Green Point	0.01	0.01	0.01	0	1.5	0.01	0.01	0.01
	Camps Bay	0.01	0.01	0.01	0	1.5	0.01	0.01	0.01
	Hout Bay	0.01	0.01	0.01	0	1.5	0.01	0.01	0.01
Naproxen	Green Point	1.3	1.9	3.7	0	3.3	0.39	0.58	1.12
	Camps Bay	2.7	3	4.2	0	3.3	0.82	0.91	1.27
	Hout Bay	0.87	2.2	3.1	0	3.3	0.26	0.67	0.94
Paracetamol	Green Point	210	240	420	0	10.0	21.00	24.00	42.00
	Camps Bay	250	620	970	0	10.0	25.00	62.00	97.00
	Hout Bay	290	330	970	0	10.0	29.00	33.00	97.00
Pentoxifylline	Green Point	0.01	0.01	0.01	0	20.0	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.02	0	20.0	0.00	0.00	0.00
	Hout Bay	0.01	0.01	0.02	0	20.0	0.00	0.00	0.00
Primidone	Green Point	0.01	0.07	0.1	0	0.3	0.03	0.22	0.31
	Camps Bay	0.02	0.14	0.93	0	0.3	0.06	0.44	2.91
	Hout Bay	0.01	0.05	0.23	0	0.3	0.03	0.16	0.72

Effluent constituent	Effluent source	Effluent concentration			Background concentration	Target concentration	Required dilutions		
		Minimum	Median	Maximum			Minimum	Median	Maximum
Sulfadimethoxine	Green Point	0.01	0.01	0.01	0	0.0	1.14	1.14	1.14
	Camps Bay	0.01	0.01	0.01	0	0.0	1.14	1.14	1.14
	Hout Bay	0.01	0.01	0.01	0	0.0	1.14	1.14	1.14
Sulfadimidine	Green Point	0.01	0.01	0.01	0	0.0	0.66	0.66	0.66
	Camps Bay	0.01	0.01	0.01	0	0.0	0.66	0.66	0.66
	Hout Bay	0.01	0.01	0.01	0	0.0	0.66	0.66	0.66
Sulfamerazine	Green Point	0.01	0.01	0.01	0	4.0	0.00	0.00	0.00
	Camps Bay	0.01	0.01	0.03	0	4.0	0.00	0.00	0.01
	Hout Bay	0.01	0.01	0.02	0	4.0	0.00	0.00	0.01
Warfarin	Green Point	0.02	0.02	0.05	0	2.4	0.01	0.01	0.02
	Camps Bay	0.01	0.02	0.02	0	2.4	0.00	0.01	0.01
	Hout Bay	0.01	0.02	0.02	0	2.4	0.00	0.01	0.01

2.4. Conclusions

A relatively wide range of organic chemicals, including pharmaceutical compounds, were present in effluent collected from the Green Point, Camps Bay and Hout Bay wastewater works in 2015 and 2016. This is not surprising considering the wide range of chemicals used in today's society. The concentrations of most metals and organic chemicals were, however, low to relatively low. Based on mass balance modelling at an assumed initial dilution of 200, they are estimated to require few dilutions in the marine receiving environments to meet water quality targets for ecosystem protection. Ammonia and total suspended solids concentrations require the highest dilution to meet their targets. At an assumed initial dilution of 200 the total suspended solids concentration in a large proportion of effluent samples from each wastewater works is predicted to not be sufficiently diluted to meet the water quality target at the margin of the zone of initial dilution. The significance is that it is probably (total) suspended solids that make the effluent highly visible when it reaches the sea surface (but other constituents will also contribute to effluent visibility). Reducing the total suspended solids concentration to comply with water quality targets would, therefore, also contribute to reducing the extent to which the effluent is visible at the sea surface.

The dissolved oxygen concentration in the farfield could possibly be depressed below the target as a result of biochemical oxygen demand associated with the microbiologically mediated decomposition

of particulate organic matter in the effluent. There is, however, uncertainty in this context since far field depression of dissolved oxygen is difficult to model.

Due to uncertainty on the minimum initial dilution for the Green Point, Camps Bay and Hout Bay outfalls and consequent implications for mass balance modelling and setting of effluent based water quality limits, the minimum initial dilution for each outfall should be established through three dimensional numerical modelling and then be validated through dye tracer dispersion studies. Recommendations in this context are provided in Chapter 4. Background values/concentrations for constituents in effluent that occur naturally in the marine receiving environments (*e.g.* nutrients, metals) should also be defined for compliance monitoring purposes. This can be done as part of the water quality monitoring component of future surveys. If these surveys are performed at various times through the year this should provide a better estimate of the background values/concentrations than an intense once off survey made at an arbitrary time.

The effective dispersion and dilution of effluent discharged through an outfall depends on the diffusers operating per their design specification. The blockage of diffusers will influence the dilution and dispersion of effluent. It is recommended that the outfalls be inspected on an annual basis to ensure they are operating as designed.